1. Introduction

Autonomous vehicles, self-driving cars, robotic vehicles. For decades, the automotive industry has been dreaming of and working towards vehicles that can operate without a driver. After many years of slow development and little progress, the technology seems poised for a major breakthrough within a few short years, impacting traffic operations almost immediately. In the long-term, autonomous vehicles (AVs) are poised to change the way that people move around their cities, neighborhoods, and regions by increasing mobility and changing travel patterns around the world.

This paper examines some of the changes that are likely to impact transportation networks and travel behavior in the long-term. This analysis accounts for the uncertainty that is inherent in the transportation world at this time, because so much is still unknown about how these technologies will be deployed and how society and the market will react to them. AV deployment and the associated impacts are likely to be different in different environments – in different cities with different characteristics and in different countries where different solutions to policy challenges are likely to result in alternative behavior changes. This paper will examine these issues and challenges from both the American and German perspectives. While none of the outcomes are known with any certainty at this early date, potential likely alternatives will be presented and explored.

1.1. Introduction to AV Technology

The Society of Automotive Engineers (SAE) has defined six levels of vehicle automation[1], that are differentiated primarily by whether the vehicle or the driver is responsible for various tasks, including execution of driving, monitoring the driving environment, and fallback responsibility in case of a system failure. These levels of automation are illustrated in Figure 1.

[1] SAE International Standard J3016, Society of Automotive Engineers, accessed October 16, 2017, https://www.sae.org/misc/pdfs/automated_driving.pdf.

Figure 1: SAE International Levels of Vehicle Automation

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Source: SAE International standard J3016

The current automobile market is already selling cars with Level 1 and 2 automation in the form of various Advanced Driver Assistance Systems (ADAS) such as adaptive cruise control and lane-keeping assist. Most manufacturers have indicated some hesitance in the development of Level 3 vehicles, due to concerns about how to keep drivers fully aware of their environment when they are not required to be fully engaged for most driving tasks. Therefore, many developers of AV technology are aiming for Level 4 automation as their next step instead.

Ultimately, Level 5 automation would give AVs the ability to pilot themselves without any human intervention at all. While this might begin in limited geographic areas only, the eventual goal would be universal coverage in all situations. At this point, vehicles could move whether or not they contained a licensed driver, or even a passenger. Vehicles could reposition themselves as needed to meet the needs of the traveling public. Many other innovations are possible with this technology, the relatively likelihoods of which are at least partially dependent on how the technology ultimately develops and how some of the challenges discussed in this paper are addressed.

1.2. Use Cases for Passenger Travel

The main focus of this paper is the impacts of AV technology on passenger travel – although AVs have potential implications throughout the transportation world, including freight and public transit. There are two primary use cases for AVs in passenger travel: private ownership and shared ownership. These use cases are likely to result in some different impacts, although both could easily exist in the same environment. Some of the benefits touted by experts accrue more under one ownership model or the other, while others have the potential to exist regardless of the prevalent business models, as they are a direct result of the technology itself.

Both ownership models will address to some extent one of the largest issues associated with the traditional model of car use: inefficiency. On average, our cars sit idle 95 percent of every day[2]. Even during the peak hours, only ten percent of the US vehicle fleet is being used[3]. Autonomous vehicles present opportunities to improve vehicle efficiency, improving personal mobility using a smaller vehicle fleet.

The private ownership model looks very similar to auto ownership as it has existed for decades, with individuals or households owning one or more vehicles. In most visions of this ownership model, the major difference is the ability for the vehicle to relocate itself while the owner is engaged in other activities. This could mean, for example, that a vehicle no longer needs to be parked at the office while its owner is working. Under this ownership model, it might be possible for a single vehicle to serve multiple drivers within a household during the day, allowing many households to decrease the number of vehicles that they own. Also possible under this ownership model could be the future envisioned by Elon Musk of Tesla[4], in which the sharing economy is applied to private automobile ownership, and households rent out their vehicles when not in use (along the lines of the business model of AirBnB).

The shared ownership model combines features from carsharing, ridesharing, and ridesourcing, providing what is essentially a fleet of autonomous taxis. The main assumption is that the majority of households will no longer own their own vehicles, and will instead hire a vehicle when required. A number of operating paradigms have been imagined for this ownership model, and others are likely to evolve as the market matures. Some of the variations include:

- Vehicles owned by private companies or public agencies or some other entity.
- Single occupancy rides or shared rides.
- Pay-by-the-ride or subscription services.

How much each of these ownership models takes hold in a specific market will depend on many factors, most especially the relative costs of AV ownership. If the purchase price of AVs is prohibitively expensive for the average household, then the shared ownership model may be more successful. However, some manufacturers are estimating only a limited increase in vehicle cost. If so, many people may continue to own their own AVs. The ownership mix will also be different based on specific geographic conditions. In cities where car ownership is particularly expensive, where parking is very scarce, or where technology is a major part of the culture are more likely to see successful deployment of shared AVs. Cities without a strong public transit system and plentiful parking may be more likely to be strong markets for the private ownership model. While travel in shared vehicles currently accounts for less than four percent of VMT, it is expected to grow in importance in the near future, and to account for more than one-quarter[5] of worldwide VMT by 2030.

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[2] “Cars are Parked 95% of the Time. Let’s Check!” Reinventing Parking, Paul Barter, February 22, 2013, http://www.reinventingparking.org/2013/02/cars-are-parked-95-of-time-lets-check.html.
[3] Daniel Fagnant and Kara Kockelman, “The travel and Environmental Implications of Shared Autonomous Vehicles using Agent-Based Model Scenarios,” *Transportation Research Part C*, 40, 1-13.
[4] “Master Plan Part Deux,” Tesla, Elon Musk, July 20, 2016, https://www.tesla.com/blog/master-plan-part-deux.
[5] “Shared Mobility on the Road of the Future,” Morgan Stanley, June 15, 2016, http://www.morganstanley.com/ideas/car-of-future-is-autonomous-electric-shared-mobility.

2. Impacts of AVs

The main drivers for the development of Autonomous Vehicles have been safety improvements and cost savings. From the perspective of the public good, safety is certainly the most convincing argument for the widespread adoption of autonomous vehicles. With 94 percent of traffic accidents caused by human error, autonomous vehicles have the potential to save over 1.1 million[6] lives worldwide every year, and prevent more than 47 million non-fatal injuries. While traffic deaths are admittedly a much larger problem in the developing world, autonomous vehicles present the opportunity to potentially save over 32,000 lives in the US and 3,300[7] lives in Germany each year.

On the other hand, the potential for significant cost savings are one of the major drivers behind autonomous vehicles in the developed world, where labor is a significant factor in the cost of transporting goods and people. Many of the potential use cases for autonomous vehicles are areas where the removal or reduction of labor costs would represent significant savings for private firms, including:

- Freight: truck platooning can allow multiple trucks to operate over long distances with only a single driver, making long-distance trucking even more cost competitive with freight rail.
- Parcel delivery: over 50 percent of parcel delivery costs are associated with the last mile[8]. Reducing these costs can make package delivery even cheaper for sellers and consumers, further encouraging the spread of e-commerce.
- Transit operations: between 40 and 70 percent of transit operating costs are associated with labor costs. Removing these costs could make it possible to run more frequent service at a lower cost.

Private passenger transport represents a $10 trillion worldwide market annually that could potentially see dramatically increased profit levels by removing labors costs. Uber, the largest startup in the world valued at almost $70 billion, has yet to make a single dollar in profit, and will not do so until it can remove labor costs entirely from its business model. This is part of the reason why Uber and dozens of other companies are so heavily invested in making autonomous vehicles a reality in the near future.

2.1. Traffic Operations and AVs

Imagine a highway fully packed with cars, all moving in harmony at near free-flow speeds. This is the promise of autonomous vehicles. The main benefit of autonomous vehicles over traditional vehicles is that AVs can react faster than human drivers. This improvement allows AVs to react to speed changes faster than traditional vehicles, effectively increasing the capacity of congested roadways, particularly on freeways and expressways where high speeds could be maintained.

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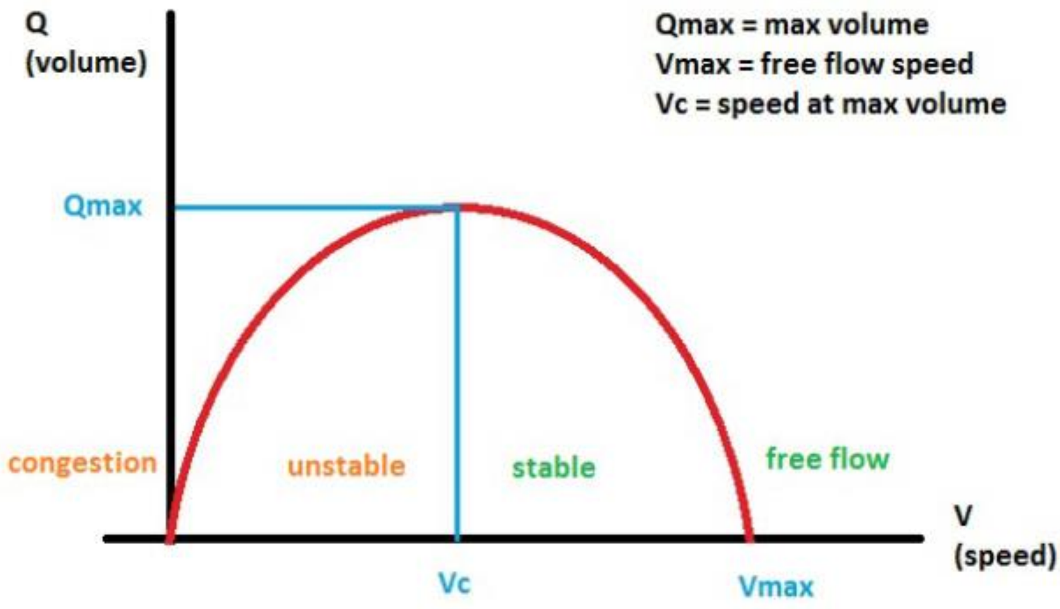
[6] "Global Status Report on Road Safety 2015," World Health Organization, 2015.

[7] "World Health Organization: Road Traffic Deaths," Global Health Observatory data, accessed January 6, 2017, http://www.who.int/gho/road_safety/mortality/en/.

[8] "Ten ways Autonomous Driving Could redefine the Automotive World," McKinsey & Company, Bertoncello, M. & Wee, D., June 2015, http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/ten-ways-autonomous-driving-could-redefine-the-automotive-world.

Traffic flow theory holds that as the volume on a roadway increases past a certain point, speeds become unstable and start to decrease, ultimately decreasing the traffic volume speeds become unstable and begin to decay, resulting in the traffic jams we have all experienced. A sample graph of this phenomenon is shown below.



Source: https://letsgola.wordpress.com/2014/03/17/

Due to the improved reaction times and operational characteristics AVs, they are able to operate at higher speeds even with higher traffic volumes. This would essentially shift the graph in the previous figure to the right, increasing speeds at high volumes, reducing the amount of time spent sitting in congestion and improving rush hour travel times. Currently, traffic congestion delays account for one percent of the GDP of the EU[9]. Of course, the level of this improvement is tied to the penetration of AVs on the roadways. As estimated in the table below, the capacity improvement begin to really accrue at 40 percent market penetration, while speed benefits continue to stack up as penetration rates increase.

Penetration Rate	**Flow (% of Capacity)**	**Speed (% of Freeflow)**
0%	81%	71%
20%	88%	77%
40%	106%	88%
60%	106%	89%
80%	106%	94%
100%	106%	97%

Source: Arnaout & Bowling, 2011.

[9] Luis Martinez, Goncalo Correia, and Jose Viegas, "An agent-based model to assess the impacts of introducing a shared-taxi system in Lisbon (Portugal)," *Journal of Advanced Transportation*, 49 (3), 475-495.

A very important qualification should be included here: The operational benefits included in this section only represent the benefits from vehicle autonomy. Other, potentially larger and more widespread benefits to traffic operations would be expected from the introduction of Connected Vehicle (CV) technology, in which vehicles are able to communicate with one another and with sensors located along the roadways. While this Connected Technology deployment is expected to occur parallel with autonomous technology, the two are separate and AVs do not require Connectivity to operate. Additional benefits from connectivity include even faster reaction times, as vehicles will be able to know about slow-downs from vehicles 100 meters or more ahead of them. Other major benefits will be seen from CVs that dramatically increase operational efficiency: traffic can be optimized so that all facilities are used to the mutual benefit of the community. Intersections with connected technology may be able to forgo traditional traffic signals entirely, as vehicles will be moved through the intersection safely by the intersection itself. Overall traffic speeds may be slightly slower in order to even out travel times and remove bottle necks from the network.

2.2. AV Fleet Size

One of the most frequently touted benefits of AVs is increased vehicle efficiencies. The average vehicle sits idle 95 percent of every day, as it is driven somewhere and then waits for its driver to go to a new destination. AVs that are able to relocate themselves while empty could be used much more efficiently, as they could be used productively while their owners are at work, at home, or at the movies. Several studies have shown that especially in cities the same number of trips could be serviced using a much smaller fleet of vehicles. Households that own an AV could meet their daily travel needs with fewer AVs than traditional vehicles.

Shared vehicles have added potential to decrease the size of the vehicle fleet, as each vehicle could meet the needs of multiple households. Studies of existing car-sharing services (i.e. ZipCar or CarToGo) have shown that each shared vehicle can replace 9-13[10] traditional household-owned vehicles. Similar reductions could be seen with a shared fleet of AVs. With an increased reliance on shared-rides, the vehicle fleet in major cities could decrease to less than 40 percent[11] of its current size.

2.3. Parking and AVs

One of the likely impacts of a dramatically decreased vehicle fleet would be the need for far fewer parking spaces for long-term vehicle storage (i.e. overnight, at workplaces). In addition, parking and activities would no longer need to be located together. Office buildings would no longer need to be built with large garages facilities, stores would not require parking lots, and on-street parking spaces would no longer be required to provide easy access to businesses. AVs could pick-up and drop-off employees, visitors, residents, and customers curbside, and then either relocate themselves to a remote parking facility or go to pick-up their next passenger.

Experts have estimated that the US alone currently has over 700 million parking spaces[12] – three parking spaces for each vehicle in the country. This amount of parking would cover over 7,000 square miles of land with unattractive, environmentally unproductive pavement. Decreasing parking requirements could

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[10] Elliot Martin and Susan Shaheen, "The Impact of Carsharing on Household Vehicle Ownership," *Access*, no. 38, Spring 2011, 22-27.

[11] Kevin Spieser, Kyle Ballantyne, Rick Zhang, Emilio Frazzoli, Daniel Morton, and Marco Pavone, "Toward a Systematic Approach to the Design and Evaluation of Automated Mobility-on-Demand Systems: A Case Study in Singapore," *Road Vehicle Automation, (Lecture Notes in Mobility)*, Springer, 2014.

[12] "The Third Transportation Revolution," The Road Ahead, John Zimmer, September 18, 2016, https://medium.com/@johnzimmer/the-third-transportation-revolution-27860f05fa91#.3vdnyhx4t.

allow the US to reclaim almost 3,000 square miles of land for other uses, dramatically reshaping many cities and suburbs.

The impacts of this change would be particularly strong in areas where space is at a premium and real estate costs are high. Parking lots and garages could be redeveloped to other uses, opening up new land for residential and commercial development. On-street parking spaces present an opportunity for creative redevelopment, whether for on-street commercial uses, or for increasing green space in highly urbanized areas. Land development costs could also decrease if parking is no longer required, especially if expensive underground parking garages do not need be constructed in association with new residential and office buildings, at a potential cost savings of $25,000-45,000 per space[13]. Cheaper real estate development ultimately translates into lower real estate and rental costs for residents, which could help address housing shortages in major cities worldwide, including San Francisco, Berlin, and London.

Studies indicate that up to 30 percent[14] of vehicles in congested downtown traffic is associated with drivers circling and searching for parking. Automation of parking, or removing the need for parking altogether could relieve this congestion by removing cars from these congested roadways and getting people to their final destinations faster.

2.4. Increased Mobility

Truly autonomous vehicles that do not require a licensed driver present a range of opportunities for improved mobility for a number of neglected or at risk populations, such as:

- The elderly: access to AVs would provide auto mobility to older residents, allowing them to maintain their active lifestyles. AVs could allow aging residents in suburban communities to age in place, living in their homes longer. Older drivers (65 or older) are responsible for a disproportionately large share of traffic accidents, and have the highest accident rate of any age group[15] except for the youngest drivers; allowing this age group to maintain their mobility without driving could therefore have a high impact on accidents. Depending on costs, policies, insurance requirements, etc. this group alone could increase VMT by 4-60 percent[16].
- Disabled populations: Many disabilities prohibit driving, and require residents to use the public transit system, often limiting their choice of residential, employment, and shopping locations. In the US, transit systems are required to operate on-demand paratransit systems that provide mobility to those who cannot use the transit network. This paratransit service is typically the

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[13] "Driverless Future: A Roadmap for Policy Makers," Arcadis, HR&A, Sam Schwartz, accessed March 2017, http://driverlessfuture.webflow.io/.
[14] Donald Shoup, "Cruising for Parking," *Transport Policy*, Vol. 13, Issue 6. November 2006.
[15] "Background on: Older Drivers," Insurance Information Institute, June 1 2017, https://www.iii.org/article/background-on-older-drivers.
[16] Zia Wadud, Don MacKenzie, and Paul Leiby, "Help or Hindrance? The travel, energy and carbon impacts of Highly Automated Vehicles," *Transportation Research Part A*, February 26, 2016.

most expensive service operated by a transit agency, on average 3.5 times more expensive[17] than a standard transit trip. AVs could provide a cheaper, better mobility option.

- Children: under licensing age, children must be accompanied everywhere by their parents or are restricted to the public transit system. A secure AV could chauffeur children (i.e. to school, social activities), freeing significant adult time for other activities.
- Impaired drivers: AVs are concerned to be a possible cure for the scourge of drunk driving.

All of these applications require that AV technologies advance to the point that a capable, licensed driver is not required to operate the vehicle. This requires a level of confidence in AV operation, and a safety fallback condition that never requires human intervention. It therefore seems likely that these impacts are likely to be seen only in the very long-term. Studies on induced demand indicate that vehicle miles traveled (VMT) may increase by 11 percent[18] due to the mobility of these types of users.

There is another type of induced demand that is likely to have an even bigger impact on vehicle miles traveled – that of empty AVs relocating themselves. The extent to which VMT will increase is dependent on a number of variables, including policies, parking prices and availability, AV operating costs, and most especially the ownership paradigms in place in a given region. For example, if AVs are privately owned but are used to serve the mobility needs of multiple family members, relocation distances might be quite large. On the other hand, shared fleets in dense urban areas would be motivated to minimize empty, unprofitable VMT. One study in Austin, Texas estimated an eight percent increase in VMT[19] associated with repositioning movements of a shared AV fleet.

While very significant increases in VMT may occur, even to the point of offsetting the capacity improvements brought by AV technology, it is important to consider the direction, timing, and location of these increases. Very real improvements in operations and congestion could still be realized if these increases in VMT occur during off-peak time periods (as may be the case for induced travel by the elderly), in the off-peak direction (as may be the case for at least some portion of empty vehicle relocations), or in other non-congested locations. Of course, negative externalities associated with additional VMT, such as pollution and noise, will need to be mitigated regardless of these concerns. But much more additional study and analysis is needed to understand the total impacts on congestion.

2.5. Transit and CAVs

AV technology is likely to have major impacts on the public transit industry around the world. The primary impact will be on transit operations directly, as human drivers are replaced by AV technology. Drivers represent a major component of the operating costs for transit operators, around 40 percent[20] of

[17] "ADA Paratransit Services – Report to the Committee on Banking, Housing, and Urban Affairs, US Senate," US Government Accountability Office, November 2012, http://www.gao.gov/assets/660/650079.pdf.
[18] Jason Henderson and Jason Spencer, "Autonomous Vehicles and Commercial Real Estate," *Cornell Real Estate Review*, 4:1, 44-55.
[19] Daniel Fagnant, Kara Kockelman, and Prateek Bansal, "Operations of a Shared Autonomous Vehicle Fleet for the Austin, Texas market," *Transportation Research Record*, No. 2536, 98-106, 2015.
[20] "A 2050 Vision for London: What are the Implications of Driverless Transport," D. Begg, August 11, 2014. https://trid.trb.org/view.aspx?id=1319762.

hourly costs in Europe, and closer to 70 percent in the US. As such, improving route frequencies to provide better, more convenient service can be a very expensive option. Better matching demand with the appropriately sized bus becomes much more financially attractive when driver costs are removed from the equation.

With the emergence of new technologies and apps, it is also becoming more feasible to economically operate demand-responsive transit service. Automation in particular has the potential to dramatically decrease the cost to provide these services, while other technologies (routing algorithms, GPS, apps, etc.) are already enabling the real-time creation of routes and vehicle dispatch. AVs have the potential to solve a long standing problem in the transit industry, bridging the gap between the fixed-route high-capacity transit network and people's ultimate origin or destination (i.e. providing a "first-mile" or "last-mile" connection from home to a rail station). This could open existing transit networks for use by a larger range of residents and employees.

However, the introduction of AVs could have negative impacts on transit services as well. Many of the users of these new driverless options, especially ridesourcing and ridesharing in shared vehicles, would have otherwise made their trips using transit. Precisely how many people will shift from transit to AVs will to depend on a number of factors, including costs, time savings, comfort levels, user preferences, and service levels. Initial studies estimate that ubiquitous use of AVs may result in a six percent decrease in transit mode share[21] as riders shift to other options.

2.6. Freight and AVs

Freight may very well be the first frontier for autonomous vehicles, with innovation driven primarily by the potential for major cost savings through reductions in labor costs. Truck platooning virtually links multiple trucks together so that any acceleration/deceleration of the front truck is immediately transmitted to the following vehicles. This would allow trucks to travel closer together on freeways, and reduce fuel usage by up to ten percent[22] for each truck. These savings, combined with reductions in labor costs, could dramatically decrease truck shipping costs, potentially making trucks cheaper than (or closely competitive with) freight rail for long distances.

Local deliveries could also be revolutionized by AV technology, and some experts estimate that 80 percent[23] of deliveries could be automated within the next ten years. This may include options such as aerial drones in rural areas and automated parcel lockers in more urban areas. Parcel delivery is expected to represent an increasing portion of roadway traffic, as e-commerce continues to take the place of traditional brick-and-mortar retail. Autonomous parcel delivery also represents the potential for significant cost savings by removing driver costs; over 50 percent of total delivery costs are associate with the last mile.

2.7. Environmental Impacts

Autonomous vehicles have many potential environmental impacts related to changes in land use, decreases in impermeable land area from reducing parking, induced demand, and other issues discussed previously. But there are also direct environmental benefits associated with the new technology. AVs –

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[21] Goncalo Homem de Almeida Corriea and Bart van Arem, "Solving the User Optimum Privately Owned Automated Vehicles Assignment Problem (UO-POAVAP): A Model to Explore the Impacts of Self-Driving Vehicles on Urban Mobility," *Transportation Research Part B*, 87, 64-68, 2016.
[22] "CR England Peloton Technology Platooning Test," M. Roeth, November 2013. http://nacfe.org/wp-content/uploads/2013/12/CR-England.pdf.
[23] "Parcel Delivery: The Future of the Last Mile," Martin Joerss, Jurgen Schröder, Florian Neuhaus, Christoph Klink, and Florian Mann, McKinsey & Company, September 2016.

shared or otherwise – would be more heavily utilized on a daily basis than conventional vehicles due to their ability to serve the travel needs of multiple people. This is turns results in a larger portion of VMT occurring in newer vehicles, which have a lower emissions profile than older vehicles. AVs could also be programmed for "eco-driving" which could result in 20 percent fuels savings[24]. In addition, shared AVs would make electrification easier, as a large fleet would be better able to accommodate the recharging needs of the vehicles. How these environmental impacts will ultimately balance out, will depend on a number of factors, but have the potential to dramatically decrease the negative environmental externalities associated with vehicle travel.

3. Differences in German and US Implementation

The United States represents one of the largest potential markets for AVs, accounting for almost 30 percent of the world's VMT[25]. Similarly, the EU accounts for one-quarter of global VMT. Combined, they represent the majority of the short-term market for AVs (although China is predicted to overtake them in the longer term as motorization there grows). German and American auto manufacturers are working to develop AV technologies for these markets on similar timelines. German manufacturers seem to be somewhat more focused on what is called the 'evolutionary path' to AVs, slowly increasing the availability of automated capabilities in their vehicles. Meanwhile, American manufacturers, led by tech and startup firms are often focused on the 'revolutionary path' to achieving automation by proceeding directly to higher levels of automation. Manufacturers in the EU also got a jump start on the development and testing of autonomous shuttle vehicles through the CityMobil project, although manufacturers are beginning to spring up in the US as well.

There are a number of issues and differences in governance, market forces, legal issues, and other social conditions that are likely to impact how (and when) AV technology is introduced and used in the two countries. This section will explore some of these issues and considerations. In the end, it may be many of these considerations that shape the implementation of AVs in Germany, the US, and other countries around the world. These differences in implementation will likely affect the scale of the impacts that will occur.

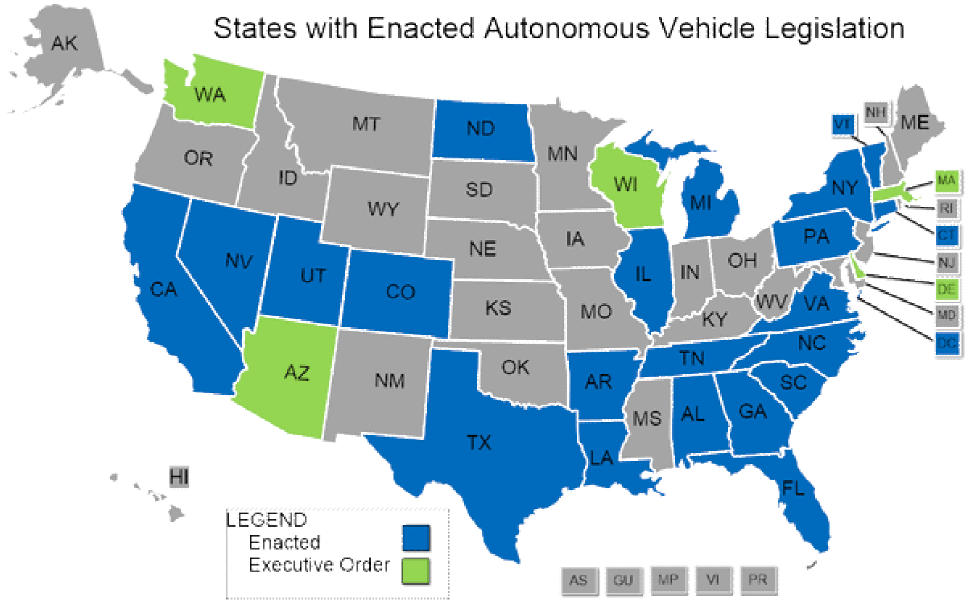
3.1. Legal

Despite both countries being major auto producers, vehicles operate in very different legal environments in Germany and the US. Driving laws vary significantly, and existing laws in the US are much more favorable to AV operations than in Germany. In the vast majority of US states, there are no laws that specifically prohibit AVs. The Federal Government is considering legislation related primarily to passenger AVs, and 21 states[26] have passed legislation related to AVs.

[24] Zia Wadud, Don MacKenzie, and Paul Leiby, "Help or Hindrance? The travel, energy and carbon impacts of Highly Automated Vehicles," *Transportation Research Part A*, February 26, 2016..

[25] "Shared Mobility on the Road of the Future," Morgan Stanley, June 15, 2016, http://www.morganstanley.com/ideas/car-of-future-is-autonomous-electric-shared-mobility.

[26] "Autonomous Vehicles Enacted Legislation," National Conference of State Legislatures, http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.



Source: National Conference of State Legislatures

To the contrary, there are a number of legal hurdles that AVs will need to surmount in Germany. While the Vienna Convention on Road Traffic has been amended[27] to allow for automated driving in most conditions, a driver is still required to be in the vehicle at all times as a potential override for the AV system. Likewise, United Nations Economic Commission for Europe (UNECE) regulations still require that a driver be in control of a vehicle at all times, and only permits automated driving functions at speeds below 12 km/hr (~7.5 mph). Proposed amendments would allow automation at higher speeds[28], but would similarly require a driver to be able to take over at all times. German law also currently requires a licensed driver, although a growing number of test permits have been issued. Full legalization of AVs is necessary in Germany and throughout the EU in order for AV operations to really take hold and begin to grow.

Europe and the US also have different procedural requirements for the production and sales of vehicles. The US uses a process called “self-certification” in which manufacturers submit documentation attesting that their vehicles meet stated safety criteria, but are not necessarily required to submit results of safety testing or other proof of these claims. In the EU, however, “type approval” is required, in which a designated approval body tests a vehicle or vehicle system for adherence to a range of standards related to safety and performance. Vehicles or specific vehicle subsystems must be approved before sales are permitted. These additional requirements and oversight may help to explain why German manufacturers are more overwhelmingly following and evolutionary path towards automation – it may simply be easier to get a vehicle design approved that is more closely related to existing technologies.

Manufacturers will also require an understanding of the regulations that will affect AVs and their operations in order to begin large-scale manufacturing and sales. Regulation remains as a series of

[27] “European Roadmap Smart Systems for Automated Driving,” European Technology Platform on Smart Systems Integration, April 1, 2015, Berlin, Germany.
[28] “Automated Vehicles in the EU: A Look at Regulations and Amendments,” In: Casualty Matters, L. Lutz, March 2016, Würzburg, Germany. http://www.genre.com/knowledge/publications/cmint16-1-en.html.

unanswered questions in both countries, and is starting to be addressed through legislation and other (primarily) Federal-level policies.

3.2. Insurance and Liability

General liability and the structure of the insurance markets in Germany and the US differ significantly. Restructuring of these markets and assignment of the legal responsibility for crashes will likely need to change as AVs enter the vehicle fleet. In the US for example, individual vehicles are insured, and liability is primarily assigned to the driver/owner of the vehicle in the case of an accident. Vehicle manufacturers are typically only found to be liable in the rare case of vehicular system failure. However, automation will remove the possibility of driver fault from the vast majority of accidents and new insurance business models will be needed to insure the vehicle manufacturers against a higher percentage of on-road crashes. Insurance companies are also considering insurance products that insure mobility instead of vehicles. Similar to existing car-sharing companies, some manufacturers are planning to bundle insurance with other trip costs or provide pay-as-you-go insurance options[29].

Experts also expect overall insurance costs to decrease significantly, as the total number of accidents and their associated costs will decrease. Further, shared vehicle fleets can offer further discounts by negotiating group rates between fleet owners and insurance companies.

3.3. Technology Acceptance

Despite both being advanced, industrial economies, Germans and Americans exhibit different levels of comfort with new technologies and reliance on them. A familiar example to anyone who has visited Germany will be a continued reliance on cash instead of credit cards, as is common in many other developed western economies. As such, it is important to consider that AVs might reach significant market penetration at very different times in different countries, not based on economics or availability, but based on the population's interest and willingness to give over the tasks of driving to machines.

One survey shows similar levels of interest in autonomous driving functions in Germany and the US – around 58 percent[30] – and the majority of those in both countries seem to prefer owning their own vehicles instead of relying on a shared fleet. However, significant concerns about safety, security, and privacy remain in both countries, and a much smaller portion of the population are ready for an AV. Additional surveys in the US indicate the highest level of interest in AV technology among the young[31] and early technology adopters. How both the general population and government agencies and road operators embrace AV technology will help determine the timeline and shape of the AV market.

3.4. Market Forces

Costs and market preferences vary significantly between Germany and the US and in ways that will impact how and when AVs take hold. Several interrelated factors will have impacts on the form that AV implementation takes, including:

- Auto Ownership levels
- Transit ridership

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[29] "How Insurers Could be Forced to Insure Mobility Rather than Vehicles," LexisNexis blog, Paul Stacy, April 2016, http://blogs.lexisnexis.com/insurance-insights/2016/09/how-insurers-could-be-forced-to-insure-mobility-rather-than-vehicles/.

[30] "China's Car Owners Prefer Robot Taxis," Audi Urban Future Initiative, Friederike Meier-Burkert, February 9, 2016, http://audi-urban-future-initiative.com/blog/china-robot-taxis.

[31] M. Kyriakidis, R. Happee, and J.C.F. de Winter, "Public Opinion on Automated Driving: Results of an International Questionnaire among 5000 Respondents," *Transportation Research Part F*, 32 (2015), 127-140, 2015.

- Cost of Auto Ownership
- Perception of Auto Ownership

Auto ownership is much higher in the US than in Germany with an average of 0.78 vehicles per person[32] in the US, as compared to 0.55 vehicles per person in Germany[33]. This statistic illustrates a stronger and more widespread reliance on cars in the US, and may indicate a stronger likelihood of continued private ownership and an unwillingness to switch to shared modes. But because there is this stronger reliance of cars in the US, the potential impacts of the switch to AVs could be that much more significant in American communities.

In conjunction with the lower auto ownership outlined above, Germans also use transit much more frequently than Americans. This indicates a higher level of comfort with sharing rides, higher occupancy travel, and the compromises in convenience often associated with public transit. These characteristics may help to contribute to the success of shared AV fleets and the continued success of the existing public transit systems. To the contrary, the ubiquity of public transit may not create the same mobility need for AVs to begin with, thus making them potentially less profitable to private companies.

Lower levels of auto ownership in Germany have a number of causes, but among the most important in this discussion are the differences in the costs of owning and operating a car. Cars in Europe are significantly more expensive to purchase than in the US, due at least in part to higher taxes. Parking is also much scarcer in most parts of Germany than in the US, further contributing to the difficulty and expense of owning a personal vehicle. Fuel is also more than 2.5 times more expensive in Germany than in the US (as of October 2017) making any vehicle expensive to use. These disparities also make shared vehicles more economically feasible and more attractive in Germany.

Auto ownership has long held a certain mystique (certainly perpetuated and capitalized on by manufacturers) in which a car serves as an important status symbol. While much has been made of the changing behaviors of millennials and their lower vehicle ownership levels, future trends on these perceptions and preferences are highly uncertain. A recent survey even showed that only six percent[34] of young people in Germany and neighboring countries consider owning a car to be "out of date." These results seem to indicate that changing perceptions may not shape the market for AVs as much as some would like to believe.

3.5. Roles of Government and the Private Sector

One of the major factors that is likely to impact the shape of AV implementation, will be society's perception of the appropriate roles of government and the private sector. These are notably different between the US and Germany, but may be even different in other countries. For example, in Germany (and many other European countries), the government is expected to provide a wide range of services, and often to regulate private industry to the benefit of society at large. Widespread public transit, universal healthcare, free university tuition, and strong support of the arts are German priorities that fall into this category. German citizens tend to support these programs, even if they don't make use of them personally.

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32 "253 million cars and trucks on US roads," LA Times, Jerry Hirsch, June 2014, http://www.latimes.com/business/autos/la-fi-hy-ihs-automotive-average-age-car-20140609-story.html.

33 "Total Number of Registered Cars. Car Sales Statistics," Henk Bekkler, March 2016, https://www.best-selling-cars.com/germany/2016-germany-total-number-registered-cars/.

34 Eva Fraedrich, Sven Beiker, and Barbara Lenz, "Transition Pathways to Fully Automated Driving and its Implications for the Sociotechnical System of Automobility," *European Journal of Futures Research*, 3:11, 2015.

Meanwhile, these types of programs and policies are less common in the US, and not as popular and well supported. The general view in the US is that where the opportunity exists for the private sector to make money, it should be allowed to do so. Each country may determine different lines that differentiate the appropriate roles of the public and private sectors, which may ultimately shape how the AV market develops.

These differences may not seem relevant to the discussion of AVs, but these perceptions and precedents may have significant impacts on how the technology is deployed. The American model, for example, seems more prone to an unregulated environment for both shared and private AV-ownership models. Implementation is more likely to be led by private companies, more likely to be implemented in more affluent regions first, to be implemented in direct competition with public transit, and more likely to be cost-prohibitive to lower income groups. The German situation on the other hand may be more likely to result in government owned or subsidized shared fleets that directly supplement the public transit system. In combination with the cost and auto-ownership issues previously discussed in this paper, this may result in a stronger market for shared AVs in Germany than in all but the densest American cities.

4. Conclusions

There are an enormous number of unknowns still associated with the development of AV technology, the forces that will shape its implementation, and the associated impacts. How to plan for these impacts in the face of this level of uncertainty remains an open question. While it may be too early to know precisely how AVs will impact our behavior and the built environment, they most certainly will cause major disruptions in the medium to long-term. Regardless of these uncertainties, it is important that planners, engineers, and designers are considering the potential for unintended consequences, so that we can be sure to harness the potential benefits and limit the risks. Scenario planning to consider the possibilities will be important in the short-term in order to help shape the policy development in a direction that is beneficial to our communities and to private industry.

While it may not be strictly necessary to coordinate all local or national policies across the Atlantic, there are some areas where significant lessons learned can be gleaned by working together. Further, AV manufacturers are likely to appreciate common requirements, making it easier for them to build and sell AVs in advanced markets around the world. All of the considerations and issues outlined in this paper require significant additional study and monitoring as the technology, policies, and regulations mature.