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AUTONOMOUS VEHICLES: A GUIDE FOR POLICYMAKERS

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EXECUTIVE SUMMARY

Autonomous vehicles, one of the most discussed technologies in the transportation industry, promise significant benefits, especially with regard to safety. With the advent of smart phones and telematics systems, distracted driving is an increasing threat to road safety. Most drivers admit to taking their eyes off the road to check their e-mail, read a book or put on makeup. For this reason alone, autonomous vehicles could substantially improve roadway safety and revolutionize transportation over the long-term. Recent leaps in "machine learning"—a field of computer science that gives computers the ability to learn without being explicitly programmed—mean autonomous vehicles will be available to consumers in the near future.

Still, many of the biggest changes are 20 to 50 years away, with significant challenges to implementing autonomous vehicles remaining. Creating technology that works in inclement weather, mastering complex urban and suburban environments, and operating in an environment with non-autonomous vehicles, buses, train crossings, pedestrians, cyclists and parked cars is complicated. Plus, autonomous vehicles are likely to change traffic, transportation and parking patterns. Additionally, recognizing non-technical challenges such as public acceptance, human behavior, price and regulation should caution policymakers and planners regarding unrealistic expectations.

Given all of the unknowns, transportation agencies and governments are unsure how to prepare for autonomous vehicles. In the next five years, policymakers should focus on the intermediate effects, including a world in which autonomous and non-autonomous vehicles share roadways. To safely and quickly hasten the development and implementation of autonomous vehicles, policymakers should:

1. Pass new AV legislation only when existing legislation is clearly inadequate to allow for development of the widest range of innovative options.
2. Encourage autonomous vehicle testing with limited restrictions, as constraints on empirical testing will delay adoption.
3. Focus on current and near-future levels of automation, such as the ways semi-autonomous vehicles and vehicles with no automation features at all might share the roads and roadway testing of autonomous vehicles.
4. Use scenario planning to sketch out a long-term vision, accounting for likely reduced use of light rail and some bus lines and changes in location of parking.
5. Become educated on autonomous vehicles and beware of uninformed, speculative claims.

TABLE ES1: LONG-TERM ISSUES TO CONSIDER

Issue	Change Due to AVs	Timetable
Reducing parking requirements	Reduce number of spaces, Move to periphery of development	2025, gradual 2040, more pronounced
Eliminating construction of light rail lines	More partnerships with on-demand services, Uber, robo-taxis	2040 or later
Reducing new road construction	Autonomous vehicles in partnership with connected vehicle technology can increase capacity by 300%	2050 or later

TABLE ES2: AUTONOMOUS VEHICLE CLAIMS AND REALITIES

Question: When Will …	Speculative Projection	Informed Projection
… level 3 (partially) autonomous vehicles become widespread?	Currently available*	Limited availability today, widespread in 2020 for appropriate areas (limited access highway or campus pedestrian zone)
… level 5 totally autonomous vehicles go on sale?	2020	2025 or later
…land use be revolutionized?	2030	2045 or later
…manual driving be prohibited?	2040	2050 or later
…AVs overcome volume limitations of aging roadway infrastructure?	2025	2040 or later
…AVs drastically reduce vehicle weight because vehicles never crash?	2050	2075 or later; possibly never
…AVs deliver rural mobility for children and seniors?	2030	2040 or later
…AVs drastically reduce car sales and parking because vehicles will be shared?	2025	2035 or later
…AVs completely eliminate driver jobs?	2025	2045 or later
…AVs eliminate crashes, traffic fines, and car insurance?	2040	2070 or later; possibly never

*** Despite claims, Tesla's latest software update includes no level 3 features, only level 2 features. A very limited number of level 3 AV vehicles are on sale to the public.**

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PART 1

INTRODUCTION

Over the past five years, autonomous vehicles have transitioned from a niche topic studied in the mechanical and electrical engineering world to one of the most discussed technologies in the transportation industry. Almost every automaker from Aston Martin to Volkswagen plans to introduce a fully autonomous vehicle in the future. Many automakers already have partially autonomous vehicles with features such as adaptive cruise control and emergency braking; most manufacturers sell vehicles with some autonomous features. Engineers have been working on the technology for more than 50 years. However, recent leaps in "machine learning"—a field of computer science that gives computers the ability to learn without being explicitly programmed—mean autonomous vehicles will be available to consumers in the near future.

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Still, many challenges to implementing autonomous vehicles remain. While partially autonomous vehicles (levels 1 and 2 on the Society of Automotive Engineering—SAE—

scale) with features such as adaptive cruise control and lane-keeping guidance are available today, developing vehicles with more-advanced features faces many challenges and unknowns. Creating technology that works in inclement weather, mastering complex urban and suburban environments, and operating in an environment with non-autonomous vehicles, buses, train crossings, pedestrians, cyclists and parked cars is complicated. For example, the vehicle would have to understand complex tradeoffs, such as the choice between hitting a parked car or a transit vehicle, and make a split-second, potentially life-and-death decision. Additionally, recognizing non-technical challenges such as public acceptance, price and regulation should caution policymakers and planners regarding unrealistic expectations.

Human behavior is another concern. Forcing humans to pay attention to the roads 100% of the time is difficult. With the advent of smart phones and telematics systems, distracted driving is already a major safety challenge. Most drivers admit to taking their eyes off the road to check their e-mail, read a book or put on makeup.[1] For this reason alone, autonomous vehicles could substantially improve roadway safety and revolutionize transportation over the long term. Still, many of the biggest changes are 20 to 50 years away.

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This study explores autonomous vehicle technology, its likely timeline for implementation, and strategies for aiding its adoption. Part 2 provides a brief explanation of autonomous vehicles and where the technology currently stands. Part 3 is a brief history of autonomous vehicle development, which has been ongoing for some 50 years. Part 4 discusses the various strategies employed by hardware manufacturers, software companies and government regulators. Part 5 explores the benefits, challenges and myths surrounding AV implementation. Part 6 examines the likely penetration rate of widespread autonomous

[1] Tison, J., Chaudhary and L. Cosgrove. "National Phone Survey on Distracted Driving Attitudes and Behavior." *nhtsa.org*. 2011. www.nhtsa.gov/staticfiles/nti/pdf/811555.pdf, accessed 18, January 2018.

vehicle use. Part 7 describes likely land use and urban design changes driven by AVs. This study concludes with some policy recommendations for lawmakers and policymakers to promote the development of AVs.

PART 2

WHAT ARE AUTONOMOUS VEHICLES?

An autonomous vehicle is capable of sensing its environment and navigating to its destination without human input. Autonomous vehicles (AVs) are often called driverless, self-driving and robotic cars. Each of the states with detailed autonomous vehicle legislation has a different definition. For example, Nevada defines AVs as "A motor vehicle equipped with autonomous technology. … 'Autonomous technology' means technology which is installed on a motor vehicle and which has the capability to drive the motor vehicle without the active control or monitoring of a human operator."[2] In comparison, Michigan has a much more complicated definition of an AV: "a motor vehicle on which autonomous technology has been installed, either by a manufacturer of autonomous technology or an upfitter that enables the motor vehicle to be operated without any control or monitoring by a human operator. The definition does not include a motor vehicle enabled with one or more active safety systems or operator assistance systems, … unless one or more of these technologies alone or in combination with other systems enable(s) the vehicle on which the technology is installed to operate without any control or monitoring by an operator."[3]

[2] Autonomous Vehicles. State of Nevada Register of Administrative Regulations. R 134-15. Chapter 482A. Web.

[3] Autonomous Vehicles. Office of Performance and Transformation, Michigan Comp. Laws § 257.2b. Web.

Developing an autonomous vehicle demands that various software developers and hardware manufacturers work in parallel. It requires many different technologies—some of which have existed for 30 years. Some of these older technologies have been refined over time. For example, cruise control has been standard equipment on cars for 30 years. Today, many new cars have adaptive cruise control, which can change the car's speed or even stop the car completely based on traffic flows.

Other existing technologies such as sensing technologies need more fine-tuning to apply to AV. For example, vehicles have trouble discerning other vehicles and detecting pavement markings in the rain. Still other technologies remain a work in progress. For example, we will need to fine-tune machine learning before a vehicle can determine when it is safe to cross a double yellow line.

Developing an autonomous vehicle demands that various software developers and hardware manufacturers work in parallel.

2.1 DETERMINING LEVELS OF AUTOMATION

From 2010 to 2014, some automakers, including GM and Ford, thought automation would occur in a progression of steps featuring increasing autonomy. Other automakers and the technology companies such as Google thought automation at first would proceed in steps and then take a massive leap. To break down the process into such steps, the Society of Automotive Engineers (SAE) classifies vehicles based on their level of automation:

- Level 0 has no automation. The human driver handles all aspects of driving.
- Level 1 is "driver assistance," in which the driver assistance system handles steering or accelerating/braking.
- Level 2 is "partial automation," in which the system handles steering and accelerating/braking while the human driver handles all other aspects.
- Level 3 is "conditional automation," in which the system handles all aspects of the driving tasks with the human needing to intervene for fallback performance.

- Level 4 is "high automation," in which the system handles all aspects of the driving task without the human needing to intervene in some scenarios.
- Level 5 is "full automation," in which the system handles all aspects of the driving task without the human needing to intervene in all scenarios.

The below chart describes the different levels. The most advanced partially autonomous vehicles on the road in 2018 from Mercedes Benz, Tesla and Toyota are level 2 and level 3 vehicles. Level 5 vehicles are robocars in which no driver will be needed.

TABLE 1: SOCIETY OF AUTOMOTIVE ENGINEERS' LEVELS OF 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* with the expectation that the *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: Society of Automotive Engineers International and J3016

Assigning levels has advantages and disadvantages. One advantage to the SAE level designation is its breakdown of full automation into two parts: level 4 (high automation) and level 5 (full automation). In general, the higher the level, the less the human driver is involved.

Yet, some experts have criticized these levels as an arbitrary ordering to a technology that will not evolve in an orderly manner.[4] Autonomous vehicle technology does not advance in straight lines. For example, it is a big leap from level 2 vehicles to level 3 vehicles. Level 2 vehicles could be subdivided into at least four levels, and advancing from one level to the next involves cooperation among technologies with uneven advancement. So, as autonomous driving systems struggle to master monitoring the environment, partially autonomous vehicles can gradually execute more and more of the driving tasks. Such staggered growth in complementary fields shows the non-linear parallel path that advancing technologies must take to create a fully autonomous vehicle.

> *“Autonomous vehicle technology does not advance in straight lines.”*

The uneven advancement in these various technologies has led some to suggest using alternate taxonomies that focus less on a strict chronological order and more on human interactions. Degree of human interaction is another possible criterion: (e.g., Hands Free, Eyes Free, Autonomous, Automatic). Still, most AV experts employ the five-level designation.

2.2 HUMAN CHALLENGES TO AUTOMATION

Early innovators anticipated human behavioral challenges to automation. They expected, for example, SAE level 2 to increase safety and roadway efficiency but lead to some driver distraction. Level 3 vehicles are completely autonomous in certain situations, and they are capable of handling more and more of the monitoring accomplished by humans in non-AV

[4] Templeton, Brad. “A Critique of NHTSA and SAE Levels of Safe Driving.” 15 January 2017. Web. templetons.com, 25 March 2017.

vehicles, making human distraction an even greater temptation. Indeed, human factors testing revealed that, for automation above level 3, the human driver stops paying attention entirely.

In situations where the human has to take control in levels 4 and 5, he often does not or cannot because his mind is not focused on the driving task. AV experts originally thought they could prompt the driver in level 3 and 4 vehicles with a verbal cue, but testing revealed that to be unreliable.[5] To acclimate drivers to the change, traditional car companies originally advocated a step-by-step approach to refining technology, while Google and Apple advocated full automation as the only truly safe level.[6] However, after testing confirmed numerous safety challenges in levels 3 and 4 due to human inattention, most of the traditional automakers are now skipping the intermediate steps and moving directly from level 2 to level 5.[7]

"Indeed, human factors testing revealed that, for automation above level 3, the human driver stops paying attention entirely."

2.3 AUTONOMOUS VEHICLES CIRCA 2018

Fully autonomous SAE level 5 vehicles that operate in robo-taxi mode, especially in mass production, remain at least 10 years away. Later sections of this paper provide an estimated timeline. While there are no completely autonomous vehicles on the road today, significant SAE level 2 technology, such as lane-departure systems, dynamic cruise control and automatic breaking, are available in many of today's vehicles. The following features are available in most luxury brands:

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[5] Campbell J.L. et al. "Human Factors Design Guidance for Driver-Vehicle Interfaces." nhtsa.org. 2011. Web. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/812360_humanfactorsdesignguidance.pdf, accessed 18, January 2018.

[6] Ingrassia, Paul, Alexandria Sage and David Shepardson. "How Google is Shaping the Rules of the Driverless Road." *reuters.com*. 26 April 2016. Web. https://www.reuters.com/investigates/special-report/autos-driverless/, accessed 18 January 2018.

[7] Davies, Alex. "Ford Skipping the Trickiest Thing About Self-Driving Cars." *Wired.com*. 10 November, 2015. Web. https://www.wired.com/2015/11/ford-self-driving-car-plan-google/accessed 22 February 2017.

- **Active lane control system:** In this technology, the vehicle issues an alert and uses braking or steering inputs to stop the vehicle from drifting into an adjacent lane.[8]
- **Adaptive cruise control (ACC)**: To sustain a preset following distance, the computer adjusts the vehicle's speed to maintain a consistent gap with the vehicle ahead of it. ACC systems allow the driver to vary the following distance of the vehicle. Advanced systems allow the vehicle to move forward without any human intervention, preventing full stops on expressways.
- **Automatic braking:** This technology detects people or objects in a vehicle's path and prevents an imminent frontal collision by applying the braking system to reduce the vehicle's speed. Some vehicles can retract the front brakes and stop the vehicle from hitting any three-dimensional object.
- **Autonomous parking:** This popular feature uses on-board cameras to determine an appropriate spot, and audible tones and the multimedia display to help the driver position the car into place.
- **Blind spot detection:** This system uses cameras in side-view mirrors to alert the driver not to change lanes. Some systems actually prevent the driver from changing lanes if a vehicle is in that lane. Some also include a rear-view monitor that operates in a similar manner.
- **Driver focus monitor:** This technology peers into the driver's eyes to ensure he/she is looking forward and can issue an alert or stop the car if the driver is not paying attention.

While these features, even when operating together, do not create an autonomous vehicle, they help drivers become comfortable with autonomous features and offer a glimpse into the future.

Recently, several companies including Waymo have announced plans to roll out level 3 AVs in limited geo-fenced geographic areas.[9] General Motors has petitioned the National Highway Traffic Safety Administration to let it test vehicles without steering wheels in 2019.[10] Both announcements suggest that level 3 autonomous continue to develop.

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8 Newcomb, Doug and Alex Colon. "The Best Driver Assist Cars of 2017." *PC Magazine.com.* 8 January 2017, Web. https://www.pcmag.com/article2/0,2817,2485278,00.asp 22 February 2017.

9 Hawkins, Andrew. "Waymo is First to put Fully Self-Driving Cars on US Roads without a Safety Driver." *theverge.com.* 7 November 2017. Web. https://www.theverge.com/2017/11/7/16615290/waymo-self-driving-safety-driver-chandler-autonomous, 18, January 2018.

10 McFarland, Matt. "GM Just Introduced a Self Driving Car without a Steering Wheel." *money.cnn.com.* 12 January 2018. Web. http://money.cnn.com/2018/01/12/technology/general-motors-cruise-self-driving-car/index.html, 18 January 2018.

PART 3

HISTORY OF AUTONOMOUS VEHICLE DEVELOPMENT

Inventors have been envisioning automated vehicles for nearly 100 years. But it has taken until now for the technology to become cheap enough and reliable enough to be used in mass-produced vehicles.

The first attempt to create an autonomous vehicle came in 1925 when Houdina Radio Control demonstrated a radio-controlled driverless car on New York City streets.[11] Norman Bel Geddes designed an exhibit for the 1939 World's Fair that showed autonomous vehicles being propelled via electromagnetic fields and circuits in the roadway. He also proposed that all cars be autonomous by 1960, but the cost of installing electromagnetic fields and circuits in roadways was cost-prohibitive.[12]

Sensing an economic opportunity, in 1952 the Central Power and Light Company published the now famous advertisement reprinted in many newspapers of a family playing the board game Scrabble in an autonomous vehicle, which garnered public interest.[13] After RCA labs

[11] "'Phantom Auto' will tour city." *The Milwaukee Sentinel*. Google News Archive. 8 December 1926. Web. 22 February 2017.

[12] Bel Gedes, Norman. *Magic Motorways*. New York City: Random House, 1960. Web. https://archive.org/stream/magicmotorways00geddrich/magicmotorways00geddrich_djvu.txt, 19 January 2018.

[13] "Power companies build for your new electric living." *The Victoria Advocate*. Amazon Web Services. 24 March 1957. Web. 22 February 2017.

built a successful miniature car guided and controlled by wires laid on a factory floor in 1953, the Nebraska Department of Roads worked with RCA labs to build a full-size system in Nebraska. The system of experimental circuits sent impulses to the car that detected metallic surfaces. After further demonstration at RCA labs, the system was expected to be used by 1975,[14] but costs and reliability prevented rollout of the system.

During the 1960s and 1970s governments and universities started researching AVs. The United Kingdom's Transport and Road Research Laboratory tested a driverless Citroën DC on a metal track.[15] The car maintained its speed and direction more effectively than any vehicle driven by a human. An initial cost-benefit analysis showed the cost of installing the system would be repaid in 30 years. The analysis found that such a system would increase road capacity by 50%, as the wide buffers between vehicles that are necessary for human response times narrowed. As well, such a system would reduce accidents by 40% by overcoming human driving errors. However, the technology turned out to be more expensive than anticipated. All funding was exhausted by the mid-1970s.

> *Inventors have been envisioning automated vehicles for nearly 100 years. But it has taken until now for the technology to become cheap enough and reliable enough to be used in mass-produced vehicles.*

The Defense Advanced Research Projects Agency (DARPA), created by President Eisenhower in 1958, was working in the field by the 1980s. DARPA funded an autonomous land vehicle that used Light Detection and Ranging (LIDAR), computer vision, and robotic control to travel at speeds close to 20 mph.[16]

In 2004, DARPA sponsored a Grand Challenge to award $1 million to any team that could finish a 150-mile Mojave Desert driving course via autonomous vehicle. While no team

[14] Ingraham, Joseph C. Electronic Roads Called Practical. *nytimes.com.* 6 June, 1960. Web. 22 February 2017.

[15] Reynolds, John. "Cruising into the future." 26 May, 2001. Web. http://www.telegraph.co.uk/motoring/4750544/Cruising-into-the-future.html 22 February 2017.

[16] Fagnant, Daniel and Kara Kockelman. "Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations for Capitalizing on Self-Driven Vehicles." *Transportation Research Record Part.* Volume 7. 167–181. 2015. Online. http://www.caee.utexas.edu/prof/kockelman/public_html/TRB14EnoAVs.pdf, 18, January 2018.

succeeded in 2004, in the second event in 2005 five vehicles completed the course.[17] By 2005, autonomous vehicles started showing up in more and more places. Several governments including China and Germany provided funding for automakers and/or researchers to develop autonomous vehicles.[18] Many major manufacturers including GM, Ford, Mercedes, Volkswagen, Toyota, BMW and Nissan started testing partially autonomous vehicles.[19] Soon thereafter, partially autonomous vehicle technologies such as adaptive cruise control began appearing as standard equipment on luxury vehicles.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 ordered the DOT to demonstrate an autonomous vehicle and highway system by 1997. The National Autonomous Highway System Consortium (NAHSAC) created a program—Demo '97—in which 20 autonomous cars, buses and trucks demonstrated close-headway platooning integrated with non-autonomous vehicles. Due to other priorities, the program was cancelled.[20]

The history of AVs' development furnishes several lessons:

- Developing AVs is both time-consuming and expensive. For most AV technologies, the cost was much higher than anticipated.
- Public approval is another hurdle. Customers will not buy a vehicle that they do not like. Some systems had trouble detecting cyclists and pedestrians, making them non-starters in most urban environments and contributing to public distrust.
- AV is extremely complicated and therefore difficult. Often the technology does not work as anticipated, and rarely does it conform to the expected timeline. Norman Bel Geddes expected his electromagnetic fields technology to be ready by 1960. The RCA Labs system of guided wires was supposed to be operational by 1975. Neither was created. DARPA, which funded the original autonomous vehicle as we know it, has been working on AVs for 30 years. Yet no mass-produced fully autonomous vehicles are currently available to customers.

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[17] Thrun, Sebastian. "Toward Robotic Cars." Communications of the ACM 53.4 99–106. Computer & Applied Sciences Complete. 2010. Web. https://dl.acm.org/citation.cfm?id=1721679&picked=formats&preflayout=tabs 22 February 2017.

[18] Thrun, Sebastian. "Toward Robotic Cars." Communications of the ACM 53.4 (2010) Computer & Applied Sciences Complete. 24 October 2014.

[19] Niel, Dan. "The driverless car is coming. And we all should be glad it is." *Wall Street Journal.com*, 24 September 2012. Web. https://www.wsj.com/articles/SB10000872396390443524904577651552635911824, 22 February 2017.

[20] Bishop, Richard. *Intelligent Vehicle Technologies and Trends*. Boston: Artech House. 2005. 300. Print.

PART 4

AUTONOMOUS VEHICLE HARDWARE, SOFTWARE AND REGULATION

Three major factors are likely to influence the development of AVs:

1. **Hardware:** The industry includes both the small number of highly regulated auto hardware makers and the more bottom-up developers of computer processors..
2. **Software:** The industry includes a high number of bottom-up actors.
3. **Regulation:** This comprises the rules and policies that are passed by governments in the name of safety.

4.1 HARDWARE

While automakers initially planned to build both the vehicles and the software themselves, they realized they did not have the technical skills to develop much of the software. Because of this, the largest traditional automakers (GM, Ford, Chrysler, Toyota, Honda, Nissan and Volkswagen) concentrate their efforts on building the autonomous vehicles themselves—hardware, not software.

It is unusual but not unprecedented for automakers to form partnerships. For example, when cars were becoming popular around 1920, carmakers pushed to develop dealer networks that require dealers to be franchises. The system allowed car companies to expand with minimal capital expenditures and in return states banned corporate dealer ownership.[21] Carmakers were quick to agree to these rules since their strength was building and not selling cars. Internationally, carmakers in Japan and Germany have similar if slightly less rigid agreements with their dealer network.[22]

Automakers are taking much the same path with autonomous vehicles. General Motors, which has been working on autonomous vehicles since the first DARPA challenge in 2007, chose to use its Onstar division to create the software in-house. However, while it is not teaming up with a direct competitor such as Google, it bought ridesharing company Lyft, in part to compete in a world with shared-use autonomous vehicles.[23] Ridesharing companies would like to replace some of their drivers with autonomous vehicles. From the deal Lyft gets an infusion of cash while GM gets a market for its autonomous vehicles.

"While traditional automakers design, manufacture and install components such as seats, steering wheels and power windows, developing the computer systems that manage modern vehicles is a different area of expertise."

COMPUTER PROCESSORS

While traditional automakers design, manufacture and install components such as seats, steering wheels and power windows, developing the computer systems that manage modern vehicles is a different area of expertise. Unlike vehicle hardware, the technology

[21] Berk, Brett. "Do We Really Need Car Dealerships Anymore." *popularmechanics.com.* 30 July, 2013. Web. http://www.popularmechanics.com/cars/a9265/do-we-really-need-car-dealerships-anymore-15748322/ accessed 24 February 2017.

[22] George, Patrick. "Why Nobody in Japan Buys GM's Cars." *Jalopnik.* 2 September, 2014. Web. http://jalopnik.com/nobody-in-japan-buys-gms-cars-1629670622, accessed 24 February 2017,

"Buying a Car in Germany." *InterNations*, Web. https://www.internations.org/germany-expats/guide/16033-transport-driving/owning-a-car-in-germany-15968/buying-a-car-in-germany-3, accessed 24 February 2017.

[23] Davies, Alex. "GM and Lyft are Building a Network of Self-Driving Cars." *wired.com.* 4 January 2016. Web. http://www.wired.com/2016/01/gm-and-lyft-are-building-a-network-of-self-driving-cars/, 24 February, 2017.

underpinning computer processors advances at an exponential rate. To quantify this phenomenon, Intel co-founder Gordon Moore founded Moore's Law—an algorithm expressing the doubling of transistors on integrated circuits.[24] Moore suggested that technological advances were coming so rapidly that the processing speed of computers would double every two years. Unsurprisingly, in 30 years, we have gone from cars guided by basic computers to those with detailed GPS systems that can monitor the location and speed of the driver. In that time frame, seat design has changed very little. Because this disparity in product evolution creates a need for different business models, traditional automakers have contracted with chip makers for the computer processors that manage modern vehicle systems.

"But autonomous vehicles demand even higher precision, and more-nuanced and complex technology, requiring a more integrated relationship between hardware and software."

But autonomous vehicles demand even higher precision, and more-nuanced and complex technology, requiring a more integrated relationship between hardware and software. This need makes partnerships between hardware (vehicle manufacturers) and software companies the standard arrangement for autonomous vehicles.

4.2 SOFTWARE

For the purposes of this report, software companies are entities with the resources to partner with existing automakers to develop autonomous vehicles. Google, Apple and Yahoo are three examples. Based in California's Silicon Valley, these companies' autonomous vehicle divisions focus on developing superior software, and then partnering with traditional automakers for the vehicle hardware.

[24] Simonite, Tom. "Moore's Law is Dead. Now What?"*technologyreview.com.* 13 May, 2016. Web. https://www.technologyreview.com/s/601441/moores-law-is-dead-now-what/ accessed 24, February 2017.

Apple, Google and Yahoo have since diversified into a range of software and hardware applications, responding to felt needs in a dynamic way. The technology companies have been able to do this because of the mutually reinforcing massive growth in demand for their products and bottom-up approach to innovation and product development.

Most tech companies are loath to change their culture. Based in California's Silicon Valley, these tech giants believe that their bottom-up approach will produce software superior to that of traditional automakers.

4.3 HARDWARE/SOFTWARE AV PARTNERSHIPS: COMPLEMENTARY BUSINESS MODELS

Vehicle hardware technology advances much more slowly than does computer technology. As a result, traditional automakers focus more on bringing a cost-efficient product to market—a traditional, top-down business model.[25]

In contrast, software technology advances comprehensively and rapidly, requiring a focus on innovation. This function has forged a business model for software companies that prioritizes creativity and the flexible workplace environment that encourages it. Rigid organizational charts are frowned upon, and originality, inventiveness and resourcefulness are prized. Thus software innovation favors a dynamic, flexible, bottom-up business model to foster diverse product development.[26]

> *"Because their core competencies favor disparate business models, traditional car companies and software companies work best in partnership, although structures vary."*

[25] In "top-down" business models, decisions directing production come from upper management, prioritizing few product types for mass markets. Companies with these business models value efficiency very highly.

[26] "Bottom-up" business models focus on innovation by encouraging the development of many different ideas by technicians. Companies with these business models value effectiveness very highly.

Because their core competencies favor disparate business models, traditional car companies and software companies work best in partnership, although structures vary. For example, Ford, Chrysler, Honda and Toyota have entered into separate joint ventures with Google. While Google's software has logged more than one million autonomous vehicle miles, building vehicle hardware is unfamiliar to Google, and it does not plan to do so, therefore it needs to partner with a traditional automaker. The manufacturers' side of the deal is non-exclusive, allowing Google to partner with other automobile makers. As a result, the deals benefit Google more than the automakers. Partnering with an automaker such as Ford allows Google to concentrate and maximize its resources on developing software instead of building vehicles. Likewise, Ford, which has not started testing its vehicles, benefits from Google's already-tested self-driving software system. With Ford, it gets a large global automaker that has some of the most popular vehicles on the road, including the F-150, the best-selling vehicle in the U.S.[27]

In 2015 Chrysler, behind on technology but sitting on a pile of cash, suggested teaming up with GM to build autonomous vehicles in a hardware-to-hardware partnership. Due to regulatory uncertainty and a lack of interest from GM, the arrangement never materialized. However, in late 2016 Chrysler teamed up with Google to build self-driving minivans.[28]

In contrast to most major automakers, Nissan has said that totally autonomous vehicles are not currently feasible, due to the amount of machine learning required.

In contrast to most major automakers, Nissan has said that totally autonomous vehicles are not currently feasible, due to the amount of machine learning required.[29] Instead Nissan is relying on machine call centers where autonomous vehicles can get guidance on decisions

[27] Rall, Patrick. "Ford F-150 Drives 34th Best Selling Vehicle Title, Toyota Takes Top Car." *tourquenews.com.* 6 January, 2016. Web. http://www.torquenews.com/106/ford-f150-drives-34th-bestselling-vehicle-title-toyota-takes-top-car, 5 March, 2017.

[28] Samilton, Tracy. "Chrysler Teams up with Waymo for Self-driving Minivans." *michiganradio.org*. 19 December 2016. Web. http://michiganradio.org/post/chrysler-teams-waymo-self-driving-minivans, 24 February, 2017.

[29] Davies, Alex. "Nissan's Path to Self Driving Cars? Humans in Call Centers." *wired.com.* 5 January, 2017. Web. https://www.wired.com/2017/01/nissans-self-driving-teleoperation/, 24, February 2017.

humans typically make, such as the appropriate times to cross a double yellow line.[30] Since AVs must make most of these decisions in real time, this technology's effectiveness is unknown.

Three traditional car companies are developing their own software in-house. General Motors, which has been working on autonomous vehicles since the first DARPA challenge in 2007, bought Cruise and is using its Onstar division for autonomous vehicle software development.[31] Volkswagen is working with Aurora International to develop self-driving software.[32] Aurora is working with Hyundai as well.

Apple, the other major new technology company, has hired engineers from the least traditional of automakers—Tesla—to work on autonomous vehicles.[33] While the exact details have been kept secret so far, Apple hired a number of top researchers in autonomous vehicle technology. The company appears to be using Lexus vehicles for its early tests, but may one day build its own hardware.[34] Apple's approach allows the company to vertically integrate design compared to having multiple hardware developers and exacting standards for the software that it develops. Apple's approach also protects its unique bottom-up culture, which it highly values.

> *Early automated vehicles are likely to be too costly for some buyers to afford. As a result, customers may choose to belong to a ridesharing service.*

[30] The vehicle would communicate with another computer that would give it guidance on how to make difficult decisions. In theory the communication would occur in a microsecond and would not cause any vehicular delays.

[31] Welch, David. "How GM Bought its Way to the Front of the Driverless Car Pack." *www.bloomberg.com*, 30 November 2017. Web. https://www.bloomberg.com/news/articles/2017-11-30/how-gm-bought-its-way-to-the-front-of-the-driverless-car-pack, 18 January 2018.

[32] Korosec, Kristen. "VW and Hyundai Tap Aurora to Develop Self Driving Cars Faster." www.fortune.com, 4 January 2018. Web. http://fortune.com/2018/01/04/volkswagen-hyundai-aurora-self-driving-cars/, 18 January 2018.

[33] Harris, Mark. "Documents Confirm that Apple is Building Self Driving Car." *theguardian.com.* 14 August, 2015. Web. https://www.theguardian.com/technology/2015/aug/14/apple-self-driving-car-project-titan-sooner-than-expected, accessed 5 March, 2017.

[34] Mills, Chris. "Apple Still Hasn't Admitted Its Working on A Self Driving Car but this Video Says Otherwise." *bgr.com*, 18 October 2017. Web. http://bgr.com/2017/10/18/apple-self-driving-car-vs-waymo-sensors/, 18 January 2018.

Automakers are also partnering with ridesharing companies. Early automated vehicles are likely to be too costly for some buyers to afford. As a result, customers may choose to belong to a ridesharing service. Uber and Lyft offer similar services today with human drivers. For their part, auto manufacturers would build the ridesharing vehicles. For example, Toyota has entered into a ridesharing partnership with Uber.[35] With this agreement, Uber drivers can lease their vehicles from Toyota. The two companies are also looking at in-car applications and how the companies can build autonomous vehicles.

As discussed previously, while GM is developing AV software in-house, it relies on the ridesharing company Lyft for marketing. From the deal, Lyft gets an infusion of cash while GM gets a market for its autonomous vehicles. VW has a similar arrangement with German rideshare company Gett.[36]

TABLE 2: COMPANIES WORKING TOGETHER TO DEVELOP AVS

Hardware Company	Software Company	Ridesharing Company	Terms
General Motors	--	Lyft	GM receives market for AVs; Lyft receives cash
--	Apple	--	Most experts believe Apple is looking to build cars itself
Fiat Chrysler	Google	--	Limited partnership to combine engineering teams to build minivans; not exclusive deal
Ford	Google	--	Ford builds self-driving hardware for Google; not exclusive deal
Honda	Google	--	Honda builds self-driving hardware for Google; not exclusive deal
Nissan	--	--	Nissan has deliberately decided not to partner
Toyota	Google	Uber	Toyota builds self-driving hardware for Google; not exclusive deal
Volkswagen	--	Gett	Volkswagen has a partnership in Germany but not in the U.S.

Source: General Motors, Ford, Toyota, Honda, Nissan, Volkswagen

35 Bhuiyan, Johanna. “Uber is Working with Toyota to Create a Vehicle and System that is Built for Ridesharing.” *recode.net.* 8 January 2018. Web. https://www.recode.net/2018/1/8/16864916/uber-partnership-toyota-ces-volvo-daimler, 18 January 2018.

36 Munford, Monty. “Gett $300 Million Investment from Volkswagen Underlines Global Threat to Uber.” *forbes.com.* 31 May 2016. Web. https://www.forbes.com/sites/montymunford/2016/05/31/gett-300-million-investment-from-volkswagen-underlines-global-threat-to-uber/#75e420cc764f, 18 January 2017.

4.4 REGULATION

FEDERAL

Unlike companies, the government does not seek profit; it is focused on societal good, typically safety. As a result, the federal government has provided suggested guidance to the states to ensure that AVs are implemented safely. These different policies will help to shape AV development.

“*As a regulator, the federal government has influenced AV technology development since it began.*”

As a regulator, the federal government has influenced AV technology development since it began. Under the Obama administration, the federal government was very active in AVs. The administration viewed technology as a way to improve transportation safety with minimal taxpayer funding. The National Highway Traffic Safety Administration (NHTSA), which is principally a safety agency, took the lead on setting AV policy. While NHTSA had a moderate regulatory touch for a Democratic administration, it issued controversial recommendations on vehicle-to-infrastructure (V2I) policy and specifically dedicated short-range communications. The agency detailed the responsibilities for both the federal and state governments in its model state policy. The policy section included a series of guidelines, but some (including a vehicle safety checklist for AV manufacturers) appear to be mandates, and others (including a section suggesting changes to the current precertification process) have made car manufacturers uneasy.[37] Under President Trump, NHTSA appears to be employing a lighter regulatory touch.[38]

Other federal agencies—including the Federal Highway Administration (FHWA), the Office of the Assistant Secretary for Research and Technology, and the Federal Motor Carrier

[37] “Government Autonomous Car Regulations are Out: Here’s What it Means.” *autoweek.com.* 20 September 2016. Web. http://autoweek.com/article/technology/us-government-sets-safety-guidelines-autonomous-autos, 18 January 2018.

[38] Beene, Ryan. “Trump’s Regulators Ease the Path for Self-Driving Cars.” *bloomberg.com.* 11 September 2017. Web. https://www.bloomberg.com/news/articles/2017-09-11/trump-self-driving-car-policy-is-said-to-alter-course-from-obama, 18 January 2018.

Safety Association (FMCSA)—also play a part in AVs. FMCSA is expected to play a big role as trucking becomes more autonomous. The other agencies will support NHTSA with research and operations.[39]

STATE

State governments have been the traditional regulator of motor vehicles. Typically, the state motor vehicle administrator (MVA) consults with the state department of transportation (DOT) in setting driver policy. The American Association of Motor Vehicle Administrators (AAMVA) and the American Association of State Transportation Officials (AASHTO), which are trade groups for the respective agencies, are working furiously to develop policies.

Some state organizations, including the National Conference of State Legislators (NCSL), are concerned with NHTSA's overreach. They worry that some of NHTSA's guidelines, such as the vehicle checklist, are designed to usurp traditional state rulemaking. Both NCSL and the Council of State Governments (CSG), which is a similar organization focused on state policy, have held conferences to educate state leaders on AV policy. Both organizations are monitoring the development of federal policy.[40]

LOCAL

Traditionally, local governments have had the regulatory powers given to them by the state. This has been limited to traffic enforcement actions such as setting speed limits or prohibiting right turns at red lights and land use policy such as zoning. Since autonomous vehicles could revolutionize zoning in the future, many cities are examining their zoning policies. Some cities have tried to regulate AVs, arguing that they are an untested danger to other vehicles, cyclists and pedestrians.[41] However, since states are the primary regulators of motor vehicles, most of these attempts have failed or been preempted by state action.

[39] Rapier, Graham. "The First Federal Laws for Self Driving Cars are Starting to Take Shape." *businessweek.com*. 27 June 2017. Web. http://www.businessinsider.com/self-driving-autonomous-vehicles-uber-waymo-lyft-congress. 18 January 2018.

[40] Both organizations have automated vehicle sessions at their annual, regional and legislative meetings and both have held special AV conferences for senior lawmakers.

[41] "Street Wars 2035: Can Cyclists and Driverless Cars Ever Coexist?" *theguardian.com*. 14 June 2017. Web. https://www.theguardian.com/cities/2017/jun/14/street-wars-2035-cyclists-driverless-cars-autonomous-vehicles, 19 January 2018.

4.5 SUPPORTING INDUSTRIES

Developing and maintaining AVs will be very different from operating and maintaining conventional vehicles. For example, car software will be just as important, if not more so, than car hardware. LIDAR and other car-sensing technologies may need to be improved over the life of the vehicle. Therefore, specific industries will develop around autonomous vehicles, both for the autonomous technology itself and for passenger entertainment including video services, mobile work and vehicle repair.

Similar to the car manufacturers, these players are likely to support commercially viable technologies such as AVs and oppose government mandates.

“

...car software will be just as important, if not more so, than car hardware.

”

PART 5

AUTONOMOUS VEHICLES: BENEFITS, CHALLENGES AND MYTHS

5.1 BENEFITS

While many drivers are looking forward to the time when they can work, sleep, or play games in the car, autonomous vehicles have numerous additional productivity and safety benefits. Some of these features will be available in partially autonomous vehicles and some will have to wait for level 5 automation.

Safety: Many safety enthusiasts, including the National Highway Traffic Safety Administration (NHTSA), are excited about the ability of autonomous vehicles to drastically reduce accidents. More than 90% of today's traffic accidents are caused by humans.[42] Some of these accidents result in fatalities. More than 35,000 people are killed in auto accidents each year.[43] Since autonomous vehicles can stop themselves, the number of accidents is

[42] "Traffic Safety Facts: 2015 Motor Vehicle Crashes Overview." National Highway Traffic Safety Administration. *nhtsa.gov*. August 2016. Web. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/8123182016, accessed 5 March, 2017.

[43] NHTSA. Traffic Fatalities Up Sharply in 2015. https://www.nhtsa.gov/press-releases/traffic-fatalities-sharply-2015

expected to decrease 80% by 2070.[44] While partially autonomous vehicles can reduce accidents, the greatest benefit will come from full automation.

But traffic accidents will never be completely eliminated for several reasons. First, computer errors will occur which will cause occasional crashes. While manufacturers will make every effort to avoid errors, including the installment of back-up systems, no technology is perfect. (Currently, AVs that are unsure of how to proceed don't move. This is likely to lead to rear-end collisions.)[45] Second, an AV may have various obstacles to avoid such as a car traveling closely behind it and a pedestrian jaywalking in front of it. In this predicament the car would be programmed to avoid the pedestrian even if that meant striking another car, as striking the car would result in minor damage but striking the pedestrian would almost always result in a fatality.[46]

> *More than 90% of today's traffic accidents are caused by humans.[47] Some of these accidents result in fatalities. More than 35,000 people are killed in auto accidents each year.[48] Since autonomous vehicles can stop themselves, the number of accidents is expected to decrease 80% by 2070.*

Productivity: Commuting time could become productive. Rather than just sitting in traffic wasting time, passengers could safely check their email, draft documents, create spreadsheets, have phone conferences and perform other office duties. Some commuters could also choose to sleep in their cars. Residents could send their cars to the carwash, or to school to pick up their children. Residents could also send their cars to services that have drive-up options such as pharmacies and fast food restaurants. As a result, almost all

44 https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/ten-ways-autonomous-driving-could-redefine-the-automotive-world

45 "What's Holding Back Self Driving Cars: Human Drivers?" *voanews.com*. 11 May 2017. Web. https://www.voanews.com/a/self-driving-cars-human/3847873.html. 19 January 2018.

46 Lin, Patrick. "The Ethics of Autonomous Cars." *theatlantic.com*. 8 October 2013. Web. https://www.theatlantic.com/technology/archive/2013/10/the-ethics-of-autonomous-cars/280360/. 19 January 2018.

47 "Traffic Safety Facts: 2015 Motor Vehicle Crashes Overview." National Highway Traffic Safety Administration. *nhtsa.gov*. August 2016. Web. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/8123182016, accessed 5 March, 2017.

48 NHTSA. Traffic Fatalities Up Sharply in 2015. https://www.nhtsa.gov/press-releases/traffic-fatalities-sharply-2015

of the time currently spent sitting in traffic could be used more productively. However, most of the productivity benefits will have to wait for full automation.

Meanwhile, carmakers are rushing to add features to partially autonomous vehicles. Wireless networks and enhanced concierge services that provide real-time information and entertainment are standard features in many luxury vehicles. Busy consumers see ways to recapture commuting time, automakers see a way to enhance their profits, and telecommunication companies such as AT&T and Verizon see an untapped market for internet services.[49]

> *Busy consumers see ways to recapture commuting time, automakers see a way to enhance their profits, and telecommunication companies such as AT&T and Verizon see an untapped market for internet services.*

Car Life: Advanced computer technology improves many aspects of cars, particularly fuel efficiency. Today's computer software allows cars with automatic transmissions to achieve better fuel efficiency than cars with manual transmissions,[50] something unheard of even 10 years ago. Autonomous vehicles will use this same software for other improvements. Autonomous vehicles will brake more efficiently, accelerate more efficiently and reduce unnecessary steering motions.[51] In addition to reducing emissions, this is expected to extend the car life of engines, transmissions and braking systems, some of the most complicated and expensive car systems.[52] However, even though the software is more efficient, if the car is a shared AV and is driven 100,000 miles per year, it will have a shorter lifespan.

[49] Briodagh, Ken. "Verizon Announces Vision for IOT Future." *IOT Evolution*. 28 October, 2015. Web. http://www.iotevolutionworld.com/iot/articles/412173-verizon-announces-vision-iot-future.htm, accessed 5 March, 2017.

[50] Verlin, Kurt. "Why Are There Fewer and Fewer Cars with Manual Transmissions." *The Newswheel*, 29 September, 2016, Web. http://thenewswheel.com/why-are-there-fewer-and-fewer-cars-with-manual-transmissions/, accessed 5 March, 2017.

[51] Bullis, Kevin. "Will Automated Cars Save Fuel." *MIT Technology Review*. 23 April, 2012. Web. https://www.technologyreview.com/s/427503/will-autonomous-cars-save-fuel/, accessed 5 March, 2017.

[52] Thompson, Catie. "8 Ways Self Driving Cars will Drastically Improve Our Lives." *businessinsider.com*. 14 December 2016. Web. http://www.businessinsider.com/how-driverless-cars-will-change-lives-2016-12, 19 January 2018.

Connectivity: Vehicles can be autonomous or connected, or autonomous and connected. Connected vehicles (CVs) use a number of communication tools to relay information to the driver, to other vehicles (known as vehicle-to-vehicle communication, or V2V), to roadside infrastructure (known as vehicle-to-infrastructure communication, or V2I) and to the cloud. This information could include anything from size, shape, construction material, speed limit zone, traffic and more, informing a vehicle of its surroundings to aid in steering, speed and decision-making. The range of connected vehicle technologies is typically referred to as vehicle to everything (V2X).[53] In theory, connected vehicles allow drivers and computer-driven vehicles to have a 360-degree view of the road landscape.

“*In theory, connected vehicles allow drivers and computer-driven vehicles to have a 360-degree view of the road landscape.*”

Vehicle-to-vehicle communication is available and is being fine-tuned. Some engineers argue that connected vehicle technology is needed to maximize road safety and efficiency. However, some manufacturers such as Google are building autonomous vehicles designed with sensors that don’t need to communicate with other vehicles.[54] Some have suggested that radio frequency identification (RFID) tags could bridge the vehicle-infrastructure communications gap.[55] While there is widespread support for V2V connectivity, there is considerable debate about whether and how to proceed with V2I connectivity.

Since autonomous vehicles have technology that many consumers may be willing to pay for, AVs have been the focus of the private sector. Regarding connectivity, the private sector is interested in V2V technologies, and the choice of technology is not controversial.[56] As a result, V2V technology is expected to be adopted. In fact, GM’s current generation of autonomous vehicles uses V2V technologies to monitor the environment around the car.

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[53] “How Connected Vehicles Work.” ITS Joint Programs Office. its.dot.gov, 2015, Web. http://www.its.dot.gov/factsheets/pdf/JPO_HowCVWork_v3.pdf, accessed 5, March 2017.

[54] Bhuiyan, Johanna. “Google’s Head of Self Driving Tech: We’re Not Building A Car, We’re Building the Driver.” *recode.net.* 3 October 2016. Web. https://www.recode.net/2016/10/3/13154350/google-self-driving-car-fb-live-dmitry-dolgov, 19 January 2018.

[55] Srairi, Salim and Anruad Gorin. “RFID Based Vehilce-Infrastructure Communication System for Road Maintenance.” *12th ITS European Congress.* June 19–22, 2017. Strasbourg, France. Unpublished Conference Paper. Web. https://www.researchgate.net/publication/318265846, 19 January 2018.

[56] Anderson et. al. “Autonomous Vehicle Technology: A Guide for Policymakers.” *rand.org.* 2016. Web. https://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-2/RAND_RR443-2.pdf, 19 January 2018.

Generalized benefits, such as helping cars merge more evenly onto the expressway, accrue to society rather than the industry. As a result, there is no business case for automakers to invest in V2I. Unless some business case is developed for V2I, some type of public funding will be needed to implement it.

The social benefits of connectivity are significant. For example, connected vehicles could reduce congestion by accommodating more vehicles per lane per hour.

Congestion: Autonomous vehicles are forecast to reduce non-recurrent congestion substantially, particularly congestion due to car crashes and weather. Following distances between vehicles are based on human vision capacity and response time. If autonomous vehicles have vehicle-vehicle and vehicle-infrastructure communication (for merging at interchanges), they will be able to travel much more closely together. One lane-mile of highway can accommodate 2,200 human-driven vehicles per hour.[57] Connected-autonomous vehicles, which can "see" all other vehicles and infrastructure and "know" all road conditions, can increase the throughput capacity to between 6,500 and 9,000 vehicles per hour.[58] Many experts estimate a 300% increase of vehicles in a given lane-mile of roadway.[59] This could, in the future, reduce the need to build new lane-miles of pavement and contribute to a reduction in emissions, benefiting the environment. Reducing congestion will require level 5 automation and vehicle-to-vehicle connectivity.

"Autonomous vehicles are likely to accelerate a trend of less vehicle ownership."

Access to Vehicles Without Ownership: Autonomous vehicles are likely to accelerate a trend of less vehicle ownership. Ridesharing services have allowed some households to go car-free and allowed others to get by on one car. Early autonomous vehicles are likely to be owned as fleets. Customers will subscribe to a shared AV service similar to how today's

[57] AASHTO Green Book.

[58] Qu, Xiaobo. "Advances in Modelling Connected and Automated Vehicles." *hindawi.com.* 2017. Web. downloads.hindawi.com/journals/specialissues/724042.pdf, 19 January 2018.

[59] Dopart, Kevin, Baruch Feigenbaum. E-mail interview. 12 July 2017. In-person.

customers are members of ridesharing services. Such services may operate similarly to utilities such as cable or cell phones. Such a societal change would likely mean less need for parking lots and driveways for individuals, businesses and cities.

Transit: AVs could be truly revolutionary for transit services. Today, most major metro areas offer some combination of the following seven transit services: commuter rail, heavy rail, light rail, express bus, bus rapid transit, limited-stop bus and local bus. While heavy rail, light rail, bus rapid transit and local bus are most used in urban cores, commuter rail and express bus are more popular in suburban areas. It is unlikely that AVs will replace heavy-rail or heavily-used light-rail traditional transit in the biggest markets such as New York City and Chicago in the near future. However, AVs could supplement existing services in these markets. Further, autonomous vehicles could reduce or eliminate many traditional transit services, particularly bus-based systems, especially in smaller cities and towns. Some bus-based transit services could be eliminated in as few as 20 years.

“*Further, autonomous vehicles could reduce or eliminate many traditional transit services, particularly bus-based systems, especially in smaller cities and towns. Some bus-based transit services could be eliminated in as few as 20 years.*”

Uber and Lyft are showing that the transit market is changing. In the past, casual carpoolers who wanted to ride together had to meet at one of the designated slugging lines. (Casual carpooling, also called “slugging,” is popular in Houston, San Francisco and Washington, D.C. due to their 3+ occupancy restrictions in high occupancy vehicle (HOV) lanes). Now smartphone applications have increased the popularity of ridesharing, and ridesharers can download the Uber Pool application to form their own carpools. Most major transit agencies are partnering with ridesharing services to offer paratransit service, since it is the most expensive transit service to provide.[60]

[60] Reyes, Roselynne. “Transit Partners with Ridesharing Services to Create Multimodal Options.” *metro-magazine.com.* 2 May 2016. Web. http://www.metro-magazine.com/management-operations/article/711884/transit-partners-with-ridesharing-services-to-create-multimodal-options, 22 January 2018.

Autonomous vehicles can take this transition one step further. Paratransit service may still be operated by ridesharing vehicles, but in the future these vehicles will be autonomous and therefore cost much less to operate without the costs of employing a driver. Transit agencies or cities can purchase a fleet of vans as substitutes for bus service in low-density suburbs with limited ridership and high headways. Even for denser cities where autonomous vehicles could not realistically substitute for buses or rail, automating transit could significantly decrease costs. Labor costs comprise more than 50% of the total cost to operate transit service. As a result, autonomous transit is expected to be much more extensive and much cheaper to operate.

Urban Form: Perhaps the biggest effect from AVs will be changes to a city's urban spatial structure. However, if these changes happen at all, they figure to be concentrated after 2050.[61] AV expert Steve Schladover of the University of California Berkeley's PATH program predicts 2070 or later before major land use changes are implementable.[62] The first change will likely involve parking; with autonomous vehicles most parking lots could be moved to land with few alternate uses. Vehicles would drop passengers off at their destination and then park themselves. Some drivers will not own vehicles; rather, they will use them as part of a ridesharing service. However, with many vehicles being operated during peak travel times, the number of vehicles needed may be higher than most planners estimate.

"Perhaps the biggest effect from AVs will be changes to a city's urban spatial structure."

[61] Schladover, Steve. E-mail interview. 12 July 2017.

[62] Ibid.

5.2 CHALLENGES OF AVS: COST, REGULATION AND MORE

COST

While AVs may revolutionize driving, their features will not come cheaply. Most experts expect costs will be one of the biggest hurdles.[63] While studies show that autonomous vehicle technology initially could cost $10,000–$20,000 extra per vehicle,[64] Oliver Cameron at Udacity believes the cost will be closer to $250,000.[65] Over 20 years that premium could decrease to as little as $2,000 per vehicle.[66] In stated preference surveys, most Americans will not pay more than $5,000 extra for an autonomous vehicle.[67] Since the average price of a new vehicle sold in 2016 is $34,372,[68] widespread penetration of single-owner AVs is unlikely until the average total cost of an autonomous vehicle drops below $40,000 in today's prices.

As a result, shared autonomous vehicles are expected to be the early choice. While $20,000 extra would be too much for an individual owner, divided among four people brings it to $5,000 each, which is a more acceptable number.

However, some individuals may have jobs in which there is an incentive to purchase an AV sooner. For example, Javier is an executive earning $100,000 year or $50 per hour. He spends two hours per day commuting, which costs $100. If he spends half of that time working, he saves $50 per day or $12,500 per year. Javier would be willing to spend an additional $35,000 for a three-year lease. In contrast, José is a salesman earning $50,000 per year. He spends one hour per day commuting, which costs $25. If José spends half of that time working, he saves $12.50 per day or $3,250. Jose would be willing to spend only

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63 Chang, Andrea. "Long Winding Way to Go Before Driverless Cars Become Mainstream." *latimes.com*, 17 November, 2015. Web. http://www.latimes.com/business/la-fi-hy-la-auto-show-autonomous-20151117-story.html, 12 March 2017.

64 Davies, Alex. "Turns Out the Hardware in Driverless Cars is Pretty Cheap." *wired.com*. 22 April, 2015. Web. https://www.wired.com/2015/04/cost-of-sensors-autonomous-cars/, 12 March 2017.

65 Etherington, Darrell. "Udacity Spin-out Voyage Aims to Build a Full Self-Driving Taxi Business." *techcrunch.com*. 5 April 2017. Web. https://techcrunch.com/2017/04/05/udacity-spin-out-voyage-aims-to-build-a-full-self-driving-taxi-business/, 22 January 2018.

66 "Vehicle-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist." United States Government Accountability Office. *www.gao.gov*. September 2015. Web. http://www.gao.gov/assets/680/672548.pdf, accessed 12 March, 2017.

67 King, Jenny. "New Cars Buyers Unwilling to Pay for Advanced Safety Features." *chicagotribune.com*. 12 November, 2015. Web. http://www.chicagotribune.com/classified/automotive/sc-advanced-safety-feature-cost-autos-1015-20151010-story.html. 12 March 2017.

68 "New-Car Transaction Prices Increase Nearly 3 Percent Year-Over-Year In September 2016." *Mediaroom.kbb.com*. 3 October, 2016. Web. ,http://mediaroom.kbb.com/2016-10-03-New-Car-Transaction-Prices-Increase-Nearly-3-Percent-Year-Over-Year-In-September-2016-According-To-Kelley-Blue-Book, 12 March 2017.

$9,000 on an autonomous vehicle. As a result, he would choose to share a vehicle or wait until the price drops.

> *Vehicle costs are unlikely to be the largest cost of connected vehicles. The cost of improved vehicle infrastructure could be enormous.*

Vehicle costs are unlikely to be the largest cost of connected vehicles. The cost of improved vehicle infrastructure could be enormous. The National Highway Traffic Safety Administration wants the U.S. vehicle fleet to be connected to roadside infrastructure and other vehicles using dedicated short-range communications (DSRC) via the 5.9 MHz spectrum.[69] This method requires the installation of connected traffic lights and wireless transmitters in every location where the technology is operable. In 2015, the Government Accountability Office conducted a study and found it was impossible to determine the cost/benefit ratio of V2I technology because it was not sufficiently developed.[70]

While vehicle-to-vehicle communications have numerous safety benefits, NHTSA does not expect the benefits to surpass the costs until 2030.[71]

REGULATION

Another challenge car makers may have to consider is government regulation. Will the government force leading-edge (the first level 3 AVs, the first level 5 AVs) autonomous vehicles to carry extra insurance? Will autonomous vehicles need to come in certain colors or require specialty license plates? There may be legitimate safety concerns, but government regulators typically follow the blame-avoidance principle, discussed below, which reduces innovation and increases price.[72]

[69] "ITS 2015-2019 Strategic Plan." Intelligent Transportation Systems Joint Program Office. *its.dot.gov.* 2014. Web. http://www.its.dot.gov/DSRC/dsrc_faq.htm, accessed 12 March, 2017.

[70] "Vehicle-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist." United States Government Accountability Office. *www.gao.gov*, September 2015. Web. http://www.gao.gov/assets/680/672548.pdf, accessed 12 March, 2017.

[71] Scribner, Marc. "Straight Talk on the Talking Car Mandate." *Real Clear Future.* 23 May, 2017. Web. http://www.realclearfuture.com/articles/2017/05/23/straight_talk_on_the_talking_car_mandate_111956.html, accessed 12, March 2017.

[72] Thierer, Adam. "The Precautionary Principle in Information Technology Debates." *The Technology Liberation Front.* 4 April, 2011. Web. https://techliberation.com/2011/04/04/the-precautionary-principle-in-information-technology-debates/, 12 March, 2017.

There may be legitimate safety concerns, but government regulators typically follow the blame-avoidance principle, discussed below, which reduces innovation and increases price.

For example, in the past, the federal government required all types of safety features in vehicles, from seatbelts to air bags to anti-lock brakes. While these features have important safety benefits, they each have a cost. In hindsight, based on actual benefits, some of these features have not been worth mandating. However, they offered strong perceived benefits so regulators required them. Airbags slightly increased the weight of vehicles, thus requiring other offsets to meet environmental standards.[73]

Such mandates increase costs and delay implementation. They can also be counterproductive to safety goals. For example, if autonomous vehicles save 10,000 lives per year, yet the federal government requires all autonomous vehicles to be connected, which delays AVs for five years, 50,000 folks may die prematurely due to a government mandate.

Such a requirement may delay the use of AVs even more than anticipated. Predicting the adoption rate and speed of autonomous vehicles is challenging. While the private sector is selling the vehicles, the government could threaten excess regulation if connected vehicle technology is not adopted. Both consumers and producers might be willing to pay some of the costs of government regulation. However, even beyond the delays that may increase road fatalities, excess regulation has a negative effect on the economy, costing producers and therefore consumers more, and increasing the time necessary to bring products to market. The Competitive Enterprise Institute estimated that, overall, excess regulation cost the U.S. economy nearly $2 trillion in 2014.[74] While government regulation plays a role in AVs, it's important to take a judicious and conservative approach.

[73] *Stimulating Low Carbon Vehicle Technologies*. Washington: Organization for Economic Cooperation and Development. 2010. 140–148. Print.

[74] Crews, Clyde Wayne. "10,000 Commandments." Competitive Enterprise Institute. 2015. Web. http://freebeacon.com/wp-content/uploads/2015/05/10KC_2015-FINAL_Embargoed-PDF.pdf, accessed 12 March 2017.

CONNECTED VEHICLES AND DSRC

Autonomous vehicles will not exist in a void. While autonomous vehicle technology is being developed, automakers and some industry players are working on connected vehicle technology.

While no connected vehicle technology has been proven viable at this time, it hasn't been for lack of ideas. Until 2017, NHTSA has proposed using dedicated short-range communications (DSRC) in the 5.9 GHz band spectrum.[75] Some automakers prefer DSRC as it is designed to be interoperable with other technologies. However, there are many competing wi-fi uses for the 5.9 GHz spectrum. The Obama administration's preference was for DSRC and wi-fi to share the 5,820–5,925 megahertz band although some portions might have been reserved for safety-of-life applications.[76] DSRC includes certain features unique to the U.S. This country's V2V program may not be compatible with Canadian or Mexican technologies, which could cause major problems especially for commercial vehicles.[77]

> *This country's V2V program may not be compatible with Canadian or Mexican technologies, which could cause major problems especially for commercial vehicles.*

However, the Trump administration appears to be moving away from DSRC. Before 2017, NHTSA was mainly interested in connected vehicle technology and DSRC; now the agency seems to be focusing on autonomous vehicles.[78]

Instead the Trump administration is promoting 5G, the newest generation of wi-fi capabilities with download speeds up to 10 gigabits per second, which will allow

[75] Fessman, Volker. "5.9 Gghz DSRC Spectrum and Potential Band Sharing." National Highway Traffic Safety Administration, *nhtsa.gov*. 2015. Web. http://nhtsa.gov/spectrum, accessed 12 March, 2017.

[76] Kirby, Paul. "Parties Disagree on 5.9 Gghz Sharing Issues." Web blog post. *National Public Safety Telecommunications Council*. July 2016. Web. https://blog.npstc.org/2016/07/11/parties-disagree-on-5-9-ghz-sharing-issues/, accessed 12 March 2017.

[77] "DSRC the Future of Self Driving Cars." *its.dot.gov*. 2017. Web. https://www.its.dot.gov/factsheets/dsrc_factsheet.htm. 22 January 2018.

[78] "U.S. DOT Releases New Automated Driving Systems Guidance." *nhtsa.gov*. 12 September 2017. Web. https://www.nhtsa.gov/press-releases/us-dot-releases-new-automated-driving-systems-guidance, 22 January 2018.

customers to send text, make calls or browse the web much more quickly.[79] This technology is already being tested, but it will not be widespread until 2020 or 2021. An interim option could be existing smartphones and cell phone networks that provide the same communications. Such a system would be temporary only but it would offer significantly cheaper prices.

A full nationwide rollout of DSRC would require putting sensors and enabling V2I communications on every mile of roadway in which this technology is used. It is estimated to cost $13,000–$17,000 per site.[80] The USDOT joint program office studied 2,785 sites in Arizona, Michigan and Virginia in suburban locations. Site costs are for one intersection and include equipment, installation, and planning/design costs. USDOT notes that equipment prices have stabilized; they are unlikely to significantly decrease in the near future. Use of a 5G system and a backup system for areas with limited coverage or coverage failures is estimated at $3,000 per vehicle, an 80% savings over V2I. Clearly, the cost of a temporary system is cheaper, but such a system would need to be upgraded at a later time.

These networks would need to be upgraded to handle more data, and a backup system would be needed for areas with limited coverage or coverage failures. However, such a system is estimated to cost $5,000, a 67% savings over V2I.[81]

SECURITY

Vehicle security is a real issue; such systems will need to be much more robust than those offered in today's vehicles. Hackers could gain access to the vehicle's control system and cause a vehicle to accelerate, brake, or maneuver unexpectedly causing a vehicle crash. Today's vehicles are designed to protect against these types of intrusions. However, the hardware does not consistently protect against threats such as hackers. The mean time between failure (MTBF), a measure of the reliability of a hardware component, for security systems is far too high to be commercially viable today. The software has reliability problems as well. Current software hacks of bank accounts and credit cards causes $15.4 billion in damage.[82] Automotive hacks could be fatal.

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79 Nunez, Michael. "What is 5G and How Will it Make My Life Better." *gizmodo.com*. 24 February, 2016. Web. http://gizmodo.com/what-is-5g-and-how-will-it-make-my-life-better-1760847799, accessed 14 March, 2017.

80 "Researches Identify that DSRC Field Infrastructure Deployment Costs can Range from $13,000 to $21,000 per Site, with Average Cost Estimated at $17,600." *its.dot.gov*. 27 June, 2014. Web. http://www.itscosts.its.dot.gov/ITS/benecost.nsf/SummID/SC2014-00325?OpenDocument&Query=Home, accessed 14 March, 2017.

81 Templeton, Brad, Baruch Feigenbaum. E-mail interview. 12 July 2017.

82 "The Real Cost of Identity Theft." *csid.com*. 9 September 2016. Web. https://www.csid.com/2016/09/real-cost-identity-theft/, 19 January 2018.

5.3 AV MYTHS

While autonomous vehicles have enormous potential benefits, there have been some wild exaggerations of the exact benefits and potential downsides of AVs. The following list examines these claims and then provides more-realistic assessments from AV researchers and experts.

> *While autonomous vehicles have enormous potential benefits, there have been some wild exaggerations of the exact benefits and potential downsides of AVs.*

Prohibiting Manual Driving: Today's partially autonomous vehicles can be operated in autonomous or manual mode. If a driver wants to operate the vehicle in manual mode, he simply turns off the automation feature. SAE level 5 autonomous vehicles are still 10 years away or more from being sold, possibly 20 years from being affordable to most.[83] Others have speculated that AVs may be similar to smart phones in that once they are introduced, they are quickly adopted. Regardless, not everybody will be an early AV adopter. Currently, it takes 20 years for the vehicle fleet to turn over.[84] Hence, some experts expect manual vehicles to be on the road for another 40–50 years. Even if most vehicles are autonomous, public opinion is expected to favor allowing manual vehicles on the road. Any prohibition on driving is likely at least 50 years away, if ever.

Providing Full Mobility for Children and Seniors: True mobility requires level 5 autonomous vehicles that can travel on any street at most any time. True level 5 autonomous vehicles will not be widely in use until 2035 or later.[85] While providing autonomy to groups that are unable to drive is one of the greatest potential economic benefits of AVs, it would be premature to plan for these benefits in the next 15 years.

83 Dopart, Kevin. Baruch Feigenbaum, e-mail interview. 12 July 2017.

84 Stevens, Matthew. "How Long Does It Take for 50% of Cars to Comply with a New Law." *fleetcarma.com.* 3 December 2015. Web. https://www.fleetcarma.com/cars-new-law-timeline/. 19 January 2018.

85 Estimate of Steve Schladover from the PATH Program at UC Berkeley and a consensus at the Princeton Autonomous Vehicles Conference.

Eliminating Crashes/Injuries/Emergency Rooms/Auto Repairs: For at least several more decades, autonomous vehicles will share the road with non-autonomous vehicles, limiting the safety benefits. Further, different AV systems may not communicate via the same bandwidth. There is no guarantee that these systems will communicate correctly with each other. No computer system is perfect. Hackers may attempt to penetrate AV systems to harm society. Finally, AVs may be faced with a choice of hitting a pedestrian or hitting another vehicle. In this case the vehicle would still crash, but avoid hitting the pedestrian.

"Jobs will not be eliminated until vehicles are completely autonomous (level 5). It will be five to 10 years until the first truly autonomous vehicle is available. And given a fleet turnover time of 20 years and additional time for all drivers to afford AVs, universal penetration is likely 40–50 years away."

Eliminating Drivers' Jobs: Jobs will not be eliminated until vehicles are completely autonomous (level 5). It will be five to 10 years until the first truly autonomous vehicle is available. And given a fleet turnover time of 20 years and additional time for all drivers to afford AVs, universal penetration is likely 40–50 years away. Autonomous buses and trucks may be available much sooner because there is a strong economic case for automating these vehicles. Labor is the largest cost for many freight and transit organizations. As a result, it will make sense for them to invest in autonomous vehicles to save expenses on labor costs. Freight and transit make up a small percentage of overall driver jobs.[86] Since there is less of an economic incentive for autonomous passenger vehicles, replacement of taxi drivers may take longer. Ridesharing services are a wildcard because while a ridesharing company such as Uber benefits from autonomous vehicles, it also has to invest in the vehicles. Its current model relies on providing funding for human drivers' vehicles. Finally, new technology will create new jobs. Some driving jobs may be eliminated, but many jobs servicing electronic vehicles will be created.

[86] Kitroeff, Natalie. "Robots Could Replace 1.7 Million American Truckers in the Next Decade." *latimes.com.* 26 September 2016. Web. http://www.latimes.com/projects/la-fi-automated-trucks-labor-20160924/. 19 January 2018.

Drastically Reducing Vehicle Weight: Since computer software problems will exist and autonomous vehicles will still crash, drastically reducing the weight of AVs is unlikely.

Overcoming Old/Limited Roadway Infrastructure: Initially, autonomous vehicles will share the roadway with human-operated vehicles. Since autonomous vehicles will use more conservative judgment than humans (longer following distances, lower turning speeds), congestion will initially increase. Reducing congestion will take a combination of V2V and limited V2I communications, a fleet penetration of AVs of 50%–80%, and a redesign of certain roads. These conditions will not occur until 2035 at the earliest.

Drastically Reducing Car Sales/Parking Due To Shared Vehicles: Some car-sharing will occur within the next two years, due to ridesharing technologies such as Uber and Lyft carpool and vanpool services. However, since drastically reduced car ownership and parking requires level 5 AVs, major decreases are not expected until 2040. And the fraction of vehicles that will be individually owned, versus used as a service, is completely unknown.

“AVs are expected to decrease car ownership, eliminating some surface parking lots.”

Revolutionizing Land Use: Land use is the hardest to predict. AVs are expected to decrease car ownership, eliminating some surface parking lots. While AVs could increase lane capacity, CVs will play a larger part, with current research estimating lane capacity increases at 300%. Vehicle miles traveled are also expected to increase. Some of this will occur from households choosing to live farther from their employment as the time cost of commuting decreases. However, much of this change is from autonomous vehicles traveling from a parking area to pick up their human passengers, to go to the car wash, or to school to drop off a child. While less surface street parking will allow greater urban density and additional space devoted to parks and recreational amenities, the demand for cars is expected to prevent other changes. These major changes require widespread fleet penetration and are at least 20 years away.

PART 6

IMPLEMENTATION CONSIDERATIONS

Many autonomous vehicle makers are vowing to have commercial AVs for sale as soon as 2019. However, most of these proposed vehicles will be partly autonomous vehicles that are not much different from SAE level 2 vehicles for sale today. Some of the promises are little more than hype. Originally, Nissan had planned to have a fully autonomous vehicle on the road by 2016.[87] By 2016, Nissan moved the date back to 2020.[88] As of early 2018, Nissan is promising to have 10 autonomous models on the road by 2020.[89] However, a closer inspection revealed that the vehicles will have park assist, automatic braking, and lane-departure systems that are not much more advanced than technology available in today's top-of-the-line Altima.[90] Since the technology is not even close to failsafe, 2020 is unlikely barring a miraculous advancement in technology. It is more likely that the first SAE level 5 autonomous vehicle is 10 years away.

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[87] Mearian, Lucas. "Nissan CEO: We Will Have an Autonomous Vehicle Next Year." *computerworld.com.* 3 April, 2015. Web. http://www.computerworld.com/article/2905565/nissan-ceo-we-will-have-an-autonomous-vehicle-next-year.html, accessed 14 March, 2017.

[88] Liedtke, Michael. "Renault-Nissan to Introduce 10 Self-Driving Cars by 2020." *phys.org.* 7 January, 2016. Web. http://phys.org/news/2016-01-renault-nissan-self-driving-vehicles.html, accessed 14, March 2017.

[89] Madrigal, Alexis. "All the Promises Automakers Have Made About the Future of Cars." *theatlantic.com.* 7 July 2017. Web. https://www.theatlantic.com/technology/archive/2017/07/all-the-promises-automakers-have-made-about-the-future-of-cars/532806/, 19 January 2018.

[90] Ibid.

Other automakers are vaguer on their AV rollout timelines. GM is using autonomous Chevy Volts on its campus in Warren, Michigan. But it had to delay plans to have a fleet of Volts roaming the business districts of select cities by the end of 2017.[91] Vehicles in both locations are/will be partially autonomous level 2 or 3 vehicles with features such as advanced cruise control.[92] There is a big difference between operating in a campus environment and on every roadway type in the country, under any and all weather conditions. True autonomous vehicles need to be capable of operating in every environment. Ford is tripling its fleet of Fusion autonomous research vehicles but the vehicles still have a driver at the wheel and are merely testing software.[93]

Noteworthy among the automakers is Toyota, which was a skeptic of autonomous vehicles but is now racing to build an AV. Toyota is pumping $1 billion into a new Silicon Valley lab to study artificial intelligence.[94] Yet, Toyota publicly acknowledged that it is more focused on partial automation at first, because the technology for full automation is not fully functioning.

There are four factors ranging from somewhat to completely outside AV makers' control that will affect the penetration rate of AVs: consumer attitude, government regulation, technology rollout, and driver behavior.

6.1 CONSUMER ATTITUDE

What percentage of folks will accept autonomous vehicles? And of that percentage, how many are excited enough about autonomous vehicles to pay more to buy one? While attitudes about new technologies typically fall along generational lines, it's not always so simple. Innovation usually occurs along a bell-shaped curve called the Innovation Adoption Lifecycle pictured in Figure 1.[95]

[91] Davies, Alex. "GM Has Aggressive Plans for Self Driving Cars." *wired.com*. 15 October, 2015. Web. http://www.wired.com/2015/10/gm-has-aggressive-plans-for-self-driving-cars/, accessed 14 March, 2017,

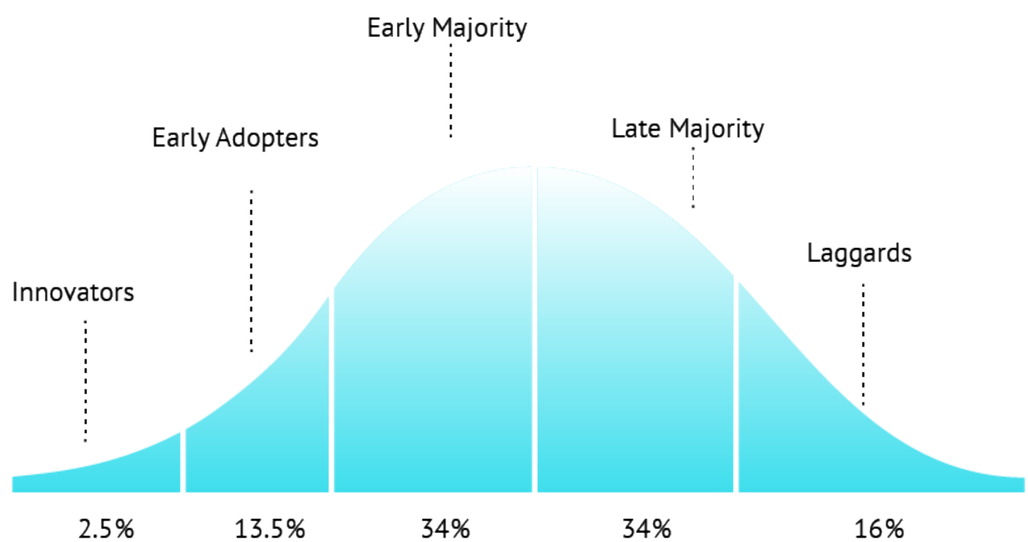
[92] Fagella, Dan. "Self Driving Car Timeline for 11 Top Automakers." *venturebeat.com*. 4 June 2017. Web. https://venturebeat.com/2017/06/04/self-driving-car-timeline-for-11-top-automakers/, 19 January 2018.

[93] Bigelow, Pete. "Ford Promises Fully Autonomous cars by 2021." *https://blog.caranddriver.com*, 16 August 2016. Web https://blog.caranddriver.com/ford-promises-fully-autonomous-cars-by-2021/, 19 January 2018.

[94] Kubota, Yuko. "Behind Toyota's Late Shift into Self Driving Cars." *wsj.com*. 12 January, 2016. Web. http://www.wsj.com/articles/behind-toyotas-late-shift-into-self-driving-cars-1452649436, accessed 14 March, 2017.

[95] Meade, Phillip and Luis Rabelo. "The Technology Adoption Life Cycle Attractor: Understanding the Dynamics of High-Tech Markets." *ScienceDirect*. Volume 71, Issue 7. (2004) 51–54. Web. http://www.sciencedirect.com/science/article/pii/S0040162504000149, 19 January 2018.

FIGURE 1: INNOVATION ADOPTION LIFECYCLE



Polling firms have not found a generational divide toward driverless cars. A Pew poll found that 48% of the traveling public wanted to ride in an autonomous vehicle while 50% did not.[96] Among 18–29 year olds the number is 52%. Among the 65 and older cohort the number is 45%. One reason there may not be as much reluctance among older demographics is because of the real value of the technology to this age range.[97]

Assuming that 50% of potential customers are confident in AV technology, what percentage is willing to spend extra money to buy a vehicle? It is realistic to assume that half of the people confident in AV technology will also be willing to pay extra to buy such a vehicle. In 2016, Texas A&M Transportation Institute study found that people who are afraid of AVs are the same group who indicate they would not spend money on the technology.[98] However, of those willing to pay for an AV, most would be willing to pay only $1,000 or less.[99]

[96] Schoettle, Brandon and Michael Sivak. "A Survey of Public Opinion About Autonomous and Self Driving Vehicles in the U.S., U.K. and Australia." University of Michigan Transportation Research Institute. 2014. Web. https://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf, accessed 14 March, 2017.

[97] Lafrance, Adrian. "One Thing Baby Boomers and Millennials Agree On, Self Driving Cars." *theatlantic.com*. 16 October, 2015. Web. http://www.theatlantic.com/technology/archive/2015/10/snake-people-cars/410923/, accessed 16 March, 2017.

[98] Zmud, Johanna, Melissa Tooley, Trey Baker and Jason Wagner. "Paths of Automated and Connected Vehicle Deployment: Strategic Roadmap for State and Local Transportation Agencies." *tti.tamu.edu*. September 2015. Web. https://static.tti.tamu.edu/tti.tamu.edu/documents/161504-1.pdf, accessed 16 March, 2017.

[99] Ibid.

While advertising/ promotional material may increase the percentage interested in paying somewhat more for an AV, many car buyers will still lack interest, money, or comfort with the technology to buy an AV in the first 20 years of production. Therefore, a 100% vehicle penetration rate may not occur until 2050 or later.

6.2 GOVERNMENT REGULATION

The second factor that could speed up or slow down AV purchases is government regulation. Originally, some states, such as California, had highly restrictive autonomous driving laws requiring AVs to have both a steering wheel and a person in the driver's seat even though that driver would have no control of the vehicle. Most of these states have since relaxed these more onerous rules.[100]

Some states have laws that make sense for conventional vehicles but not for AVs. For example, Texas has a statute that defines driving under the influence as sitting in the driver's seat of a car and having a blood alcohol level of 0.08 or higher.[101] Regardless of whether the car is sitting in a garage with the ignition off, or not, the driver would still be guilty of driving under the influence. Autonomous vehicles can help reduce accidents and injuries related to drunk driving, but only if such restrictions are eliminated for AVs. These types of mandates slow down the rollout of technology because companies have to include unnecessary features and limit their testing.

“*Some states have laws that make sense for conventional vehicles but not for AVs. ...These types of mandates slow down the rollout of technology because companies have to include unnecessary features and limit their testing.*”

[100] Shieber, Jonathan. “California DMV Changes Rules to Allow Testing and Use of Fully Autonomous Vehicles.” *techcrunch.com.* 11 October 2017. Web. https://techcrunch.com/2017/10/11/california-dmv-changes-rules-to-allow-testing-and-use-of-fully-autonomous-vehicles/ 19 January 2018.

[101] “Driving While Intoxicated.” Texas Alcoholic Beverage Commission. *tabc.state.tx.us.* 2018. https://www.tabc.state.tx.us/enforcement/driving_while_intoxicated.asp, 19 January 2018.

6.3 TECHNOLOGY ROLLOUT

The third factor is the rollout of technology. Many of the automakers have had trouble getting their vehicles to function in rain, fog and snow as vehicles have a tougher time determining road markings and distance between vehicles. Automakers such as Google had expected to solve this problem by now.[102]

6.4 DRIVER BEHAVIOR

The final factor is driver behavior. Most new cars have some driver-assisted automation features. How human drivers respond to these features will affect the rollout speed of fully autonomous vehicles. For example, Tesla's partially autonomous driver-assist feature is in beta mode. According to the manufacturer, drivers should be "extremely careful" when using the feature.[103] However, Tesla driver Joshua Brown died when the Tesla failed to distinguish a white truck from the background of the sky.[104] Brown repeatedly filmed himself in the autopilot mode, which is not behavior that can be described as "extremely careful." There is even debate whether beta-testing autonomous vehicles is ethical.[105] Regardless, improper use of the technology will delay the rollout.

[102] Muoio, Danielle. "Google Self Driving Cars Have Driven Over 2 Million Miles but They Still Need Work in One Key Area." *businessinsider.com*. 24 October 2016. Web. http://www.businessinsider.com/google-self-driving-cars-not-ready-for-snow-2016-12, 19 January 2018.

[103] Puzzanghera, Jim. "Driver in Tesla Crash Relied Excessively on Auto Pilot but Tesla Shares Some Blame, Federal Panel Finds." *latimes.com*. 12 September 2017. Web. http://www.latimes.com/business/la-fi-hy-tesla-autopilot-20170912-story.html. 19 January 2018.

[104] Golson, Jordan. "Tesla Driver Killed in Crash with Autopilot Active, NHTSA Investigating. *theverge.com*. 30 June, 2016. Web. http://www.theverge.com/2016/6/30/12072408/tesla-autopilot-car-crash-death-autonomous-model-s, accessed 16 March, 2017.

[105] Solon, Olivia. "Should Tesla be 'Beta-Testing' Autopilot if There is a Chance that Someone Might Die?" *theguardian.com*. 6 July 2016. Web. https://www.theguardian.com/technology/2016/jul/06/tesla-autopilot-fatal-crash-public-beta-testing. 19 January 2018.

PART 7

POTENTIAL EFFECTS

There has been considerable focus on the potential effects of fully level 5 autonomous vehicles. As described in Parts 2 through 5, we are at least 10 years away from the rollout of true SAE level 5 autonomous vehicles. The first vehicles will be extremely expensive, appealing to a small segment of the automotive market. It will take at least five more years for autonomous vehicles to be a mass-market alternative. Today, the average car on the road is 11.4 years old, meaning it will take another 20 years for the entire fleet to become autonomous.[106]

> *With increasing market penetration fully autonomous vehicles may lead to substantial changes in land use, vehicle operations, city design and more.*

With increasing market penetration fully autonomous vehicles may lead to substantial changes in land use, vehicle operations, city design and more. Policymakers should take likely future long-term effects into consideration when determining near-term approaches.

[106] Stevens. "How Long Does It Take for 50% of Cars to Comply with a New Law?"

7.1

LAND USE

Determining how autonomous vehicles could change land use patterns is both complicated and contentious. Currently, the planning trend in most major regions is to increase density and prioritize investments in transit, biking and walking. Many cities are eliminating minimum parking requirements, decreasing parking spaces and making commuting by automobile more challenging.

More conservative areas such as Atlanta are less accepting of higher automobile costs and denser development. However, such regions are finding innovative ways to increase density. The Atlanta Regional Commission is directing growth into rural hamlets that preserve open space while clustering single-family development.[107] Similar approaches are being used in the suburbs of Dallas and Houston.

The adoption of autonomous vehicles could reverse the increasing density trend. The success of Uber and Lyft shows that in fights between technology and established policy, technology tends to win.

“*Some forecast that shared autonomous vehicles will reduce auto ownership by at least 20%.*”

Some forecast that shared autonomous vehicles will reduce auto ownership by at least 20%.[108] However, this might not result in fewer vehicle miles of travel (VMT), since it is also assumed that shared vehicles will remain in motion most of the day, to be ready for other users. Further, owners of autonomous vehicles could use them in new ways, which could also increase VMT. For example, a busy mother might send the car to the car wash instead

[107] “Population and Employment Forecasts.” Atlanta Regional Commission. *atlantaregional.org*, 2016. Web. http://www.atlantaregional.com/info-center/forecasts, accessed 16 March, 2017.

[108] Clements, Lewis and Kara Kockelman. Economic Effects of Automated Vehicles. Transportation Research Record Number 2602. 2017. Web; Zmud, Johanna, Ipek Sener and Jason Wagner. “Consumer Acceptance and Travel Behavior Impacts of Automated Vehicles.” *tit.tamu.edu*. January 2016. Web. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/PRC-15-49-F.pdf, accessed 16 March, 2017; Steinmetz, Katy. “Automated Vehicle Experts Say Future Could Be Bright—or Dystopian.” *time.com*. 19 July, 2016. Web. http://time.com/4413686/autonomous-vehicle-symposium-2016-tesla/, accessed 16 March, 2017.

of driving herself; she might order milk from the supermarket and have an AV deliver it in 30 minutes or less. People tend to avoid getting stuck in congestion, partly because they have better things to do with their time. But a car does not value time. The only negative of a car sitting in congestion versus traveling at free-flow speeds is the excess energy consumption, vehicle emissions and wear and tear on the vehicle. These factors still amount to costs to car owners, especially for AV fleets, but the cost will be lower than today.

The First Automated Vehicle Roads

Some states are considering dedicating certain lanes or specific roads to AVs to encourage development and adoption of the technology.[109] Researchers have suggested managed lanes (carpool, express toll, etc.) could be set aside for AVs since these lanes have fewer access/conflict points and may be suitable for level 4 AVs. Others have suggested regions that are growing quickly and regions that are technologically friendly, such as Austin, should dedicate urban roads to AVs or shared AVs.[110] The Transportation Research Board is studying how to test AVs on managed lanes to determine how AVs may interact with human-driven vehicles.[111]

Additionally, since "drivers" could work, sleep or enjoy leisure time in a level 5 vehicle, the meaning of congestion will decrease for drivers as well. As a result, some people may choose to live farther from their jobs where they can buy a more affordable house. Others may not be as affected by congestion, choosing to ride alone rather than take transit.

With the behaviors of car owners and drivers changing, autonomous vehicles could change land use patterns in several ways.

[109] Fagnant, Daniel and Kara Kockelman. *Preparing a Nation for Autonomous Vehicles.* Washington DC: Eno Foundation, October 2013. 80–88. Web. https://www.caee.utexas.edu/prof/kockelman/public_html/ENOReport_BCAofAVs.pdf

[110] Schneider, Benjamin. "Do Autonomous Vehicles Need Their Own Roads Around Manhattan." *citylab.com.* 26 July 2017. Web. https://www.citylab.com/transportation/2017/07/will-autonomous-vehicles-lead-to-a-resurgence-of-auto-centric-infrastructure/534804/ 19 January 2018.

[111] The Transportation Research Board is producing a report that will examine automated vehicles in managed lanes. The report will study conflicts between conventional and automated vehicles as well as challenges accessing the lanes.

Decreasing Land Tied to Parking: Parking, except for handicapped spots, could be moved to less-valuable land within or on the edge of development. Many university campuses have tried to do this with conventional vehicles.[112] In this scenario, the autonomous vehicle would drop its passengers off at their destination, and then the vehicle would search for parking along the development's periphery. When the passenger is ready for the vehicle, he could call it. This change could be implemented fairly quickly in campus settings, and over 10–20 years after level 5 AVs become widely available.

This change could increase the amount of developable land in one area. While the total number of parking spaces would remain the same at first, parking could be confined to more-limited areas, since spaces would not need to be in easy, walking distance. Over time, as car sharing increases, the number of spaces could be reduced. Some spaces in an easily reachable area could be kept for the elderly and disabled. Some policymakers may want to remove spots close to development to encourage consumers to purchase autonomous vehicles.

Increasing Density: Currently, most development requires some type of on-site parking. These parking requirements often preclude denser uses. However, if the autonomous vehicle could park nearby, cities might feel comfortable allowing more-intensive land uses. However, residents will still need some space to store their cars. Further, since the cars will have to travel to pick up their passengers, this density will increase congestion.

Repurposing Roadways: Autonomous vehicles, combined with connected car technology, could increase the capacity of roadways. Most experts expect a 300% increase in capacity to be achievable. However, this will not occur until all vehicles are autonomous and connected—likely between 2040 and 2050.

Reimagining Transit: Transit could be in for some of the biggest changes. Once level 5 AVs are widespread, many experts believe ridesharing companies will offer autonomous shuttles or vanpools to supplement or replace many fixed-route buses. Charriott offers these types of services in select markets, albeit with human drivers.[113] The biggest advantage for both buses and shuttles will be the elimination of drivers. Labor is more than

[112] Prevost, Lisa. "On the College Campus of the Future, Parking May be a Relic." *nytimes.com.* 5 September 2017. Web. https://www.nytimes.com/2017/09/05/business/college-campus-parking.html, 19 January 2018.

[113] Marsh, Aaron. "Somewhere Between Traditional and Uber, New Takes on Urban Transport." *fleetowner.com.* 24 July 2017, http://www.fleetowner.com/hd-pickup-van/somewhere-between-traditional-and-uber-new-takes-urban-transport, 19 January 2018.

50% of the cost to operate transit.[114] Bus routes that operate with low headways at capacity much of the time will remain, but buses that operate half-full with high headways can be replaced with shuttles.

Today, most transit lines operate at a loss.[115] Many transit agencies have entered into partnerships with Uber, Lyft, Taxi services or other ride-providing companies to replace buses in low-density areas.[116] This has allowed transit agencies to focus on more-popular lines with smaller losses, but most lines still lose money. Transit agencies would like to replace other lines as well, but there is not enough of a supply of alternate rides. Currently, Uber is having trouble meeting the demand of some of its contracts. A fleet of autonomous ridesharing vehicles is expected to allow transit agencies to transfer or contract out more of their service and allow them to focus on core rail and bus rapid transit services.

However, any change will be gradual because there will not be a sufficient supply of autonomous vehicles to meet demand until the fleet is 50% autonomous. And transit systems may fight ridesharing companies as competitors. The full transfer of many bus lines, but probably not major bus or rail lines, is expected to take until 2050.[117]

7.2 LAND TYPE ADOPTION RATE

Autonomous vehicles will be adopted in different ways in different areas. There are at least five major types of land uses: downtown, dense development, campus zone, suburban and rural.

DOWNTOWN

In downtown areas autonomous vehicles must detect vehicles, walkers and bikers all crossing in front of the AV. Further, crossing traffic is likely to occur anywhere on the road,

[114] Bureau of Transportation Statistics. "How Much Does Transportation Cost?" *rita.dot.gov*. 2018. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/transportation_economic_trends/ch3/index.html, 19 January 2018.

[115] Ibid.

[116] Spector, Julian. "Why Transit Agencies Are Finally Embracing Uber." citylab.com. 11 April 2016. https://www.citylab.com/transportation/2016/04/uber-lyft-ridesharing-apps-public-transportation/475908/, 19 January 2018.

[117] McFarland, Matt. "How Free Self-Driving Car Rides Could Change Everything." money.cnn.com. 1 September 2017. Web. http://money.cnn.com/2017/09/01/technology/future/free-transportation-self-driving-cars/index.html, 19 January 2018.

not just at designated intersections or crosswalks. Because of these challenges, downtown areas are expected to be late adopters of autonomous technology.[118]

DENSE CITY DEVELOPMENT

Dense city developments typically refer to city areas outside of downtown. They don't have skyscrapers and usually are more residential than commercial, but they still have a large number of pedestrians and cyclists. Most crossing tends to occur at intersections, but on quiet streets mid-block crossings are typical. Less challenging than downtown, but still challenging, are dense neighborhoods, also expected to be relatively late adopters.[119]

CAMPUS ZONES

Campus zones figure to be the first adopters of autonomous vehicles. Such areas are cut off from major arterials and freeways, making them a testbed for low-speed autonomous vehicles. The large presence of walkers and pedestrians is challenging, but given the low overall travel speeds, autonomous vehicles are expected to fully conquer campus zones within five years.

SUBURBS

Suburbs may be one of the earlier adopters of autonomous vehicles. Suburbs feature less walking and cycling, and due to problematic transit service they could benefit more from autonomous ridesharing services than cities. The biggest challenge of suburban roads is conquering the challenging travel patterns. Expressways with managed lanes, in contrast, offer a semi-dedicated gateway for autonomous vehicles. The Transportation Research Board (TRB) is currently studying the interaction between manned and unmanned vehicles in managed lanes.[120]

RURAL AREAS

Rural areas figure to benefit less, initially, from autonomous vehicles. Therefore, they likely will be late adopters. While the lower traffic volume and relatively few walkers decrease

[118] Zmud, Johanna, Ipak Sener and Jason Wagner. *Consumer Acceptance and Travel Behavior: Impacts of Automated Vehicle.*, Study 15-49F. College Station, TX: Texas A&M Transportation Institute, January 2016. Web. https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-15-49-F.pdf, 19 January 2018.

[119] Ibid.

[120] The Transportation Research Board is producing a report that will examine automated vehicles in managed lanes. The report will study conflicts between conventional and automated vehicles as well as challenges accessing the lanes.

the technical challenges for autonomous vehicles, traffic congestion—which is one of the top reasons people are interested in autonomous vehicles—is much less severe. Rural areas could be suitable testing areas, but are far less likely to justify separate lanes for autonomous vehicles.

PART 8

RECOMMENDATIONS

Given all of the unknowns, transportation agencies and governments are unsure how to prepare for autonomous vehicles. AVs could be the biggest revolution in transportation since the Model T nearly 100 years ago. However, in the next 20-plus years, policymakers should focus on the intermediate effects, including a world in which autonomous and non-autonomous vehicles share roadways. While there is no one "right" approach, policymakers should:

#1 PASS NEW AV LEGISLATION ONLY WHEN EXISTING LEGISLATION IS CLEARLY INADEQUATE

Early adopting states, such as California, rushed to enact legislation that regulated numerous aspects of AVs, only to pass additional legislation that retracted many of those regulations. Autonomous vehicle experts, including NHTSA and the Self Driving Coalition for Safer Streets, recommend passing new legislation only when existing legislation is insufficient or problematic. There are several different types of insufficient or problematic legislation. For example, many states have legislation determining safe following distance for human-driven passenger vehicles. One benefit of autonomous vehicles is that the shorter following distances between vehicles can allow more vehicles on a given road stretch, thus reducing congestion. Another example of legislation that needs to be modified to exempt autonomous vehicles is Part 6's example of Texas' drunk driving statute.

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#2 ENCOURAGE AUTONOMOUS VEHICLE TESTING WITH LIMITED RESTRICTIONS

Different states have taken very different approaches to regulating autonomous vehicles. California has very stringent requirements.[121] The state requires $5,000,000 in insurance coverage, surety bond, notification of specific autonomous vehicle testing and enrollment in certain pull programs. Other states such as Florida, for example, have taken a light regulatory touch.[122] Florida requires vehicle insurance, assigns basic liability, and provides minor restrictions on test locations.

Autonomous vehicles' greatest impact is likely to be a reduction in traffic accidents and fatalities. Strict regulations will extend the timeline needed to develop autonomous vehicles. Lighter regulations may lead to a few additional accidents and potential fatalities, but that number would be dwarfed by the 35,000 people killed in auto accidents each year. If even 80% of those deaths are preventable (safety advocates claim it is 94%), then every year we speed up the development of AVs will save 28,000 lives.

In addition, judicious use of regulation can have economic advantages for states. AV manufacturers are mobile. Many are moving from states with more-stringent regulations to

121 "Deployment of Autonomous Vehicles for Public Operation." State of California Department of Motor Vehicles. *dmv.ca.gov.* 30 November, 2017. Web. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/auto, accessed 12 December, 2017.

122 "Automated Driving: Legislative and Regulatory Action." *cyberlaw.stanford,edu*. Stanford University. 27 April, 2017. Web. http://cyberlaw.stanford.edu/wiki/index.php/Autonomous_Driving:_Legislative_and_Regulatory_Action, accessed 12 December, 2017.

states with more-limited regulations. Autonomous vehicles employ many high-wage earners, and states will want to keep AV jobs within their borders.

#3 FOCUS ON CURRENT AND NEAR-FUTURE LEVELS OF AUTOMATION

There is considerable hype about level 5 autonomous vehicles, the potential benefits of robocars and the potential to change cities' urban form. These benefits are on the horizon, but even if robocars were to be introduced in 2020 (which is extremely unlikely), it would not be until 2040 that they would be widespread, and that would be if all new car purchasers bought a level 5 vehicle. Land use changes are expected to take even longer since widespread penetration of level 5 vehicles is required. AV expert Steve Schladover of the University of California Berkeley's PATH program predicts 2070 or later before major land use changes are implementable.

Policymakers should focus on near-term challenges such as the ways semi-autonomous vehicles and vehicles with no automation features at all might share the roads. Some experts have suggested allowing SAE level 3 and higher autonomous vehicles to use managed lanes. But is the appropriate cut-off between level 2 and level 3? The regulatory approach toward autonomous vehicle testing is another near-term problem.

#4 USE SCENARIO PLANNING TO SKETCH OUT A LONG-TERM VISION

While many of the land use changes enabled by autonomous vehicles will not occur for decades, it is not too early to consider the role of AVs in future plans. For example, slightly reducing parking requirements and placing more of the parking on the periphery for new buildings can be incorporated today. Looking more critically at light rail lines and some bus lines that might no longer be needed with AVs providing transit service is important. However, self-driven vehicles will remain the majority of the fleet for at least the next 20 years, so eliminating 50% of parking or discontinuing transit service is premature.

TABLE 3: LONG-TERM ISSUES TO CONSIDER

Issue	Change Due to AVs	Timetable
Reducing parking requirements	Reduce number of spaces, Move to periphery of development	2025, gradual 2040, more pronounced
Eliminating construction of light rail lines	More partnerships with on-demand services, Uber, robo-taxis	2040 or later
Reducing new road construction	Autonomous vehicles in partnership with connected vehicle technology can increase capacity by 300%	2050 or later

#5 BECOME EDUCATED ON AUTONOMOUS VEHICLES

Autonomous vehicles are a nascent technology, generating many unknowns about the speed of development and end result. However, that has not stopped folks from offering wildly unrealistic projections of the technology's development or the possibilities for societal change from AVs. The following chart shows some of the more hyperbolic claims, labeled "Speculative Projection," originating from car manufacturers, the popular media and futurists. The right column shows more-grounded predictions, labeled "Informed Projection," from researchers.

Policymakers are encouraged to continually educate themselves about autonomous vehicles. Autonomous vehicles have many advantages but it is critical to be skeptical of unrealistic claims.

TABLE 4: AUTONOMOUS VEHICLE CLAIMS AND REALITIES

Question: When Will …	Speculative Projection	Informed Projection
… level 3 (partially) autonomous vehicles become widespread?	Currently available*	2020 for appropriate areas (limited access highway or campus pedestrian zone)
… level 5 totally autonomous vehicles go on sale?	2020	2025 or later
…land use be revolutionized?	2030	2045 or later
…manual driving be prohibited?	2040	2050 or later
…AVs overcome volume limitations of aging roadway infrastructure?	2025	2040 or later
…AVs drastically reduce vehicle weight because vehicles never crash?	2050	2075 or later; possibly never
…AVs deliver rural mobility for children and seniors?	2030	2040 or later
…AVs drastically reduce car sales and parking because vehicles will be shared?	2025	2035 or later
…AVs completely eliminate driver jobs?	2025	2045 or later
…AVs eliminate crashes, traffic fines, and car insurance?	2040	2070 or later; possibly never

*** Despite claims, Tesla's latest software update includes no level 3 features, only level 2 features. A very limited number of level 3 AV vehicles are on sale to the public.**

ABOUT THE AUTHOR

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