Safety and Liability of Autonomous Vehicle Technologies

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Executive Summary

Autonomous vehicle (AV) technologies have the potential to significantly improve transportation safety and offer immense social, economic and environmental benefits. As driving functions become increasingly automated, not only do technical specifications and safety regulations become increasingly outdated, but there is also a shift in responsibility from the human driver to the vehicle itself. This motivates a new look at both the safety and liability regimes so that maximum benefit may be derived from AVs. Our goal is to provide recommendations for California's Department of Motor Vehicles (DMV) to assist autonomous vehicle integration in the California legal system, which may become the groundwork for safety and liability regulations of AVs at the federal level.

In the first half of this work, we present an overview of AV technology. After specifying the definitions of the various levels of AVs and outlining the scope of the paper, limiting our research to the safety and liability of AVs, we present the objectives and a high-level view of our recommendations. Then, we delve into the historical development of this technology and the potential benefits and costs that it could bring. This inspires an elaboration on the methods that were adopted to carry out our research and analysis in the pursuit of recommendations for safety and liability regulations for AVs. Next, we examine the existing AV technology and the current legislative activity governing their safe operation. We find that the current AV technology has severely outpaced regulations, that there is currently little legislation in place, and that legislators may not be entirely qualified to enact policies.

In the second half of this paper, we engage in discussions on the safety and liability regulations of level 2 (in which some driving functions are automated), 3 (in which most driving functions are automated), and 4 (in which all driving functions are automated) AV technologies. In the safety subsection, our case studies on airbags and autonomous aerial technology provide a framework that we use to develop our recommendations from possible alternative recommendations. In the liability subsection, we distinguish tort liability from manufacturer liability and use a case study on the 2001 Firestone and Ford tire controversy and interviews with representatives of car companies and technology experts to justify our recommendations for liability regulations.

Our research will explore both the safety requirements and performance standards that should be in place for the safe operation of AVs, and how liability should be appropriated in light of AVs.

1 Introduction

Autonomous vehicle (AV) technologies have the potential to revolutionize transportation. As these technologies increasingly become competent in taking over driving functions and transition from the testing to commercial phase, safety regulations become increasingly important. Furthermore, the anticipated shift in responsibility for driving from the driver to the vehicle itself motivates an analysis of the liability concerns.

The continuum of this technology can be best summarized by the National Highway Traffic and Safety Association (NHTSA) in five levels of automation.[1] We will use this five-level hierarchy throughout this paper:

- **Level 0:** The human driver is in complete control of all functions of the car.
- **Level 1:** One function is automated.
- **Level 2:** More than one function is automated at the same time (e.g., steering and acceleration), but the driver must remain constantly attentive.
- **Level 3:** The driving functions are sufficiently automated that the driver can safely engage in other activities.
- **Level 4:** The car can drive itself without a human driver.

Policymakers have become progressively more aware of the huge economic, social and environmental changes that AVs may present[2]. They face many policy questions, many of which will determine the adoption and impact of AV technology. This paper will focus on suggesting appropriate policy principles to guide policymakers to decide when this technology should be permitted on the roads and an appropriate liability regime.

1.1 Objectives

Through our research analysis, we aim to ensure and expedite the integration of autonomous vehicles into our society by a gradual implementation and adoption of safety standards, insurance policies, and government-run initiatives that are tailored to levels of automation.

Our research explores three questions:

[1] NHTSA's statement of policy on automated vehicles which defines the different levels: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf
[2] Preparing a Nation for Autonomous Vehicles http://www.enotrans.org/wp-content/uploads/wpsc/downloadables/AV-paper.pdf

1. What safety requirements or performance standards should be in place for the safe operation of Level 2, Level 3, and Level 4 autonomous vehicles
2. How should liability be appropriated for the different levels of autonomous vehicles?
3. What factors do legislators, specifically in the state of California, need to consider in order to encourage adoption of autonomous vehicles at each level?

Without airtight safety standards, we run the risk of unexpected traffic accidents, resulting in not only the loss of lives but also negative public sentiment against autonomous vehicles. The public would respond more negatively to technological failure of an autonomous vehicle than it would to a similar accident involving a human driver. Technological breakdowns would jeopardize the long-term feasibility of autonomous vehicles.

Furthermore, clear and reasonable determination of liability is highly important to encourage car companies to explore autonomous vehicle technologies. According to Kent Kresa, former interim CEO of GM, car companies currently have little incentive to develop autonomous vehicles. They can implement technology for level 2 vehicles, but level 3 technologies add a whole new layer of risk and liability. He states that no matter what deals or reassurances are made by tech companies, car companies would certainly be liable for any sort of accidents that take places in an autonomous vehicle, even if the malfunction was entirely technological. He recommends determining sensible insurance policies to alleviate companies' concerns.[3] Greg Larson, Chief Technologist at the Office of Traffic Operations Research in Caltran's Division of Research, Innovation, and Systems Information also expressed that car companies "are not going to accept additional liability for level 2 driving. They're going to acknowledge that drivers are still responsible for safe responsibility for their vehicles." For level 3, that's "not the case… If something happens that the driver can't handle, it's going to be the automobile industry's responsibility."[4] Thus, car companies have less incentive to move on to level 3 technology.

1.2 Background

In the mid 1920s, a radio-controlled 1926 Chandler called the "Iinrrican Wonder" drove down the streets of New York. It was the first major public display of a driverless car in

[3] Kresa, Kent. "Interview with Kent Kresa, former CEO of GM." Personal interview. 22 Oct. 2014.
[4] Larson, Greg. "Interview with Greg Larson, Chief Technologist at the Office of Traffic Operations Research in Caltran's Division of Research" Personal interview. 7 November 2014.

the United States. At the 1939 World's Fair, General Motors introduced the Futurama ride and advocated for a national automated highway system, encouraging many to dream of a world where automated vehicles could replaced human drivers entirely.[5]

In the decades that have followed, automation has been brought to the air (via drones), sea (via submarines) and even to outer space (via Mars rovers). However, until very recently, self-driving cars have been mostly relegated to science fiction novels. Advancements have been made in machine learning and machine vision technology over the past decade, and the goal of autonomous vehicles on our nation's roads and highways has become a more tangible reality.

On March 13th, 2004, the first Defense Advanced Research Projects Agency (DARPA) challenge was held in the Mojave Desert, with a prize of $1 million for any team whose self-driving car could complete the 150 mile course. The first place teamed lasted only 7.32 miles, but this was cause for excitement. In the following year's challenge, five teams successfully completed the course, and in 2007, DARPA organizers revamped the challenge to simulate an urban environment.[6] As of April 2014, Google has boasted that its self-driving cars have completed around 700,000 autonomous miles, including many in urban or suburban environments.[7] Major car companies such as GM, Mercedes Benz, Audi, and many others have followed with their own research on autonomous vehicles, incorporating elements of autonomy such as parking assistance and lane keeping. Other major tech companies are becoming involved as well - Tesla, for example, recently announced that their model S sedans are taking the next leap forward in automated technology with a limited autopilot mode and exploration of other autonomous features.[8] Some car companies believe that the technology for full autonomy could exist by 2025.[9]

1.3 Potential Benefits

AV technologies offer benefits in a variety of ways, from economic to environmental. First and foremost, AVs hold promise in increasing passenger safety. While the potential benefits of fully automated level 4 vehicles hold promise, even level 1

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[5] Source: http://blog.unhaggle.com/1956-self-driving-cars-first-appeared/. Also http://www.vcars.co.uk/news/industry-news/the-history-of-the-driverless-car-from-dreams-to-reality-10749.html

[6] http://en.wikipedia.org/wiki/DARPA_Grand_Challenge#2013_FANG_Challenge for now, should switch to official website results

[7] http://googleblog.blogspot.com/2014/04/the-latest-chapter-for-self-driving-car.html

[8] http://www.huffingtonpost.com/2014/10/10/tesla-driverless-car_n_5966870.html

[9] http://www.drive.com.au/motor-news/jaguar-joins-the-race-to-driverless-cars-20141003-10ply7.html

technologies have helped reduce accidents, with features such as dynamic brake support, forward collision and lane departure warning, blind spot assists, and adaptive headlights assisting drivers on roads today. The Insurance Institute for Highway Safety (IIHS) estimates that if all vehicles on our roads today adopted these features, nearly a third of vehicular accidents could be prevented.[10]

In 2013, the NHTSA found that 34,080 Americans lost their lives in traffic accidents.[11] They've asserted that the vast majority of accidents occurred as a result of human error, with estimates at around 93%.[12] A plurality (40.1%) of accidents occur as a result of recognition errors, such as inadequate surveillance, and decision errors (37.0%) are not far behind.[13] Level 1 and 2 technologies, such as forward collision warnings and lane departure warnings, can help reduce the accidents, and fully automated vehicles have the potential to do far more to help save tens of thousands of lives annually in the US alone. Other forms of transportation like bicycles, trains and airplanes have significantly lower death rates per mile traveled, but cars are still the most popular method of transportation for most people. Thus, it's vitally important to develop technology to reduce the rate of automobile-related accidents.

In addition to increased public safety, AV technologies could also increase mobility for several disadvantaged populations. Level 4 technologies that don't require a human driver could dramatically enhance mobility for the blind, disabled, children under the age of 16, and elderly. Tech companies working on AV technology are aware of how their efforts could serve these people, as evidenced by Google's 2012 YouTube video depicting its autonomous car transporting Steve Mahan, who is "95% blind."[14] Benefits to these disadvantaged groups include increased personal independence, greater access to essential services, reduced isolation, and feelings of empowerment.[15]

Furthermore, AV technologies can make a positive social and environmental impact. Road congestion can be a major issue, with traffic jams costing drivers many hours of their lives. According to the 2014 Intrix Scorecard, commuters from Los Angeles waste an average of 64 hours stuck in traffic each year, the worst rate in the nation, and a rate that's increasing with each passing year.[16] AV technologies can allow automobiles to be

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[10] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 15
[11] National Highway Traffic Safety Administration (2012a). Fatal Analysis Reporting System. U.S. Department of Transportation, Washington D.C.
[12] http://automotivedigest.com/2012/06/automation-could-reduce-the-fatality-rate/
[13] http://www-nrd.nhtsa.dot.gov/Pubs/810930.PDF
[14] http://www.youtube.com/watch?v=cdgQpa1pUUE
[15] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf p. 16
[16] http://www.inrix.com/press/2764/

routed along the best route possible in order to save time in traffic jams, not to mention saving time by the possibility of drivers engaged in other activities when using Level 4 AV technologies.[17] Environmentally, automobiles use currently accounts for 20% of Greenhouse Gas (GHG) emissions. Part of this results from driving inefficiencies. Cruise control aspects of level 1, 2, and 3 AV technology can increase fuel economy by an estimated 4-10%[18]. Furthermore, in an ideal world where level 4 AVs are the norm, accidents happen at a minimal rate and cars can be built to be much lighter. Thus, the amount of gas required to operate them would decrease significantly as well. While AV technology is certainly not a unique solution to pollution, environmental benefits are an often ignored positive byproduct of investment in AV technologies that may be important to note.

Overall, the number of automobile crashes in the United States has been gradually declining, but the astounding number of fatalities and injuries still poses a major public health problem[19]. One can imagine an ideal world where technology has improved to the point where our vehicles are automated and accidents do not occur. Over time, integration of autonomous vehicle technology into our society could save millions of lives and billions of dollars in property damage and public health costs. One research paper estimates that even "at 10 percent market penetration, the technology has the potential to save over 1,000 lives per year and offer tens of billions of dollars in economic gains."[20] Ultimately, lives saved are the biggest potential benefit of greater integration of AVs into our society.

1.4 Potential Costs and Challenges

As with any new technology or social undertaking, autonomous vehicles bring forth a variety of new challenges. First, satisfactory sensor technology need to be developed. Light Detection and Ranging (LIDAR), the current sensor technology used by AVs, has not developed enough to handle tricky conditions, such as when lane markers are obscured by snow.[21] Additional investment and research needs to be conducted to develop safe AVs. Furthermore, drivers will need to absorb part of the costs of additional technologies - according a report conducted by IHS inc., the price of

[17] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf p. 17
[18]http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf 29-30.
[19] Statistics on US Motor Vehicle Accidents and Fatalities:
http://www.census.gov/compendia/statab/2012/tables/12s1103.pdf
[20] Preparing a nation for autonomous vehicles
http://www.enotrans.org/wp-content/uploads/wpsc/downloadables/AV-paper.pdf
[21] Interview with Professor John Leonard

entry-level cars will increase by $500 to $1500 and the price of luxury cars will increase by $7,000 to $10,000.[22]

In addition to tangible costs, concerns have been raised about privacy (will automation technology also allow companies to access a disturbingly large amount of user data?), ethics (if forced to make a decision, should a driverless car value the life of its passengers over the life of a child crossing the street?), social norms (can Americans adapt to the idea of not controlling their own cars?), and security (can we guarantee that AVs can't be hacked into and turned into mobile kidnapping vehicles?), and more. For the purposes of narrowing the scope of this paper, we will focus on safety and liability and not address these concerns, but they should be noted as problems to consider.

Another challenge faced by AVs is public acceptance. A survey conducted by the University of Michigan across the U.S., U.K., and Australia this year concluded that, while most Americans have heard of autonomous vehicles (70.9%) and have a positive impression of them (56.3%), they are also at least somewhat concerned (61.6%) with driving or riding in a vehicle with level 3 self-driving technology and even more concerned (66.8%) with level 4 technology.[23] It's important to keep public opinion in mind when determining AV policy and integration plans.

Furthermore, AVs face the challenge of living up to their own hype. Several auto manufacturers have publicly stated that level 3 autonomous cars will be developed by 2020 or earlier, including major car companies like BMW, Ford, and Mercedes-Benz.[24] However, these companies may not live up to their predictions. Professor John Leonard, MIT's team lead in the 2007 DARPA, noted that the leap between Level 2 and Level 3 technology is quite extreme, and that Google's test environments have not accounted for extreme but realistic conditions such as snow, glare from the sun, and difficult left-turn situations. He noted that little progress has been made since the DARPA challenge in providing answers to tough questions (such as what to do if snow covers lane markings) and expressed doubts that level 3 technology will be available as quickly as car companies claim.[25] Thus, it's important for our discussion and policy

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22 http://orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/IHS%20_EmergingTechnologies_AutonomousCars.pdf

23 http://deepblue.lib.umich.edu/bitstream/handle/2027.42/108384/103024.pdf?sequence=1&isAllowed=y

24 http://orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/IHS%20_EmergingTechnologies_AutonomousCars.pdf pg 6

25 Leonard, Dr. John. "Interview with MIT Professor and 2007 DARPA challenge MIT team lead John Leonard." Personal interview. 24 Oct. 2014

recommendations to be flexible and not depend on the existence of specific parts of technology on a defined timeline.

1.5 Recommendations

To ensure the safety of AVs at each level of automation, we recommend an increasingly strict safety requirement from level 2 to level 4.

At level 2, while only part of the driving functions are automated, we recommend the introduction of a written or computerized test that outlines the functions of the AV technologies for the owner of the AV. We also recommend the addition of equipment that assists driver alertness through audible or tactile negative feedback.

At level 3, in which the driver can expect most of the driving functions to be automated, we recommend the addition of equipment that regains the attention of the driver that is tailored to the attention of the driver. In particular, the less the driver is attentive, the longer time he should be given to regain control over the vehicle. Moreover, we recommend the comparison of the number of miles driven before the AV gives back control versus the average number of miles driven before a crash as a test statistic to give significant confidence that AVs are safer than human drivers.

At level 4, in which the car can drive itself without a human driver, we recommend the NHTSA develop a tests suite for all possible environments on top of using the test statistic of number of miles driven before an AV crashes versus the average number of miles driven before a crash *not attributable to human error*. Also, we recommend that level 4 AVs have a steering wheel, brake and throttle, but disable it's use once the AV technology is turned on. Lastly, with regards to the ethics of the AV in inevitable crashes, we recommend that the AV be modified to mimic the decision making of the driver - hence, develop an ethical questionnaire for the driver or passengers, so that the vehicle can make the same decision-making outcomes as the driver.

As for liability recommendations, the main purpose is to create a liability scheme that does not deter car companies from deploying AVs while still holding them accountable for accidents that they're at fault for. There are several AVs level 2 technology on the roads today, so we focus on making recommendations for levels 3 and 4. Liability can be broken down into tort liability - liability faced by individuals - and manufacturer liability. We focus on manufacturer liability, but also provide a couple recommendations for tort liability.

We recommend that states use no-fault liability policies to handle tort liability. If some states decide not to use no-fault policies, at the very least it's important that they do not use strict liability. For elaboration on what each of the policies would entail, see the liability section, 4.1. We also recommend that policymakers work with insurance companies to determine new insurance schemes to handle accidents, since traditional actuarial methods that use factors like age, driving experience, etc. become irrelevant.

As for manufacturer liability, we recommend that legal systems use the consumer expectations test rather than cost-benefit analysis to determine whether a manufacturer should be liable for design defects. We further recommend that users should not assume all risk so that AV companies can still be held accountable for accidents. To prevent these companies from being deterred from implementing level 3 technology, we recommend that policymakers create reasonable legal limits for damages that car companies can be held liable for in the event of accidents so citizens cannot simply go after car companies with the deepest pockets.

Overall, integrating autonomous vehicles into society presents a tough challenge for policymakers, tech companies, and car companies alike. While increasing the rate of integration on a broad, nationwide scale would help save more lives, it's also possible that rushing integration without airtight safety standards could lead to unexpected traffic accidents, resulting in heavy social backlash and lawsuits against car and tech companies. A gradual approach that takes into consideration interests from all parties is necessary to ensure that AVs can be integrated into society on a reasonable timeline.

1.6 Methods

Our research for this project consisted of personal interviews and literature reviews. AVs affect multiple industries, so we interviewed a diverse group of experts who could provide perspectives from an automobile manufacturer, policymaker, and technologist. We reached out to several people in each of these fields and were ultimately granted 4 interviews: Kent Kresa, former CEO of GM, Greg Larson, Chief Technologist at the Office of Traffic Operations Research, Lee Gomes, a reporter who's written about AVs for Slate and the MIT Technology Review, and John Leonard, MIT's team lead in the 2007 DARPA challenge and current MIT professor.These individuals were very helpful in providing different perspectives of how AV technologies affect their areas of expertise and directed us towards excellent literature to examine, and we thank them for their help.

In our review of literature, we examined government policies, large-scale research papers on AVs, and case studies of previous technological advancements that were analogous to the development of AV technology. We developed a comprehensive view of the government's view of autonomous vehicles, both on a federal and state level, but examining statements made and bills proposed by different departments (DoT, NHTSA, etc.) and state spokespeople and focused on the most recent developments and policies that related to safety and liability. Additionally, large-scale research papers, particularly the RAND Center's "Autonomous Vehicle Technology" publication, were helpful in developing an overarching view of issues surrounding AV technology. By comparing viewpoints across multiple papers and personal interviews, diving into safety and liability, we were able to develop a comprehensive account of the issues and make recommendations that addressed concerns made from different sources and interest groups.

Finally, to develop a deeper understanding of safety and liability, we drew upon the experiences gained from case studies such as airbags and aerial vehicles to ensure maximum safety of AVs while expediting its integration. To sort out liability, we examined real issues that occurred with major companies such as the 1970s' Ford Pinto scandal, the 1990s' GM C/K pickup series gas tank lawsuits, and the recent Ford-Firestone tire controversy in order to understand how liability is assigned and how litigators and car companies act.

2 Current Status Quo

AV technology has been advancing over the past decade, but more testing, specifically on a more varied set of road and weather conditions, is necessary for technology to advance to the next level. Tech companies have been urging policymakers to create regulations and legalize different forms of testing for several years, and we appear to be on the brink of major legislative changes. Before diving into our specific safety and liability recommendations, we examine the current state of AV technology and legislative activity.

2.1 Autonomous technology

Most car companies working on autonomous vehicles have established level 2 technologies. Level 2 features, such as lane keeping systems and automated breaking, have been built into Toyota, Ford, and many other companies, that drivers can buy today.[26][27] There is, however, a huge gap between driver-assisted level 2 and fully

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automated level 3 technology, and the public doesn't realize the difference. Generally speaking, "autonomous vehicles" and "self-driving cars" are terms that evoke images of level 3 or 4 vehicles. Aside from Google, almost all of what we hear in the media about AVs refers to Level 2 vehicles. Google is looking into Level 3 and Level 4 automation. They've tested early prototypes that initially didn't have steering wheels or pedals to remove driver influence altogether.[28] Mercedes-Benz is also advertising that their soon to be released C-Class models allow for unassisted driving under limited conditions, with an "Intelligent Drive" safety system that allows their cars to follow others at speeds under 37 mph, which has elements of watered down Level 3 technology.[29] Rupert Stadler, Audi's chair of the board of management, expressed that "piloted driving," where "the driver can take his hands off the steering wheel… liberated… to use it to do FaceTime with his customers, with his business, [and] with his family," will happen by 2016 at the latest. He also expressed that Audi is "in the lead" for piloted driving and "others will follow." Many are skeptical of this claim, however. All of the experts that we interviewed were far less optimistic than Mr. Stadler, expressing more or less that Level 3 is several years away and beyond what we hear from auto industry soundbites.

The biggest roadblock for Level 3 technology appears to be sensor quality. Autonomous vehicles currently functions similar to robots, following a "sense-plan-act" design. Sensors interpret data, such as lane markings on the road and nearby objects, use the data to determine a plan, and then act accordingly. In an ideal world, AVs would respond even better than human drivers to an event such as a child running into the street - sensors could perfectly calculate the child's and the car's trajectory to determine exactly how much to swerve and break. Today's sensor technology uses lidar systems which are limited by range (unable to work over long distances) and reflectivity (poor reflection off of some materials, susceptibility to glare). AVs have also explored using *radar*, a system that uses radio waves which are limited by inability to detect non-metallic objects (i.e. pedestrians). Other types of sensors are also used in combination with lidar, such as ultrasonic sensors that are effective at near ranges (1-10 meters) infrared sensors that overcome some of the weather and lighting limitations of lidar but only work at near ranges as well.[30]

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http://www.ford.com/services/assets/Brochure?make=Ford&model=Explorer&year=2014&postalCode=11110

27 http://www.toyota.com/prius/ebrochure/ pg 13

28 Interview with Greg Larson

29 http://www.techhive.com/article/2087440/2015-mercedes-c-class-gets-semi-autonomous-braking-distancing-and-parking.html

30 http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 63

Tech companies are working on combining different types of sensors to handle varied environmental conditions, but current technology is not sufficient for all real life conditions. Google's DARPA challenge results showed that AVs are quite capable of navigating on predetermined routes under favorable weather conditions - teams were provided with GPS coordinates for the course's road segments and stop signs - but sensor technology needs to be enhanced to react quickly enough to adapt to real life situations.[31]

2.2 Legislative Activity

In 2001, the National Transportation Safety Board (NTSB) issued a report on AV technology and emphasized the need for regulation and performance safety standards. It recommended that the U.S. Department of Transportation to take the lead on rulemaking. However, to date, there are no federal regulations specifically regarding AV technology.[32] Several organizations have published optional requirements and recommended standards, but there is no industry-wide set of standards in place. The overall mood towards autonomous vehicles, however, appears to be positive. The NHTSA, for example, has expressed support for the development of AVs, stating that "the agency would like to emphasize that it is encouraged by the innovations in automated driving and their potential to transform our roadways." They also recognize that "premature regulation can run the risk of putting the brakes on the evolution toward increasingly better vehicle safety technologies."[33]

On the state level, Nevada, California, Florida, Michigan, and the District of Columbia have passed legislations that authorize the testing of AVs. These legislations define AVs as "vehicles with the capability to self-drive without being actively controlled or monitored by a human operator," which can be translated to refer to level 3 AVs.[34] In California, AVs are required to have visual indicators of when the autonomous technology is engaged and operational, a system to safely alert the operator if a technological failure is detected, a way of engaging and disengaging the autonomous system, and a driver in the driver's seat who is capable of immediately taking manual control of the vehicle. Manufacturers who perform the testing are also required to purchase insurance, surety bond, or proof of self-insurance cover at least $5 million.[35]

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[31] ibid pg 64
[32] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 103
[33] http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf pg 10
[34] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 41
[35] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 47

Current legislation does not permit operation of any level 3 or above AVs beyond testing on non-public roads.[36]

Little legislation is currently in place, and legislators may not be entirely qualified to enact policies. Understanding AVs requires a deep technical understanding, which can be difficult for policymakers to absorb. Furthermore, states may enact legislation before they are ready in order to compete with one another to be viewed as tech leaders. Lee Gomes expressed that Google originally turned to Nevada to obtain licenses for testing their technology because policymakers in Nevada were less tech literate and more enamored with tech companies - they "don't want to stand in the way of all the cool things that Google is doing."[37] Professor Leonard described Nevada as a "pushover" due to their "lack of technological depth."[38]

Google then leveraged their position in Nevada to force California to move faster. According to an article by AP journalist Justin Pritchard, Google met with California Senator Alex Padilla, who "greed to push a bill [in California]." Padilla further expressed that in the AV industry, California needed to "catch up and try to lead the nation."[39]

Bryant Walker Smith, who teaches a course on self-driving car legislation at Stanford, expressed similar concerns about the major influence that Google and other tech companies have over legislators. In meetings that the Nevada DMV held with Google and the car companies, he said that it "wasn't always clear who was leading" in determining policy - Google or the DMV.[40] It's been argued that AV tech companies may serve their own interests at the expense of the public, and with legislators and lobbyists under the influence of Google, the public is ill-equipped to defend itself. On the flip side, it could be argued that tech companies understand AV technology and their risks better than most legislators. Legislators that better understand technology, such as Senator Padilla, who's an engineering graduate of MIT, may be perfectly suited to interact with tech companies and tackle AV regulation. Thus, it would be natural for tech companies and tech-savvy legislators to push bills forward and take the lead in shaping policy.

In either case, there is currently pressure on legislators to compose bills to regulate AV

[36] http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf pg 10
[37] Personal interview with Lee Gomes
[38] Personal interview with John Leonard
[39] http://www.usnews.com/news/business/articles/2014/05/30/how-google-got-states-to-legalize-driverless-cars?page=2
[40] http://www.usnews.com/news/business/articles/2014/05/30/how-google-got-states-to-legalize-driverless-cars

testing. Regulations can dramatically change the direction of tech and car companies - Google, for example, had designed autonomous vehicles without steering wheels before it was mandated that autonomous cars must be accompanied by drivers, even in testing.[41] It's important for legislators to fully understand the different levels of AV technology and the interests of all parties involved - car companies, tech companies, various lobbying groups, and the general public - as they implement policies speed up or slow down AV integration by several years.

Most significantly, California's Department of Motor Vehicles' has a report that is due by January 1st 2015 that is intended to address autonomous vehicle integration in the California legal system.[42] In particular, the DMV has been charged to:

"…adopt regulations as soon as practicable, but no later than January 1, 2015, setting forth requirements for the submission of evidence of insurance, surety bond, or self-insurance required by the bill and requirements for the submission or approval of an application to operate an autonomous vehicle, including any testing, equipment, or performance standards, as specified, and to hold public hearings on the adoption of any regulation applicable to the operation of an autonomous vehicle without the presence of a driver inside the vehicle."

Our goal is to provide recommendations in time for California to use them to adopt a sensible set of regulations. However, our recommendations are generalized for use of developing safety and liability regulations at the federal level. Hence, our recommendations are targeted towards the NHTSA and US Department of Transportation (DOT).

3 Safety

While the aforementioned benefits of AV technology can potentially revolutionize today's automobile industry, clear guidelines to ensure the safety of these technologies can prevent unintended consequences.

While the implementation of seemingly futuristic AV technology in Google, Audi or Tesla's cars have received much hype in the media, with news articles claiming that autonomous motoring are "soon (to) be a reality"[43] and "coming to a street near you"[44],

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[41] Interview with Lee Gomes.

[42] Full SB-1298 bill: http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120SB1298

[43] The Economic Times article: How semi-autonomous vehicles may soon be reality on American roads http://economictimes.indiatimes.com/magazines/panache/how-semi-autonomous-vehicles-may-soon-be-reality-on-american-roads/articleshow/44495781.cms

the dangers and potential faults of AV technology are often left unaddressed. Without proper safety guidelines and regulations in place, faulty technology can wreck havoc. For example, over-reliance on cruise control technology has resulted in possibly avoidable fatalities,[45] and unintended acceleration from electronic throttles have forced Toyota to recall some 12 million cars from 2009 to 2010.[46] As much as Google's self-driving cars have become iconic for the AV revolution, we should bear in mind that it only merited a "B" in its driving test, in spite of having a predefined route and allowed to avoid troubling weather.[47]

In this section, we address a critical question - "How safe is safe enough?" - for autonomous vehicles. The scope of this questions extends beyond consideration of measures of safety, such as number of miles per accident, and recognizes that different safety requirements and performance standards may be required for the different predefined levels of AV technology for their safe operation. It is clear that autonomous vehicles aim to take away the fallibility and physical limitations of human drivers, yet imperfections in AV technology in dealing with the driver or with the ever-changing environment are also expected. Through analysis of the regulations of air bags and autonomous unmanned vehicles, and discussions with knowledgeable individuals, we aim to set forth safety principles and expectations for level 2, 3, and 4 of AV technologies.

3.1 Safety Regulation

3.1.2 Overview

Today, while the automobile Industry is heavily regulated with the aim of increasing safety, many of the regulations and safety standards in place do not address autonomous technologies. The two main body of government regulators are the U.S. Department of Transportation (DOT) and, at the federal level, the NHTSA.

The U.S DOT is in charge of maintaining the Federal Motor Vehicle Safety Standard

[44] The Economist article: Coming to a street near you
http://www.economist.com/news/business-and-finance/21618531-making-autonomous-vehicles-reality-coming-street-near-you
[45] Celadon pays $18.5M settlement over fatal crash
http://www.ibj.com/articles/42809-celadon-to-pay-18-5m-settlement-over-fatal-crash
[46] Ford faces class-action lawsuit over unintended acceleration
http://blogs.cars.com/kickingtires/2013/04/ford-lawsuit.html
[47] Google's autonomous car gets a 'B' in driving tests: Not great, but better than most of us:
http://www.extremetech.com/extreme/187438-googles-autonomous-car-gets-a-b-in-driving-test-not-great-but-better-than-most-of-us

(FMVSS), which outlines a host of safety standards and test procedures, covering transmission braking effects to windshield defrosting systems to accelerator control systems and retrofit on-off switches for air bags[48].

The NHTSA was charged with the fundamental goal of reducing fatalities and accidents from motor vehicles through the National Traffic and Motor Vehicle Safety Act[49]. This was a response to an increasing number of cars and associated fatalities and injuries on the road. The NHTSA has the authority to issue vehicle safety standards and to require manufacturers to recall vehicles that have safety-related defects or do not meet Federal safety standards.[50] Moreover, through the New Car Assessment Program, the NHTSA can influence the marketplace by rating the safety of cars from one to five stars based on their performance in crash-testing and roll-over resistance tests[51]. In recent evaluations, crash avoidance systems have been included in their tests.

It is important to note that although the safety laws[52] give NHTSA broad authority over all motor vehicles and motor vehicle equipment, there are certain limitations on its authority. In particular, the FMVSS are *standards* that are simply recommendations available to the public that are established by the consensus of the technology community. This differs from *regulations*, which is legislation that mandates certain specifications[53]. So while the NHTSA can stop third-party modifications that affect safety aspects of automobiles, it cannot directly regulate the operation of cars[54]. Also, since the NHTSA does not have authority to require retrofitting existing vehicles with new equipment, as the U.S. code of Federal Regulations gives them authority only to promulgate safety standards for commercial motor vehicles after manufacture of the vehicle, they must rely on each individual state to execute their own periodic inspections of motor vehicles for safety and roadworthiness. The FMVSS are a set of safety standards that help guide the safety inspections.

3.1.3 Current Autonomous Vehicle Technology Regulation

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48 NHTSA FMVSS safety standards http://www.nhtsa.gov/cars/rules/import/fmvss/
49 U.S. Code, 1966 and 49 U.S.C Chapter 301
50 NHTSA Motor vehicle safety defects and recalls campaigns http://www.nhtsa.gov/Vehicle+Safety/Recalls+&+Defects/Motor+Vehicle+Safety+Defects+and+Recalls+Campaigns
51 NHTSA New Car Assessment Program http://www.nhtsa.gov/webapi/Default.aspx?SafetyRatings/API/5
52 U.S. Code, 1966 and 49 U.S.C Chapter 301
53 Standards and Regulations differences http://www.alueurope.eu/what-are-the-differences-between-standards-and-regulations/
54 U.S. Code, 2006

To date, there are no federal regulations specifically related to AV technologies. Both NHTSA and the Research and Innovative Technology Administration (RITA) have produced recommendations to states to help them better oversee self-driving vehicle development, for test purposes. Yet none of the AV technologies are currently required in any type of vehicle and there are no mandatory standards tailored to specific their design or performance.

Two main reasons for which rulemaking for AV technologies has not yet occurred are:

1. Rapid technological changes make it difficult to create a set of standards and regulations that remain relevant.
2. A consensus among all the different stakeholders (manufacturers, government organizations, technology companies, private citizens) is difficult to reach given the diverse range of interests.

In particular, Greg Larson brought to light the recent “ironic” dilemma of implementing testing regulations - “while Google was the one backing the DMV to create testing regulations for automated vehicles, their initial design didn’t have a steering wheel or pedal, yet the DMV went through a public outreach process and concluded that there needed to be someone who can take control of the vehicles for testing. Google had to bring back the steering wheel and brake and throttle controls.”[55]

While regulation has not yet taken set to ensure the safety of AV technologies, many government and non-government groups have developed proposed standards. For example, the International Organization for Standardization (ISO) proposed a standard for lane departure warnings such that an “easily perceivable haptic and/or audible warning shall be provided” (ISO).[56] In a similar way, the society of automotive engineers (SAE) created a standard for adaptive cruise control (ACC) so that it is “capable of responding to all licensable motorized road vehicles, including motorcycles, intended for use on public roads”[57]. Yet neither stipulations take environmental conditions into consideration, nor specifications of the driver (whether the driver is capable of detecting the “easily perceivable haptic or audible warning”). These matters become considerably more important when we are considering level 3 and above technologies.

3.2 Case Studies

[55] Greg Larson, Chief Office of Traffic Operations Research, Caltrans Division of Research, Innovation and System Information
[56] ISO http://www.unece.org/fileadmin/DAM/trans/doc/2010/wp29grrf/AEBS-LDWS-04-09e.ppt
[57] Adaptive Cruise Control (ACC) Operating Characteristics and Interface

3.2.1 Airbags

The automatic intervention of airbags in a crash offers some insight into the policymaking steps required for autonomous vehicle technologies. Initially conceived by John W. Hetrick in 1952, the air bag was originally going to be first deployed in Fords and Mercurys in 1971. However, performance problems in the components intended for mass production and the potentially fatal blows from air bags for children prevented deployment. It was not until 1990 that legislation required all cars sold in the US to be equipped with either air bags or automatic seat belts. In 1991, Congress enacted the Intermodal Surface Transportation Efficiency Act that ordered the NHTSA to require both driver side and passenger side airbags in all new vehicles by 1998.[58]

While air bags were originally estimated to save on the order of 9,000 lives per year based on it's ability to hold passengers in place during a crash, history showed that the first generation air bags posed a risk to many passengers, including women of small stature, the elderly and children.[59] The initial crash tests promised considerable auto safety improvements but were conducted using an adult male-sized dummy and didn't account for smaller individuals. Later studies estimated that while air bags reduced fatalities by 24 percent among adults, they increased fatalities by 34 percent among children under the age of 10.[60] The implementation of airbags essentially shifted traffic fatality risks from adults to children.

The unintended consequences of air bags were eventually corrected, with safer air bags deployed with a force tailored to the occupant's seat position and weight. However, the airbag regulations offer a unique experience to better tailor regulations for AV technologies:

1. It raises the question of how to tailor technologies as to prevent the shift of fatalities from one sample set to another.
2. The idea that seat belts became more of a supplement than a substitute for seat belts questions whether AV technologies could, or should, completely replace the human driver.
3. The long delay of nearly 20 years between the early 1970s, when airbags were

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[58] History of the Air Bag http://web.bryant.edu/~ehu/h364proj/sprg_97/dirksen/airbags.html

[59] Thompson, Segui-Gomez, and Graham, Validating Benefit and Cost Estimates: The Case of Airbag Regulation, Risk Analysis, Vol. 22, No. 4, 2002

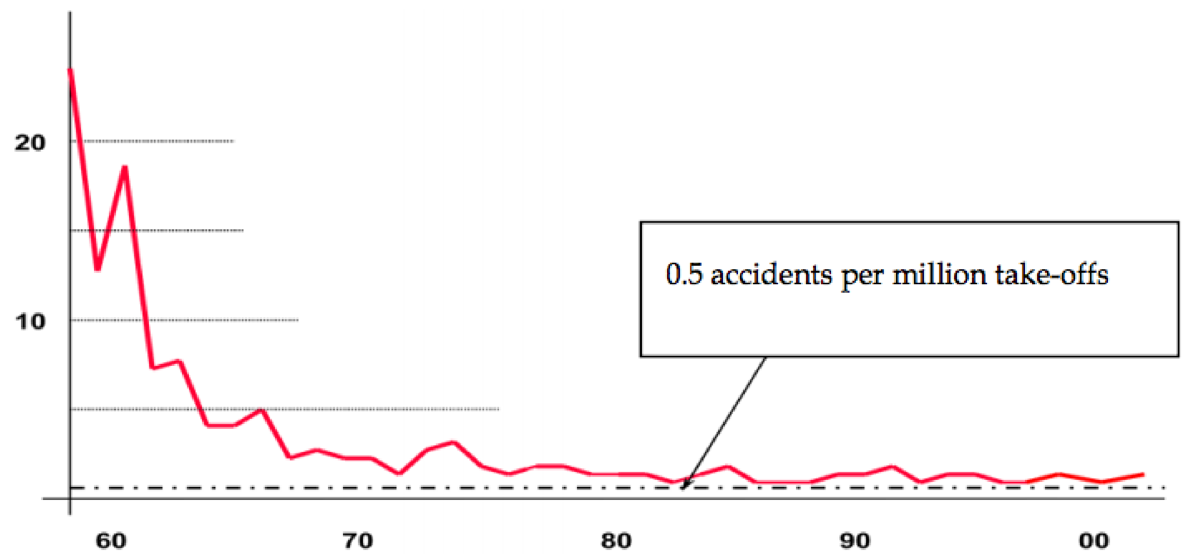
[60] Elisa R. Braveret al., "Reductions in Deaths in Frontal Crashes among Right Front Passengers in Vehicles equipped with Passenger Air Bags", Journal of the Americal Medical Association 278, no. 17 (1997): 1437-39

reasonably mature, until 1998, when they were required in all vehicles, and the number of perhaps preventable casualties during that time, suggests regulation should provide a conducive environment for such technologies.

These issues point towards the need to ensure that new technologies integrated into society do not change the risk levels from one set of the population to another. For example, the increased safety of AVs should not come at the cost of increase risks of collision of cyclists or pedestrians. Moreover, this case study presents the idea that in developing AV technologies, there is a strong need strike a tradeoff between ensuring the safety of the AVs and integrating the technology into society to incur its benefits.

3.2.2 Manned and Unmanned Aerial Vehicles Case Study

The introduction of auto-pilot, auto-throttle, flight director, and other autonomous technologies in aviation during the 1950s and 1960s led to significant reduction in the number of accidents per million take-offs (see diagram below).



Source: ICAO doc. 9683/950. Accident rate over the years

Today, the original factors related to human performance that led to the loss of control of the aircraft such as the impact of fatigue, attention, high workload sustainability, stress mismanagement, etc. have largely been resolved through automation. In their stead, however, is an increasing dependency on the automated technology, leading to a loss of mode awareness.

Not only have pilots made mistakes such as descending too early or missing their destination, reports on flying have shown that pilot confusion or inattention to cockpit automation has resulted from too much reliance on technology.[61] Pilots have been suspended for sleeping, being inattentive while the plane dropped 5,000 feet,[62] and landing at the wrong airport.[63] A study on the role of pilot monitoring in the loss of mode awareness on automated flight decks found that:

1. Pilots have difficulty using certain elements of flight automation correctly.
2. Pilots "fail" to verify mode changes on the Flight Mode Annunciations (FMA) in 30-60% of cases, calling into question the effectiveness of the green-box cue.
3. Even when pilots do fixate the mode annunciation, they often fail to understand the implications of that mode for airplane performance.
4. Pilots have shallow knowledge of automation concepts.[64]

These issues certainly call into question the use of AV technologies below level 4, where the driver is still largely in control of the vehicle or responsible for taking control when problems arise. In particular, there is a strong need to address how the operator of the vehicle and the AV technologies can work together such that the driver doesn't develop too great a dependency on the AV technologies. For level 4 vehicles, these examples question whether occupants of the vehicle should have the ability to take back control.

In the unmanned vehicle space, safety is also a crucial element. In this arena, the National Airspace System facilitates air transportation and sets forth the rules by which aircraft operate. Unmanned aerial vehicles (UAV) create a number of safety issues such as potential air collisions, ground collisions and system reliability.

Wiebel and Hanson conclude that smaller UAVs could fly over 95% of the country with little risk while larger UAVs could fly over 20% of the country and meet the current established levels of risk if the vehicles could operate around 100,000 hours between accidents, the current standard for aviation safety. According to testimoney from Nancy Kalimnowski, FAA Vice President for System Operations Services, "the Custom Border

[61] FAA flight deck automation working group report
http://media.nbcbayarea.com/documents/FAA_Final_Report_Recommendations+11-22-13.pdf

[62] News report on DGCA suspension of 2 Jet pilots for sleeping
http://ibnlive.in.com/news/dgca-suspends-2-jet-pilots-for-sleeping-being-inattentive-while-plane-dropped-5000-feet/492107-3.html
[63] News report on second incident in two months where pilots land in the wrong airport.
http://www.bloomberg.com/news/2014-01-14/pilot-inattention-a-repeat-theme-in-southwest-landing.html
[64] Analysis of pilot's monitoring and performance on an automated flight deck, Mamaw, R. et al presented at the 11th International Symposium on Aviation Psychology.

Patrol (CBP) accident rate is 52.7 accidents per 100,000 flight hours. This accident rate is more than seven times the general aviation accident rate (7.11 accidents/100,000 flight hours) and 353 times the commercial aviation accident rate (0.149 accidents/100,000 flight hours)."[65] To meet or exceed acceptable levels of risks, "Improving reliability is a recognized goal of the UAV community and is actively pursued by aircraft manufacturers."[66]

When examining the ability of air traffic controllers to manage the UAVs, it was found that "the human influence in UAV accidents is approximately 70 percent less on average than in manned aircraft (due to UAV automation capabilities) and therefore human/system interactions account for a proportionally higher degree of accidents"[27]. The cause of this was attributable to the suggestion that "rather than receiving direct sensory input from the environment in which his/her vehicle is operating, a UAV operator received only that sensory information provided by onboard sensors via datalink" [67].

In the same way that there is a metric by which UAV are measured against for safety, the adoption of AV perhaps should also rely on a similar metric. The designation of particular areas of the country over which UAV may be safer suggests that AV should perhaps also be incrementally implemented in different areas to make use of its higher levels of safety in distinct areas, whether by geography or by industry. Namely, this presents the idea that AV could perhaps be first implemented first in low-speed zones, before in suburban areas, small cities and larger cities. Alternatively, perhaps AV technologies should first be introduced in areas where public transport is along a fixed route, before general public transport and everyday vehicles.

3.3 Analysis

While the case studies have indicated drawbacks in both the airbag technology and the autonomous aerial technology, they provide good frameworks to begin analysis of alternative regulations and standards that the NHTSA can set for the various levels of AV technology.

This section will analyze both alternatives and present recommendations for safety

[65] Testimony - Statement of Nancy Kalinowski (2010) http://www.faa.gov/news/testimony/news_story.cfm?newsId=11599

[66] Degarmo "Issues Concerning Integration of Unmanned Aerial Vehicles in Civil Airspace", at MITRE, Center for Advanced Aviation System Development. Accessed July 1, 2012, at http://www.mitre.org/work/tech_papers/tech_papers_04/04_1232/04_1232.pdf

[67] McCarley J.S. and Wickens C.D. 2005, Human Factors Concerns in UAV flight http://www.hf.faa.gov/docs/508/docs/uavFY04Planrpt.pdf

regulations for level 2,3 and 4 AV technology.

3.3.1 Level 2

3.3.1.a Recommendation

We recommend:

- The introduction of a written/computerized test outlining the functions of the AV technologies for those purchasing the vehicle.
- Level 2 AVs be capable of monitoring how alert the driver is at all times, and provide audible or tactile negative feedback for the driver when the driver's alertness is below a certain threshold.

3.3.1.b Analysis

AVs are categorized as Level 2 when "more than one function is automated at the same time (e.g., steering and acceleration), but the driver must remain constantly attentive." Many of these technologies are already in place in current day automobiles. While the current safety standards in place help guide the safety aspects of such technologies, such as adaptive cruise control or anti-lock braking, our research has indicated that operators may understand the autonomous technologies much less than anticipated, just as pilots don't really understand the signals from the FMA. Our research has also shown that the reliance of automated mechanisms reduce the operator's attention. Indeed, not only has urban legend cited cases in which people thought adaptive cruise control meant they could give up control of their vehicle entirely[68], a recent French study has shown that people's over reliance on cruise control results in increased drowsiness.[69]

One way of potentially reducing the first problem is to mandate a driving test for those purchasing automobiles with such systems. Thus, only those with a license would be legally able to drive these cars. However, while this solution may eliminate all ambiguity of these systems, the relative economic costs may be too high. In particular, requiring another set of tests such that only licensed individuals can drive these cars would place a heavy burden on end-users. Moreover, the feasibility of this would also diminish as new technologies require constant updates to the driving test.

Perhaps a better solution would be to require a written/computerized test outlining the functions of the AV technologies for those purchasing the vehicle. This would ensure

[68] Urban legend cases where drivers fell asleep or got distracted when using cruise control http://www.snopes.com/autos/techno/cruise.asp

[69] French Study investigates Danger of Speed Limit Fixation http://www.thenewspaper.com/news/42/4212.asp

that, at the minimum, the purchaser of the vehicle understood the functions of the AV technologies. This solution may not obtain a penetration level of users understanding the AV technologies as high as the previous one, but it is more economically feasible and can easily be integrated into the current system.

While level 2 AV technologies do not predominantly take control away from the user, technologies such as adaptive cruise control and lane departure warning reduce the required attention span of the user. In this way, level 2 AV technologies are often succumb to the Peltzman effect, in which the predicted benefits from regulations and technologies aimed to increase safety is reduced because people adjust their behaviour in response to the perceived level of risk.[70]

As level 2 AV technologies are unlikely to substantially take over the driving functions, if we assume that the driver understands the limitations of the technology using the aforementioned recommendation, perhaps an extra safety feature to integrate into vehicles with level 2 AV technology is a mechanism to keep the driver alert. Drawing from the pitfalls of automated technologies in aerial vehicles, we recommend that for all level 2 AVs, the vehicle must be able to monitor how alert the driver is at all times, and provide audible or tactile negative feedback for the driver when the driver's alertness is below a certain threshold. This technology is certainly viable, and steps have already been taken in this direction, with seats that monitor heart rate to assess driver fatigue and alertness[71].

3.3.2 Level 3

3.3.2.a Recommendation

We recommend:

- Level 3 AVs be capable of monitoring the alertness of the driver, and change the time allocated to allow the driver to regain control based on his/her alertness.
- The test statistic - the number of miles driven before an AV gives back control versus the average number of miles before a crash, to determine the that AVs are significantly safer than human drivers.

3.3.2.b Analysis

[70] The Peltzman Effect: Do Safety Regulations Increase Unsafe Behaviour: http://www.asse.org/assets/1/7/fall07-feature02.pdf
[71] Creepy New Seat Monitors Your Heart, Knows When You're falling Asleep: http://www.motorauthority.com/news/1093267_creepy-new-seat-monitors-your-heart-knows-when-youre-falling-asleep

Level 3 AV technologies are those that have “the driving functions sufficiently automated that the driver can safely engage in other activities”. The biggest difference between this level of technology and the previous level is that the driver expects the automobile to essentially drive for the most part, and only take back control when the circumstances require it.

On top of requiring the passenger to understand how the autonomous vehicles operate, several concerns need to be addressed to ensure of the safety of the passenger. First, from the experience of automation in aerial vehicles, it would appear that a way of retaining the attention of the driver for the entire journey becomes difficult once they develop a reliance on the automated systems. A recent study found that drivers operating in vehicles with ACC and lane centering engaged in a wide range of secondary tasks and to have, on average, significantly more off-road looks away from the forward roadway[72]. In particular, twenty-five percent of test subjects were observed reading while the vehicle was in autonomous mode. Driving simulator studies produced similar results[73]. Second, the automobile must be able to take care of most of the conditions that we would expect a human driver to also be capable of handling.

Several ways of retaining or regaining the attention of the operator have been either tried or suggested. In particular, in the aerial vehicle arena, the scrutiny over pilot inattention due to over dependence on automation has made the “current systems require pilots to ‘check in’ with different monitoring tasks all the time”[74]. This could perhaps be implemented with level 3 AVs. In particular, perhaps a monitoring system, similar to the one mentioned in the previous level, that monitors the user’s attention on the road, mirrors and dashboard could be used to keep the driver attentive at all times. While this seems like a virtually complete solution to the inattention to the road problem, it does reduce the effectiveness of the AV. Given that one potential benefit of AVs is its ability to give users more time to do other tasks while in the car, the need for constant monitoring could make the technology undesirable.

Alternatively, perhaps a system could be implemented such that when the AV believes it cannot handle the situation or anticipate a situation where it needs to give control back to the driver, some tactile and/or audible feedback mechanism that gives the user plenty of warning could be implemented. This is the currently suggested mechanism by the

[72] Human Factors Issues Associated With Limited Ability Autonomous Driving Systems: Drivers’ Allocation of Visual Attention To The Forward Roadway: http://drivingassessment.uiowa.edu/sites/default/files/DA2013/Papers/015_Llaneras_0.pdf
[73] Behavioural Changes in Drivers Experiencing Highly-automated Vehicle Control in Varying Traffic Conditions: http://www.sciencedirect.com/science/article/pii/S0968090X13000387
[74] Interview with Joe Hall, CTO at Center for Democracy and Technology

ISO[75]. The danger of this system is two fold. First, the length of warning time could be insufficient to recapture the attention of the user before the completely giving back control. Note that while the American Association of State Highway and Transportation Officials (AASHTO) recommends highway designers to allow 200 to 400 meters for a drive to perceive and react to an unusual situation when driving at 100km/hr[76], which corresponds to 7 to 14 seconds, the range of today's radar is only 9 seconds[77]. Second, the user may develop a reliance on the systems after a long period of time without taking back control, and end up in a crash when the AV gives back control in a hurry.

Perhaps an optimal solution is one that combines the previous two. Namely, tailor the technology to adapt to the condition of the driver. In particular, just as the force of ejection of airbags is now tailored to each individual's weight and position, one way to incur the greatest benefits of AVs while ensuring maximum safety is to not only monitor the user's level of attention to the road, mirrors and dashboard, but also adjust the warning time to recapture the driver's attention. Hence, an inverse relationship between the level of attention of the user and the length of warning time given to the user when a situation arises could be adopted - the less attentive the driver, the longer the warning time. While at first, this approach may require numerous tests to optimize, this solution tailors the technology to maximize the benefits of AVs, so that alert drivers can still operate different tasks while behind the wheel.

There are two alternative ways to ensure that a level 3 automobile is able to take care of most of the conditions we would expect a human driver to also be capable of handling. Firstly, we could define a list of environmental and user conditions that the automobile should be able to pass in a test. Second, the NHTSA could mandate that the AV technology only be commercialized and progress from the testing phase when the technology has surpassed a particular testing statistics. While a list of environmental conditions under which the automobile can pass could be helpful to guide safety standards of the AV technologies, level 3 autonomous vehicles are still able to return control to the user, the relative cost of executing such tests on all level 3 vehicles could be excessive. Moreover, although enumerating general conditions such as heavy snow, rain, hail, wind or listing specific conditions such as a sudden obstacle emerges or bright light shines into cameras can be useful for developing safety guidelines, the pace of technology development and possible unforeseen circumstances make this method

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[75] ISO http://www.unece.org/fileadmin/DAM/trans/doc/2010/wp29grrf/AEBS-LDWS-04-09e.ppt

[76] American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highways and Streets: http://nacto.org/docs/usdg/geometric_design_highways_and_streets_aashto.pdf

[77] Bosch, LRR3: 3rd Generation Long-Range Radar Sensor: http://www.bosch-mobility-solutions.com/media/db_application/downloads/pdf/safety_1/en_4/lrr3_datenblatt_de_2009.pdf

inefficient. Most importantly though, since level 3 autonomous vehicles can also rely on returning control back to the human driver, the danger of not specifying the behaviour of the AV in all environmental conditions is minimal. Hence, we recommend using a test statistic to measure the level of safety.

In transitioning from the testing phase to the commercial phase, two different sets of requirements could be adopted. First, we could use the fatal accident rate, defined as the number of fatal accidents on a per-vehicle-mile-driven basis (fatal accidents per 100 million vehicle miles traveled), which is statistic regularly used for assessing safety. The fatality rate fell to 1.13 in 2002[78]. This test statistic is particularly infeasible due to the impracticality of requiring testing vehicles to drive on the orders of magnitude of 100 million miles. To date, Google has completed 700,000 miles autonomous miles. At this rate, technological updates would never reach commercializable standards. Another more reasonable statistic that can be levered is number of miles driven before the AV gives back control, i.e. safety critical human intervention. Bryant Walker Smith estimates, using a Poisson distribution, that "AVs would have to drive themselves, without intervention, more than 725,000 representative miles without incident for us to say with 99 percent confidence that they crash less frequently than conventional cars."[79]

Drawing from our airbag case study, one might argue that although the number of crashes decreases, the risks may have simply been transferred from one subset to another. In our analysis of AVs at level 3 technologies, we believe that since the driver is ultimately responsible for the state of the vehicle, a reliable and regulated mechanism to pass control back to the driver would erase the concerns in this area.

3.3.3 Level 4

3.3.3.a Recommendation

We recommend:

- The NHTSA develop a test suite for all possible environments and outline the expected behaviour of the AV in each environment.
- The test statistic - the number of miles driven before an AV crashes versus the average number of miles driven before a crash *not attributable to human error*, to determine that level 4 AVs are significantly safer.
- The development of an ethical questionnaire for the driver that provides ethical choices that the AV can mimic in the case of an inevitable crash.

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[78] NHTSA accident report http://www-fars.nhtsa.dot.gov/Main/index.aspx

[79] Bryant Walker Smith, Human error as a cause of vehicle crashes http://cyberlaw.stanford.edu/blog/2013/12/human-error-cause-vehicle-crashes

3.3.3.b Analysis

An AV at level 4 is one that "can drive itself without a human driver". The most significant difference between level 4 and the previous levels is that at this stage, the AVs must be able to confront all the conditions that the automobile may face.

Several more concerns arise when we jump from level 3 to level 4 AVs. Now that the users are taking a back-seat and letting the technology drive the entire journey, the safety requirements not only need to address all the possible conditions the automobile may face and whether the user can take back control, but also the ethical decisions the AV may be forced to make when facing an inevitable crash and how to adjust the technology based on the user. Policymakers also face the issue of how to ensure that the lower risk of one group of individuals don't simply get replaced by the higher risks to another group.

Similar to level 3, there are two ways to measure the level of safety required of AVs. The first way is to introduce an exhaustive list of environmental conditions under which the AV must perform optimally. The second method is to determine a test statistic that can show under a high confidence level that level 4 AVs are "safe enough". The level of safety needs to meet a "common sense criteria - if this car is in front of your house, with your kids playing in front of it, the expectation is what an alert law abiding citizen would do"[80].

Since level 4 AVs do not require drivers, it must be able to operate without any reliance on a human passenger. While airbags initially suffered from failing to address the different types of passengers, leading to fatalities for children and fragile women due to the force of the airbag, level 4 AVs must be able to handle all the different environmental conditions, such as different types of weather, cyclists, animals, little children, fallen trees, glaring sunlight and complete darkness. Charged with the goal of reducing fatalities and accidents from motor vehicles, the NHTSA should consider all the possible different environments that the vehicle may face. Since level 4 AVs must be able to drive without the help of a human driver, the reasons for not creating an exhaustive list in level 3 are comparatively less significant considering the safety expected from a driverless vehicle. While the NHTSA could prevent the commercialization of level 4 AVs until all such possible scenarios are well tested and expected behavior obtained, we recognize that this may result in slow penetration rate and delayed accrual of benefits. Much like that of airbags, there is a delicate balance

[80] Interview with Lee Gomes.

between developing the technology that may improve reducing fatalities immediately and ensuring the safety of the technology.

There are several ways the NHTSA could address how the AV deals with the environment. A potential solution is to control the environment of all AVs. Specifically, much like the initial vision presented at the 1939 World's Fair, AVs could operate in special highways and on predefined tracks. To encapsulate the AVs and protect them from possible inclement weather, perhaps AVs could operate in tunnels specifically built for this purpose. Coupled with constant communication between all AVs, the AVs could be almost entirely isolated from uncertain environments. While this method would certainly evade the problem of level 4 AVs' interactions with the environment, the potential drawbacks of this solution is it's infeasible implementation. Not only would the construction of these special tunneled highways present a financial strain on any country, the time required to replace or built alongside the current plethora of complex highways would be enormous. Instead, the NHTSA could propose measures to require level 4 AVs be capable of interacting with the current transport system, without the need for automated vehicle-only zones/ highways. This method would certainly require greater technical ability, and incur a greater safety risks, since the AVs would have to interact with human drivers, pedestrians, bicyclists, motorcyclists, debris, wildlife and inclement weather. However, this method would certainly reduce the time required to integrate AVs into society and is more financially feasible. While the explicit examination of every possible environment an AV may face is out of the scope of this paper, we recommend that the NHTSA create safety tests for level 4 AVs to be able to safely stop or pull over whenever it is susceptible to unexpected environments, that is, environments that the NHTSA has not regulated the expected behaviour of the AV. Moreover, until desired behavior in these unexpected circumstances are determined, and safety tests created, or until the circumstances alleviate (such as in the case of inclement weather), level 4 AVs should be capable of safely pulling over and coming to a stop. Note that there are certainly situations in the current transport system where coming to a full stop or pulling over is unsafe - what AVs should do in these extreme cases remains unclear, since a human driver can possibly do no better in these situations either. However, overall we believe this is a better alternative as it allows the level 4 AVs to be integrated as quickly as possible, even while not all safety tests for different environments are created, while maintaining a high level of safety.

Along with specifying the behaviour of AVs under different environments, a test statistic should also be developed to ensure that the safety of AVs is significantly greater than that of human drivers. While examining level 3 AVs, we recommended the comparison between the number of miles driven before the AV gives back control and the average number of miles driven before a crash, perhaps level 4 AVs require a more stringent statistic. While the previous statistic shows that AV technology may have reached a point that is significantly better than human drivers on average, the use of this statistic alone may result in a shift of risks from bad drivers to all drivers. In particular, even though AVs may on average be better than human drivers, the risks may have simply been reduced due to the AV being able to pay greater attention to the road and handling multitask better than a human driver. Hence, the AV may have reduced risks due to bad driving behaviour, but possibly increased risks for all the passengers in the AV if the risks of technical problems, such as software malfunctions, increase. To take this into account, we recommend comparing the level 4 AVs' average number of miles driven before a crash to the average number of miles driven before a crash *not attributable to human error.* If some ninety percent of motor vehicle crashes are caused at least in part by human error[81], this would suggest that level 4 AVs would require a crash rate of approximately 10 times less than that of level 3 AVs.

Another area of focus to ensure the safety of level 4 AVs is the degree of control that human drivers or passengers should have. The possibilities here range from one end of the spectrum where none of the passengers have any control whatsoever, to another end of the spectrum in which there is still a steering wheel, brake and throttle. Google has experimented with a possibility nearer the "no-control" side, where the driver only has access to a "stop-go button and a screen showing the route"[82]. On the side of the spectrum where the driver has access to a steering wheel, brake and throttle, and may obtain control over the vehicle, unpredictable circumstances, such as when a tree blocks the road where there are double yellow lines, or when the driver is in a hurry to get to a hospital, could be simply resolved. However, the danger with this method is that human drivers may panic during close-collision maneuvers and inadvertently result in a crash. Also, since level 4 AVs, by definition, do not require a human passenger, this method may result in technology built with some remaining reliance on a capable human passenger able to take back control or give appropriate directions. On the other side of the spectrum, where passengers have little to no control, the danger of passengers haphazardly taking back control of the vehicle and result in inadvertent crashes is avoided. However, the converse is true - exigent circumstances, such as emergency needs to run red lights or cross over double yellow lines, become difficult to overcome. This idea has also appeared in science fiction. Namely, the 1973 futuristic

[81] Bryant Walker Smith Human Error as a Cause of Vehicle Crashes: http://cyberlaw.stanford.edu/blog/2013/12/human-error-cause-vehicle-crashes

[82] No steering wheel or pedals, Google's self-driving car :http://www.dailymail.co.uk/sciencetech/article-2641300/Google-launches-25-mph-driverless-car-fitted-ONLY-stop-button.html

science fiction film “Sleeper” depicts self-driving cars that have no windows so that passengers are not scared by the environment[83]. We recommend that the NHTSA implement a policy that takes the best of both spectrums. In particular, we believe a third solution that is a mixture of the two aforementioned, is have a steering wheel, brake and throttle in the level 4 AV, but disable it’s use once the AV technology is turned on. This solution has three benefits. First, the driver can choose to drive without AV technology at all. Second, the danger of the driver haphazardly regaining control in the midst of panic is avoided. Third, in exigent circumstances, the driver can simply turn the vehicle off once it has come to a safe stop or pulled over, and then navigate accordingly.

Despite the recommendations above, all level 4 AVs operate with some risk, and must be able to allocate this risk without a human driver’s oversight. In instances where an automated vehicle cannot avoid crashing, there are ethical decisions that it must make. While a full discussion of the ethical decision making for autonomous vehicles is outside the scope of this paper, we will briefly outline some guidelines for which to think of the ethics of autonomous vehicles with regards to maximizing safety. First and foremost, we can assume that crashes will occur since, as Bryant Walker Smith argues, “systems fail” [84], perhaps due to hardware or software bugs, or unpredictable behaviour of dynamic objects (wildlife, pedestrians, bicyclists). Given that inevitable crashes will occur, then, there exists moral questions similar to the trolley problem[85], where a decision needs to be made whether to switch the path of the trolley onto a track that will kill one person in order spare five passengers. To make decisions like this, the machine vision in the AV must be capable of determining the difference between a cat running onto the road versus a child crawling onto the road. Two common ethical frameworks used to examine how to best direct the morality of the autonomous vehicle is the Utilitarian framework and the Deontological framework. While Google argues that under both frameworks, society will be better off as a whole with autonomous vehicles that are significantly safer than human-driven cars[86], they leave out the micro-ethical issues the AV must execute when faced with such decisions. While utilitarians would be in favour of level 4 AVs developing an ethical stance that maximizes the number of lives saved in every unavoidable crash, deontologists would prefer a system that prescribed a set of rules for AVs that it cannot violate. Despite having both advantages and disadvantages, both set of ethical frameworks may result in changes in risk levels from one group to

[83] 13 real technologies Woody Allen predicted in the 70s: http://www.dvice.com/archives/2012/10/12_surprisingly.php
[84] Driving at perfection http://cyberlaw.stanford.edu/blog/2012/03/driving-perfection
[85] Enough of the trolley problem, already. http://ideas.4brad.com/enough-trolley-problem-already
[86] Google’s Autonomous Vehicles Ethics: http://googlesautonomousvehicle.weebly.com/ethics.html

another. For example, if the general population of drivers that crash are selfish, the implementation of a utilitarian ethical system may result in more crashes that sacrifice these drivers in favour of saving more lives. The risks may hence increase for the subset of individuals who are more likely to be in a crash, since without the AV technology, they would rather save themselves. Perhaps a better ethical framework in this light would be one akin to patient autonomy in medicine, in which respect for patient's autonomy is a fundamental guideline of clinical ethics[87]. Just as physicians have an obligation to create the conditions necessary for autonomous choice in others, AV technology should also allow drivers, or passengers in the vehicle, to determine the ethical stance of the vehicle. Bearing this in mind, we recommend the NHTSA develop an ethical questionnaire that drivers of level 4 AVs must take, which would be used as the fundamental ethical grounds of the vehicle. Although more research needs to be done to overcome questions such as what is the ethical stance of a vehicle with no driver, or that for public transport vehicles, or that for a vehicle with multiple passengers, this ethical framework would certainly minimize the change in relative risks from human drivers to AVs, since the AVs would have an ethical stance that mimics that of the driver.

4 Liability

In a perfect world, level 4 autonomous vehicles function without accidents, or at least with accidents as infrequent as plane crashes, and personal car insurance becomes a thing of the past. At the very least, autonomous technology has the ability to reduce the total number of accidents and reduce the number of incidents where assigning blame and issuing lawsuits is necessary. For the foreseeable future, however, AV technology complicates liability. If a car company advertises automatic braking technology, and a man forgets to brake in time and rear ends another vehicle, can he sue the manufacturer? And if the car failed to brake as a result of a software failure implemented by a 3rd party tech company, will the car company be held liable? These are the questions that vex policymakers and deter car companies from further developing AV technology.

If liability is not handled correctly by policymakers, AV technology will face major setbacks. Even if such technology leads to an overall reduction in accidents, responsibility will shift from drivers to manufacturers, pushing drivers away from the socially desirable outcome of developing and marketing autonomous vehicles.[88] As

[87] Autonomy vs. Beneficience UCSF School of Medicine http://missinglink.ucsf.edu/lm/ethics/Content%20Pages/fast_fact_auton_bene.htm

[88] http://www.law.asu.edu/Portals/31/Marchant_autonomous_vehicles.pdf pg 1334

detailed in the introduction, most American are curious about autonomous vehicles and have a positive impression of them, but also express concerns. Accidents could lead to major public backlash against car companies, which, when coupled with the prospect of millions of dollars in legal fees and lawsuits, could completely deter car companies from advancing AVs.

The purpose of this section is to create recommendations for policymakers in order to mitigate liability faced by car and tech companies, to a reasonable degree, so that they aren't deterred. Level 2 technology doesn't bring unique liability issues to the table, and level 4 technology is relatively simple to tackle, so we focus most of our attention on Level 3. We'll begin by outlining different ways liability is determined in the status quo, examine what will change as AV technology progresses, and provide analyses and recommendations for Level 2, 3 and 4 technologies. For a reminder of what our recommendations are, see section 1.5. Recommendations will also be detailed at the end of this section.

4.1 Types of Liability

Liability can be broken down into two parts - tort liability concerning drivers and insurers and manufacturer liability concerning manufacturers and tech companies. Most of the focus will be on addressing manufacturer liability, but it's also important to understand the current state of tort liability and how drivers and insurers are affected as AV technology advances.

4.1.1 Tort Liability

A tort can be defined as "any civil wrong or injury to a person or to property attributable to the violation of a duty owed to the injured party."[89] In the case of automobiles, drivers are responsible for their vehicles and are liable for injuries and damages they cause in violation of their duties toward other parties. There are three types of tort liability that affect drivers - traditional negligence, no-fault liability, and strict liability. Each type uses a different way to resolve liability issues.[90]

Under traditional negligence, drivers are held responsible for harms that they reasonably should have prevented, where the reasonability of an action is left up to a

[89] http://www.virginiadot.org/vtrc/main/online_reports/pdf/04-r30.pdf pg 6
[90] http://scholarship.law.berkeley.edu/cgi/viewcontent.cgi?article=2895&context=californialawreview pg 1422-1424

jury's interpretation. Drivers generally buy insurance to mitigate damages they face should they be held responsible for an action, and insurance rates are calculated based on a variety of factors, including age and previous accident history. AVs do present new challenges for the insurance industry - today's system is not perfect, but it uses a set of actuarial tables that examine set factors such as age, gender, miles driven per-year, etc. that have been used for a long time.[91] The insurance scheme changes if the greatest predictor of accidents turns into quality of AV software. Ideally, accidents become so infrequent that automobiles are handled like airplanes in insurance schemes.

Moving on from traditional negligence, twelve states use no-fault liability, where victims are not allowed to sue other drivers unless their injuries reach a threshold. This could have advantages for AV technology, as minor injuries sustained by accidents at the onset of technology would receive more negative attention than they would under regular drivers. Lastly, under strict liability, drivers who engage in "ultrahazardous" activities - those that are highly unusual and have a high likelihood for damages to occur - are completely liable for any crashes that occur, regardless of their negligence. This could be problematic if early adoption of a level 3 autonomous vehicle, as with early adoption of any new technology, gets categorized as "highly unusual" or "ultrahazardous."[92]

Thus, within tort liability, we recommend that states use no-fault liability as AVs become integrated so that legal issues are minimized. At the very least, driving a level 3 or 4 autonomous vehicle should not be categorized as "highly unusual" or "ultrahazardous" so that strict liability does not apply. Furthermore, developing a new insurance scheme is important for insurance companies, but we the details of such a scheme do not fall within the scope of this paper. Overall, the best way to handle tort liability is to follow our safety recommendations and deploy AVs that are not prone to accidents.

4.1.2 Manufacturer Liability

As more features become automated, more blame for accidents will shift from drivers to manufacturers. This could deter many car companies from further integrating higher levels of AV technology into their vehicles, or at least raise prices in anticipation for lawsuits.

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[91] Interview with Greg Larson
[92] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 111-114

Officially, manufacturer liability is determined by negligence, defined by an unreasonable failure to prevent harms.[93] As with tort liability, reasonability is left intentionally vague, and it can be unclear whether an automobile was defective or if the car company made a reasonable design choice that turned out for the worse. Defects can be separated into three categories - manufacturing defects, design defects, and inadequate instructions or lack of warnings. Manufacturing defects occur when a product fails to meet design specifications, either due to assembly error (e.g. bolt not tightly screwed on) or flawed raw materials (e.g. brittle steel).[94] Manufacturers are almost always found liable for manufacturing defects, so this does not present a unique case for AVs to handle. There is an issue of 3rd party manufacturing defects (e.g. tire or airbag manufacturer, and now with AVs, software companies) creating liability for car companies, and this case will be handled throughout later sections.

Next, car companies can also be held liable when there are inadequate instructions or lack of warnings: “when the foreseeable risks of harm posed by the product could have been reduced or avoided by reasonable instructions or warnings, and their omission renders the product not reasonably safe.[95] Thus, manufacturers of autonomous vehicles have an obligation to disclose any risks of failure and provide adequate instructions for operation, and with a couple exceptions, this case is relatively straightforward as well.

Design defects are trickier to handle. In some cases, negligence is clear cut - for example, in 2010, Toyota faced dozens of lawsuits due to manufacturer error in acceleration and braking. This forced massive recalls and billions of dollars in damage between legal fees, recalls, and depreciated value of Toyota’s brand.[96] Sometimes, however they are forced to make tradeoffs that will inevitably lead to loss of life. Some decisions are clearly better than others, and manufacturers should carefully examine the consequences of each choice, as they have life-or-death implications, but decisions can be difficult to make. For example, in the 1990s, GM was sued because they placed their C/K pickup series gas tanks on the side of their vehicle, outside the frame, which would increase the risk of deadly fires after side impacts. GM argued that this design decision was reasonable - comparative analyses showed that the overall crashworthiness of its vehicles were better than most, that the C/K pickup had an equivalent or lower rate of fatalities and fire fatalities from all types of accidents, and that placing the fuel take in another location would increase fatalities in different types of

[93] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 119
[94] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 122-125
[95] http://www.ali.org/ali_old/promo6081.htm
[96] http://articles.latimes.com/2010/feb/12/business/la-fi-toyota-liability12-2010feb12

crashes. This argument was not effective, and juries return verdicts that punished GM with large punitive damages.[97] AV technologies may face similar no-win situations - the classic example being the case where a car must decide between running into a child who crossed into the street or swerving and taking the driver off a bridge - so car companies should be carefully examine each design decision and be prepared to accept inevitable damages due to lawsuits.

Design defects are typically handled using one of two methods, the consumer expectations test and cost-benefit analysis. The consumer expectation test more or less has juries determine whether a product is defective based on the expectations of users - the test "makes the seller of a product liable if the product is in a defective condition unreasonably dangerous to the consumer…. A product falls beneath consumer expectations when the product fails under conditions concerning which an average consumer of that product could have fairly definite expectations.[98] The consumer expectation test has been criticized by some because consumers have unrealistic expectations and juries tend to sympathize with individuals and their families over large companies. Kent Kresa illustrated this with an example of how a fighter pilot was recklessly doing loops and crashed his plane. His family was unable to sue the military, so they filed a lawsuit against the airplane manufacturer. Although the plane did not malfunction, the jury found the airplane manufacturer liable, and Mr. Kresa believed that it was because the jury did this out of sympathy for the widow and her three kids.[99]

Under cost-benefit analysis, courts determine that a design is not defective if the benefits outweigh the costs. Thus, if an automated technology, such as automatic braking, works 90% of the time and causes a dramatic decline in the number of rear-end accidents, this could save many lives and millions of dollars of property damage. In the event that automatic braking doesn't work and an accident occurs, a court would be less likely to rule in favor of the plaintiff than under the consumer expectations test, so car companies would not shy away from implementing automatic braking and more social good overall would occur.[100]

The issue with the cost-benefit model is that car companies may have the choice between an expensive design that works 90% of the time and a cheap design that works 80% of the time and ultimately choose to go with the cheaper choice at the

[97] http://www.law.asu.edu/Portals/31/Marchant_autonomous_vehicles.pdf pp. 1331-1332
[98] http://www.law.cornell.edu/wex/consumer_expectations_test
[99] Personal interview with Kent Kresa
[100] http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf pg 125

expense of human lives, since they wouldn't be liable in either case. This is most famously illustrated in the Ford Pinto case - in the 1970s, Ford sold cars that would easily burst into flames when rear ended, even though they held a patent on a much safer gas tank. Their internal memos revealed that they chose not to recall the cars because it would cost them more to do so. Some estimate that 500 people burned to death as a result of this, although the NHTSA database holds Ford responsible for only 27.[101][102] The company used NHTSA numbers to determine the value of a human life, and this was standard protocol, but the public was understandably outraged when the internal memo was released. Ford lost in the eyes of the public, and in 1978, a jury awarded $128 million to plaintiffs in a case where one person died another was burned due to gas tank explosion.[103]

The above examples show the importance of understanding incentives when determining a liability scheme for AVs. Cost-benefit analysis appears to be more favorable to manufacturers than the consumer expectations test, but lives can be lost as a result of it. A good scheme ideally does not deter companies from integrating technology for social good out of fear of liability, and but it shouldn't incentivize them to intentionally deliver unsafe products. Thus, our recommendation is to stick with the consumer expectations test. This should not deter companies from level 2 AVs, and other methods can be used to ensure that companies are not deterred from level 3 & 4. We elaborate on these methods in section 4.3

4.2 Level 2

Level 2 AVs implement a variety of features that have the potential to save lives but also malfunction and result in lawsuits. In that sense, they're similar to airbags or weather-proof tires. They present new liability challenges for car companies to consider, but these are not as unique and difficult to handle as those presented by Level 3, because responsibility is mostly still on drivers. Empirically speaking, level 2 technology is not a major deterrent, as some major car companies have already incorporated automated systems into their vehicles.

An interesting case study to examine is the Firestone and Ford tire controversy that took place in 2001. Ford Explorers equipped with 15 inch Firestone tires had high rollover rates that resulted in at least 174 deaths and 700 injuries.[104] Ford and Firestone had worked together since 1896, but their relationship quickly deteriorated as hundreds of

[101] http://www.pointoflaw.com/articles/The_Myth_of_the_Ford_Pinto_Case.pdf pg 1030
[102] http://www.motherjones.com/politics/1977/09/pinto-madness?page=1
[103] http://www.colson.com/press-mentions/ford-settles-tire-lawsuits-quietly
[104] http://content.time.com/time/business/article/0,8599,128198,00.html

lawsuits were filed. Ford would spend $3 billion to recall and replace 13 million Firestone tires and decline to ever do business with Firestone again. Ford argued that between 1995 and 1997, 1,183 of the 2.9 million Firestone tires fitted on Explorers had issues with treads separating, compared to only 2 such failures on a similar number of Goodyear tires.[105]

Firestone admitted that “those tires were no good” but maintained that everything else they produced was safe.[106] Firestone tires did not face lawsuits in other cases, so perhaps it was simply a matter of bad fit with the Ford Explorers, but they did admit that their tires were not up to standard. Ford was not off the hook, however. As Ford and Firestone publicly feuded, investigators were “cheered by the split” because it enabled them to “pit one company against the other in court.”[107] Despite arguing that they were not to blame, Ford ultimately settled hundreds of cases out of court for $3 to $6 million per death because they didn’t like their chances of winning in front of juries.[108]

While academics may attempt to assign blame by looking at negligence and divvying up fault, this case shows what really happens when a liability case receives publicity and gets taken to court. When one part of a car, manufactured by a third party, is determined to be flawed, blame is inevitably assigned to both the third party manufacturer and the car company. Kent Kresa expressed as much in a personal interview, stating that litigators would go after “whoever has the deepest pockets” since the amount of money awarded is often based on the amount a company can afford to give out rather than some fixed amount based on actual damages.[109] This sentiment is expressed by multiple other liability experts as well.[110] The lesson this shows is that car companies should be prepared to take on liability if AV software malfunctions, even if the malfunctioning part was entirely produced by a 3rd party.

4.3 Levels 3 and 4

In a conventional car accident, blame is distributed between the driver(s) involved and the vehicle manufacturers. Partial autonomy can shift some blame from the driver to the vehicle, but with Level 3 and 4 technology, responsibility for avoiding accidents shifts completely to the vehicle and its accident avoidance systems. Programming errors or

[105] http://www.economist.com/node/664146
[106] http://content.time.com/time/business/article/0,8599,128198,00.html
[107] http://content.time.com/time/business/article/0,8599,128198,00.html
[108] http://www.colson.com/press-mentions/ford-settles-tire-lawsuits-quietly
[109] Interview with Kent Kresa
[110] http://www.law.asu.edu/Portals/31/Marchant_autonomous_vehicles.pdf pg 1329

system failures that result in AV crashes could implicate multiple liable parties, including the vehicle manufacturer, the manufacturer of a component of the autonomous system, the software engineer who programmed the code for the AV, or even a road designer if an intelligent road system is used to help guide AVs.[111] Companies and legislators alike are well aware of the new challenges that this creates. California's DMV has a steering committee and, with aid from Caltran and the Department of Insurance, they are dedicated to making recommendations to handle liability in the transition between levels 2 and 3.[112] As a result of liability issues, most companies have shied away from full automation, with the most notable exception of Google.[113]

In the past, society has proven itself to be disproportionately averse to new technologies that reduce overall safety. Some psychologists have documented the phenomenon of "betrayal aversion," where people have stronger reactions to individual cases of safety innovations causing harm, even when the technology has a highly net positive effect overall.[114] Juries may also be more likely to punish high-tech manufacturers who may be perceived as reckless for deploying premature technologies.[115] Legislators can protect AV manufacturers through a few methods, including assumption of risk defense and legislative protections. Assumption of risks determines that a user knowingly accepts the risks of a hazardous product and assumes all or some of the responsibility for using it. These cases usually involve a contract where the user waives certain rights such as the ability to sue manufacturers.[116] Legislative actions could include putting caps on damages paid out by lawsuits, which has been done in the past for other new technologies like vaccines or nuclear plants.[117]

Having users assume the risks of AVs has some appeal. This would require manufacturers to fully disclose potential risks of a vehicle, but this seems reasonable for car companies. They would only be held liable if they didn't identify one of their own risks, which is a reasonable demand, and this still incentivizes companies to thoroughly examine the risks of their own products. In practice, however, assumption of risks poses some problems as well. For one, as mentioned in the cost-benefit analysis portion of the manufacturer liability section, this can incentivize car companies to roll out more dangerous products to save money, knowing that they won't be held liable. Car

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111 http://www.law.asu.edu/Portals/31/Marchant_autonomous_vehicles.pdf pg 1328
112 Interview with Greg Larson
113 Interview with Lee Gomes
114 http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID1755667_code51570.pdf?abstractid=1755667&mirid=1
115 http://www.law.asu.edu/Portals/31/Marchant_autonomous_vehicles.pdf pg 1335
116 http://www.legalmatch.com/law-library/article/defenses-to-tort-liability-assumption-of-risk.html
117 http://www.law.asu.edu/Portals/31/Marchant_autonomous_vehicles.pdf pg 1337

companies will still be incentivized to maximize safety in order to establish a good reputation at the critical early stages of adopting technology, but sometimes companies can be short sighted and focus too hard on immediate monetary gains. Furthermore, full assumption of risk could deter users from using cars. A case where AV technology caused an accident and the car company was not held liable could be a PR nightmare for all companies. Finally, it's not entirely clear that assumption of risk would even work. Courts have refused to recognize assumption of risk defenses in the past. Kent Kresa expressed that a contract that has one party assume all responsibility may not hold up, regardless of how explicit it is, depending on legal structure, where the case is being tried, and how big the company is.[118] Furthermore, full disclosure of potential risks can be difficult to prove, and juries will once again find a hard time not awarding damages to a single parent with young children regardless of what contract was signed by a deceased father or mother.[119]

Thus, we turn to legislative action. While it's not common, courts have in the past adopted legislation that have limited the amount of liability faced by new technologies. In 1957, the Price-Anderson Act was put into law. It provides a Nuclear Waste Fund so that members of the public who incur nuclear or radiological damage can be swiftly compensated, regardless of who is liable. Justification for the act included the reason that many companies would not have entered the nuclear space had liability limitation not been available.[120] Companies are required to contribute millions of dollars per reactor to the insurance pool. Through the Act, millions of dollars have been claimed by Americans, most famously following the Three Mile Island incident in 1978, and the Act is generally viewed as a success, having been renewed for another 20 year term in 2005.[121]

Another famous example is the General Aviation Revitalization Act (GARA) of 1994. Following rapid decline of aircraft production in the 1980s and 1990s,[122] Congress identified liability as a major concern of aircraft manufacturers, including the rapid implementation of strict liability. With a couple exceptions, GARA protects aircraft and aircraft part manufacturers from lawsuits if the aircraft or part is more than 18 year old at the time of the crash.[123]

Legislative action has potential to mitigate liability concerns for manufacturers. A

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[118] Personal interview with Kent Kresa
[119] http://www.law.asu.edu/Portals/31/Marchant_autonomous_vehicles.pdf pg 1336-1337
[120] http://www.nuclearconnect.org/wp-content/uploads/2014/07/54_PriceAnderson_Background.pdf
[121] http://www.gpo.gov/fdsys/pkg/CRPT-109srpt99/pdf/CRPT-109srpt99.pdf
[122] http://www.bls.gov/mfp/mprkh93.pdf pg 1
[123] http://www.bvatriallaw.com/2011/10/25/general-aviation-revitalization-act-of-1994/

common insurance pool scheme is unlikely, as car companies are highly competitive and tech companies, especially Google, seek to stay ahead of the pack and have full control over their own policies.[124] Limitations on damage awarded to those involved in accidents could, however, have promise. As noted by Kent Kresa, one of the biggest concerns faced by companies is the tendency of lawyers to go after car companies with deep pockets and juries awarding varied and disproportional awards to claims victims.[125] If the problem proves to be serious, it would be best to avoid risk assumption, not hold companies to strict liability, and implement policies that limit damages faced by car companies to reasonable amounts. Reasonability can be determined by examining their payouts in non-AV cases so that Level 3 and 4 liability risks look similar to Level 2 risks. Companies will still be incentivized to implement AV technology that minimizes accidents, and a clause that provides exceptions for explicit negligence on the part of the car manufacturer (and not software bugs) can also help keep car manufacturers honest.

Of course, liability is best prevented by the implementation of safe products. There's no need for complicated liability schemes if AVs are well tested before hitting the roads. Accidents may inevitably occur, however, and car companies are afraid of being punished for AV software malfunctions. Limiting the damages they face for having deep pockets could be a huge step towards motivating them to develop and implement autonomous technology.

5 Conclusion

Through most of the past century, automated vehicles could only be found science fiction novels, but new technologies are making this possibility a foreseeable, even imminent, future. Yet before we can reap the huge potential benefits of AVs, we must ensure that we have policies in place to guide its safety regulations and liability regimes.

Drawing upon case studies on the development of airbags and automation in aerial vehicles, we recommend the following safety regulations and standards at each respective level:

Level 2

- The introduction of a written/computerized test outlining the functions of the AV technologies for those purchasing the vehicle.

[124] Personal interview with Lee Gomes
[125] Personal interview with Kent Kresa

- Level 2 AVs be capable of monitoring how alert the driver is at all times, and provide audible or tactile negative feedback for the driver when the driver's alertness is below a certain threshold.

Level 3

- Level 3 AVs be capable of monitoring the alertness of the driver, and change the time allocated to allow the driver to regain control based on his/her alertness.
- The test statistic - the number of miles driven before an AV gives back control versus the average number of miles before a crash, to determine the that AVs are significantly safer than human drivers.

Level 4

- The NHTSA develop a test suite for all possible environments and outline the expected behaviour of the AV in each environment.
- The test statistic - the number of miles driven before an AV crashes versus the average number of miles driven before a crash *not attributable to human error*, to determine that level 4 AVs are significantly safer.
- The development of an ethical questionnaire for the driver that provides ethical choices that the AV can mimic in the case of an inevitable crash.

Drawing upon examples of how liability has been handled in previous cases of new technology involving Ford and GM, we make the following recommendations for handling liability as technology progresses from level 2 to level 3::

Tort Liability

- Use no-fault liability policies to handle accidents. If some states decide not to use no-fault policies, at the very least it's important that they do not use strict liability.
- Reach out and work with insurance companies to determine new insurance schemes to handle accidents.

Manufacturer Liability

- Use the consumer expectations test rather than cost-benefit analysis to determine whether a manufacturer should be liable for design defects in order to eliminate the possibility of incentivizing companies to deploy less safe vehicles.
- Do not allow users to assume all risk so an errant car company does not create an unsafe vehicle that gets into an accident and receives negative publicity
- Create reasonable legal limits for damages that car companies can be held liable for in the event of accidents so they are not deterred from developing level 3 AVs.

While California's DMV may find these recommendations useful in crafting their proposals by Jan 1 2015, the U.S. DOT and NHTSA should bear these recommendations in mind when developing the framework for the safety and liability of AVs.

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