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**Planned Adaptation of Autonomous Vehicles**

1. **Introduction – Autonomous Vehicles**

The technology is finally catching up to the name. In 1899, the New York Times ushered the term “automobile” into the public vocabulary with its description of motorized vehicles[[1]](#endnote-1). Fast forward over 100 years, however, and technological capability is just now approaching the reality of autonomy within vehicles. Spurred on by the current and promised capabilities that modern computers and sensors offer, private firms have poured significant research and development into the concept of autonomous vehicles. This new technology elicits visions of societal benefits provided through increases in safety and efficiency along with significant positive economic impacts. Such a technology also presents a high amount of uncertainty and potential challenges surrounding its integration into society to include issues of liability, ethics, and even technical feasibility. The significance of new technology does not necessarily rest upon its technical capabilities, but rather the impact that it creates upon society. This is where regulators have a substantial amount of power, acting as gatekeepers between how, when, and to what extent technology is allowed to develop within society. With the technology of autonomous vehicles swiftly accelerating towards public deployment, government policymakers face the pressure and responsibility for determining how it should be regulated.

This paper will explore this developing technology of autonomy within cars along with the potential benefits, challenges and uncertainties that regulators must assess and ultimately decide how to handle. Many conflicting voices have interests at play that add to the dynamics and intricacies of the regulatory process, which will also be addressed. Ultimately, the aura of uncertainty surrounding autonomous vehicles prevents a perfect regulatory outcome from occurring, and thus, this paper argues, a need exists for deliberate processes that foster planned regulatory adaptation in order to consistently push towards less uncertainty and more effective regulations.

1. **Current State of Technology**

While the term “autonomous vehicles” may invoke images of cars that drive themselves without human input of any kind, this understanding does not fully encompass the spectrum of autonomous technology. With each passing day, the possibility of driverless cars entering society seems to be a more achievable reality, yet it is easy to forget that automation within automobiles has already entered public use. Many of today’s cars employ autonomous technology of some kind, from autonomous alerts and warnings to automatic braking capabilities. This autonomous technology is making significant contributions to driver safety, as evidenced by an estimated 2,200 lives saved from 2008-2010 through the implementation of electronic stability control (ESC) systems that use computers to individually brake the wheels of a car that is losing control[[2]](#endnote-2). Autonomous technology is emerging at unprecedented levels and many organizations are rapidly developing vehicles with increasingly driverless capabilities.

* 1. *Google*

One of the most publicized frontrunners in the race towards driverless technology is not an automotive giant, but rather a company best known for its search engine and Internet applications, Google. As of October 31, 2015, Google cars had driven 1,268,108 miles in “autonomous mode” without any handling of manual controls by the accompanying test drivers[[3]](#endnote-3). Created in 2009, Google’s driverless car program has since expanded into a fleet of 48 vehicles currently being tested on public streets in both Mountain View, CA and Austin, TX. Over the course of the program, Google’s cars have been involved in 16 minor accidents, yet “not once was the self-driving car the cause of the accident”[[4]](#endnote-4). Human error on the part of the other parties involved in the accidents gives further credibility to Google’s ultimate vision of entirely removing humans from the driving process. Any version of autonomy short of full, driverless autonomy requires the user to stay in the loop to some extent, yet tests and observations by Google confirmed that humans tend to trust autonomous technology too much and do not remain safely engaged in the driving process. To solve this problem of human-automation interaction, Google has chosen to bypass it completely by designing a car that requires no human input whatsoever (their prototypes do not even have a steering wheel, Fig.1). To allow its cars to drive without humans, Google uses a system of onboard radar, lasers, and sensors capable of detecting objects up to 200 yards away, creating a 360 degree model of the car’s environment[[5]](#endnote-5).



Figure 1. Google’s driverless car and its interior

* 1. *Tesla*

The innovative, electric car maker, Tesla, sparked increased public awareness of autonomous technological development with its public release of highly automated “autopilot” software in October of 2015. This software allows Model S cars built within the past year and all Model X Tesla vehicles to parallel park on command, automatically steer within highway lanes, change lanes with a tap of the blinker, and automatically adjust speed through acceleration and braking while on a highway. Stressing that drivers are “still responsible for, and ultimately in control of, the car,” Tesla CEO, Elon Musk, explicitly stated that drivers will still be liable for any accidents that occur[[6]](#endnote-6),[[7]](#endnote-7). Tesla has a key advantage over a company like Google in that while Google has a fleet of 48 cars to gather data from, Tesla has 60,000 publicly deployed vehicles offering “realtime data feedback” on their new autonomous capabilities to ensure “that the system is continually learning and improving upon itself”6.

* 1. *Other Players and the Future*

While Google and Tesla command the media spotlight as leaders in the race for automotive automation, many other players are developing their own autonomous technology. These companies include nearly all major auto makers in America, Europe, and Asia along with others seeking to capitalize on this new market opportunity, like Uber and Apple[[8]](#endnote-8). With the expanding amount of research and development invested in this market coupled with the impressive displays of capability from companies like Google and Tesla, one might wonder when the first public release of autonomous vehicles will be. According to Elon Musk, creating an autonomous car safer than a human-driver car is a “solved problem”; he predicts that we shall see autonomous cars entering the market by 2018[[9]](#endnote-9). A Business Insider report on self-driving vehicles predicts driverless cars will debut in 2019[[10]](#endnote-10).

1. **Benefits, Challenges and Fears of Autonomous Cars**

In general, few would argue against the need for technological innovation and the benefits it provides for society. Indeed, autonomous vehicle technology promises potential benefits that encompass not only convenience and economics, but more significantly, human lives saved. The magnitude of these benefits cannot be taken lightly. Unfortunately, these benefits are also closely accompanied by well-founded challenges and fears that cannot be disregarded. This section examines these various matters in order to create a better understanding of the arguments and issues that regulators must sift through and understand.

* 1. *Benefits*

Autonomous car technology offers the potential for a wide variety of both personal and societal benefits. For individual users, a fully autonomous car would allow its owner to accomplish many different activities while “driving,” to include texting without endangering himself or others, reading a book, or even catching up on work or even sleep. The typical daily work commute for American workers averages around 50 minutes per day according to a report from the Office of the New York City Comptroller[[11]](#endnote-11). For those who drive to work, this equates to over four hours per week dedicated to nothing but the task of successfully navigating a vehicle from point A to point B – a significant opportunity cost of time when viewed from an economic perspective.

Many potential benefits accrue to society as a whole in addition to individual users of self-driving cars, to include increased motor vehicle and travel efficiency. Autonomous control systems “conserve fuel more efficiently than the average driver,” according to a report from the National Highway Traffic Safety Administration (NHTSA)[[12]](#endnote-12). Additionally, much of the surface area of the roadways we drive on is not covered by vehicles at any given moment, and an IEEE study estimates that widespread adoption of self-driving car technology could increase highway capacity by up to five times by packing cars closer together[[13]](#endnote-13). While directly benefiting individual owners of self-driving vehicles through decreased fuel purchases, this greater efficiency in fuel consumption could also create positive public and environmental externalities through reduced emissions3. Furthermore, self-driving cars open up new possibilities of travel for millions of disabled persons who are limited in their ability to drive vehicles themselves.

The aforementioned potential benefits describe only a portion of the impact autonomous technology could have on society. NHSTA reports that over 90% of vehicular accidents are caused by human error, error which could be significantly reduced, if not eliminated, by autonomous technology[[14]](#endnote-14). Not only do accidents result in increased congestion, but they also result in injury, death, and associated emotional and monetary damages. In 2013 alone, 32,719 people died in motor vehicle accidents in the United States, with another 2.3 million injured. In evaluating these statistics, NHTSA estimates that these accidents resulted in direct costs of $242 billion and associated societal costs of $594 billion from “loss of life and the pain and decreased quality of life due to injuries.”[[15]](#endnote-15) Again, returning to the finding that over 90% of these accidents result from human error, autonomous car technology has the potential to vastly reduce these statistics.

* 1. *Challenges and Fears*

Perhaps even more compelling than the potential benefits of autonomous vehicle technology, are the troubling issues that also must be addressed with its integration into the public. Responsible stewardship and pragmatism require that these challenges be considered and understood before making final conclusions about the technology.

The current system of assigning vehicular accident liability within the United States is well-established, yet autonomous technology threatens to disrupt modern conventions. The central question is this: in the event of an accident, who is liable? The manufacturer, the user, the code developer? Currently, when individuals operate vehicles they assume liability for any accidents of their causing since they are voluntarily taking control of the car and the responsibilities associated with such control. Manufacturers, on the other hand, must create vehicles that meet given standards and expectations of performance; thus, they can be liable for accidents if a defect or failure in their manufactured vehicle contributes to an accident. Ultimately, individuals and manufacturers serve as proxies for their respective insurance companies who bear the majority of the burdens of liability, and hence have a vested interest in liability policy. Yet, autonomous technology requires a reassessment of vehicular liability. With driverless technology, an individual could operate a vehicle without actually having control of the vehicle’s actions. Many questions have surrounded how liability should be established by future regulations, but one car manufacturer has preempted regulators in this arena. A statement made by Volvo’s Car Group President and CEO, Håkan Samuelsson, expresses that Volvo will accept full liability when its future cars are in autonomous mode[[16]](#endnote-16). This view follows a strict interpretation of product liability in that producers would be liable for the vehicle’s performance, even though the accident would not have occurred if the owner had not been using the car. This approach seems reasonable for driverless technology in that such a technology would promise safety without the need for human intervention, creating liability for the manufacturers if any product should fail to live up to those expectations. The situation becomes less clear, however, when considering accident scenarios involving vehicles using semi-autonomous technology. Any mode that is not fully driverless necessarily infers human control and interaction to some degree, and any level of human control introduces the possibility for human error and, consequentially, liability. With an endless source of unique accident scenarios that could develop, it is impossible to determine an all-encompassing policy on the relationship between autonomous cars and liability. Since this issue cannot be satisfactorily addressed currently, one might be tempted to wonder if autonomous car technology is doomed to smother under this miasma of legal uncertainty, but this would be unnecessarily pessimistic. A report released by the Brooking Institution on “Product Liability and Driverless Cars” acknowledges the liability challenges that will tailgate the arrival of autonomous vehicles, yet claims that solving the liability conundrum should not be a precondition for the technology’s “commercial rollout”[[17]](#endnote-17). According to the report, the product liability law of the United States “has proven to be remarkably adaptive to new technologies” and the existing framework will be “well equipped to address and adapt” to the issues of liability that will develop as the new technology diffuses into public use9. Based on its history, the U.S. legal system should prove more than capable of adding autonomous vehicle technology to the vast array of technologies that have arrived and subsequently been appropriately handled9.

Consideration of existing laws further complicates the challenges of autonomous vehicles. While the spirit of the law and its detailed specifics like speed limits strive to protect the public, there can be times when strict adherence contradicts the law’s greater intention. In certain driving situations, for example, the average flow of traffic can be faster than the speed limit, and strictly following the speed limit is more dangerous than speeding for both the driver and others on the road. This exact situation has recently sparked public discussion following statements by Google stating that its cars are programmed to drive up to 10 mph above the legal speed limit if conditions dictate the safety measure[[18]](#endnote-18). In cases like these, regulators must ask themselves: Should manufacturers legally be allowed to create products intentionally designed to break the law?

Questions on ethics also emerge in the discussion of autonomous vehicles. Up until now, humans have been in control of and responsible for the actions and judgments involved in driving. Is it justifiable for humans to willingly place these burdens of responsibility and judgement on a machine (and ultimately upon those that code “judgments” into the machine)? Product liability frameworks may very well handle the economics of insurance liability in accidents, but how does one address the morality of giving non-sentient machines freedom of action previously only accessible to humans? One such ethical question concerns how to program a driverless car to respond in the event of an unavoidable accident. Suppose a child darts out into the path of a driverless car, giving the vehicle only enough time to choose whether to continue and hit the child or intentionally swerve off the road into oncoming traffic or a roadside barrier. As one option, the vehicle could be programmed to protect its occupants at all costs, leading to no difference in its decision making between one or ten children on the roadway as it would always hit the children before sacrificing its occupants. Conversely, programmers could design the vehicle to minimize the potential loss of life in these scenarios. In this case, five children would cause the car to swerve and crash if it contained only one occupant, but a van carrying a family of five would chose to impact one child on the road rather than sacrifice its family. Some may argue that these scenarios present ivory tower, philosophical conundrums that have little relevance to the real world, but considering that over 3 trillion miles are traversed by vehicles in the U.S. yearly, a highly improbable event for an individual can suddenly become highly probable for society[[19]](#endnote-19). While it might seem ethical to program driverless cars to minimize the loss of life, many consumers would likely balk at purchasing a vehicle that might purposefully harm them. These unwilling consumers of driverless technology could in turn lead to more driving deaths resulting from their human error than deaths caused by non-self-sacrificial programming[[20]](#endnote-20). No perfect solutions exist for these issues, but the decisions made in this arena could have major impacts upon the social acceptability of driverless cars into society.

* 1. *Full Autonomy in Commercial Aviation*

While the integration of autonomy into automobiles is relatively new, autonomous technology within aviation has enjoyed a much longer existence. With the advent of the Boeing 757 and 767 in the 1980s, the commercial airline industry was introduced to the new, “glass” cockpit and its entailing automation that has since permeated the industry. While still an impressive technological feat, the concept of fully autonomous aircraft faces a much more structured and predictable environment than that of autonomous cars. Indeed, self-driving cars like Google’s may ultimately contain up to 100 million lines of code, contrasted with the highly automated F-35 systems that contain 5-10 million[[21]](#endnote-21). Despite the fact that aircraft automation is well-developed and pilotless aircraft may be a technically attainable proposition, there has been little movement towards pursuing fully autonomous commercial aircraft. Why the aviation industry has avoided fully automated aircraft, when its application would be simpler and more attainable than for vehicles, is a question worth examining. Comparing the automotive and aviation industries can offer helpful insight for understanding social and economic factors that can dictate the path of an industry’s innovation.

Similar to autonomous vehicles, liability and insurance play a significant role in the discussion of autonomy in airliners. In the event of autonomous airline accident, the question is would the airline company would be held responsible, or rather the Boeing or Airbus manufacturers and their insurers. Unlike an autonomous vehicle, which may carry up to eight passengers, a commercial aircraft carries hundreds of passengers and an accident would result in a litany of lawsuits. Due to issues with insurance in the commercial airline industry, currently it is impossible to insure aircraft that have less than two pilots[[22]](#endnote-22). While dealing with just a few individuals in a lawsuit from an autonomous car accident might seem much less daunting than the hundreds that could result from an autonomous airline accident, the amount of people affected by autonomous car accidents would be much higher in total numbers due to the greater number of users and greater complexities inherent in driving environments. This should give rise for concern. Perhaps an even greater task than that of changing the mind of the insurance industry, however, would be changing the mind of an even more powerful actor – the public. As is, many individuals have inflated fears over the dangers of flight, exacerbated by periodic news reports of catastrophic accidents. Removing pilots from the cockpit would not only provide opportunities for imaginations to run wild about the many ways autonomous technology could fail, but would also remove the public’s assurance of “shared fate,” since computers do not have the same incentives to stay alive as pilots do15. For the automotive industry, an important lesson is that public perception, even when based on inflated and irrational fears, is a powerful agent. An MIT professor illustrated the impact of public fears of autonomy when only two or three students in her class said they would be willing to fly on an imaginary pilotless airliner. The number of students increased to over half the class, however, following the offer of a very cheap ticket. This provides a second lesson: perception can be changed15. All that must be offered is the right incentive.

Despite the aforementioned concerns, money may be the primary reason for the difference between the automotive industry’s push for autonomy and the airline industry’s relative complacency toward fully autonomous innovation. In short, there is little monetary incentive for it. While a large potential market exists for autonomous cars, the market for airlines, traveling passengers, would not change if pilots fly the planes or not. What fully automating airliners would require, however, would be extremely costly renovations of airline fleets for the relatively inconsequential reward of recouping the wages of no longer used pilots[[23]](#endnote-23). Additionally, unlike driving, flying in airliners is very safe from a statistics perspective (the chance of dying in a U.S. commercial flight by some estimates is equal to the probability of getting stuck by lighting seven times[[24]](#endnote-24)), and fully automating commercial aircraft would not necessarily generate a significant increase in safety. According to James Albaugh, president and CEO of Boeing Commercial Airlines, “A pilotless airliner is going to come; it’s just a question of when”15. Yet until means are developed to generate significant increases in revenue and safety through pilotless technology, there remains little incentive to change.

1. **Collective Action Issues**

The case study of autonomous vehicles provides an excellent forum for discussion on the issues of collective action. Developed by Olson, the theory of collective action argues that large groups formed of individuals with common interests often fail to advance their collective interests due to burdens of high individual costs needed to achieve those benefits. Any work to advance the interests of the group results in concentrated costs upon the working individuals who in turn receive the same marginal increase in benefit that diffuses through the entire group. In the absence of extreme altruism, rationality keeps individuals from incurring the disproportional costs compared to benefits, resulting in little to no promotion of the group’s interests. To offset this dilemma, organizations must provide what Olson describes as “selective incentives,” incentives that apply “selectively to the individuals depending on whether they do or do not contribute to the provision of the collective good”[[25]](#endnote-25). This theoretical framework on collective actions provides an explanation for why pure communism creates economic problems in the real world: individuals incur high personal costs while increasing the majority’s good (including their own good) by a marginal amount, creating no incentive to work. Capitalism provides the antidote to this condition by providing individual actors with needed select incentives (profits, promotions, etc.) to promote growth and development. Even in capitalistic environments, however, additional selective incentives may be needed to spur on desired individual actions that result in public benefit. These incentives span a wide spectrum of possibilities to include positive incentives like subsidies and tax breaks, and also negative incentives like removal of membership privileges or exclusion from governmental aid (like the select incentive for states to retain the legal drinking age of 21 due to the decrease in federal highway apportionment if otherwise lowered).

Steering the discussion back to the subject of autonomous vehicles, there may be a potential collective action problem that regulators should be aware of. As discussed earlier, there are many significant potential benefits to the infusion of autonomous vehicles into society, to include decreases in accidents, greater highway efficiency, reduction in emissions, etc.; but many of these benefits constitute a collective public good. These benefits cannot accrue unless individuals buy this new technology, and furthermore will not accrue to any significant extent without a large number of users. To achieve these collective benefits, users will need to incur high individual costs of not only buying new cars, but buying vehicles that are more expensive than their less advanced counterparts. The sensor instrument on the top of Google’s vehicles currently costs around $80,000[[26]](#endnote-26). Even as the technology develops and becomes cheaper to manufacture with increased knowledge and economies of scale, vehicles equipped with this technology will still undoubtedly cost more than traditional vehicles. Additionally, ownership of autonomous vehicles could incur nontraditional costs to users such as the need for higher-priced, specialized mechanics who are able to deal with advanced hardware and software designed for the new technology. Researchers at the RAND Corporation address this problem through self-released guidance for policymakers in which they suggest that regulators “may wish to consider a system of subsidies and taxes to help equalize the public and private benefits”[[27]](#endnote-27). In other words, they argue that providing selective incentives to individuals may be valuable for aiding the promotion of this technology and the collective benefit it could proffer society.

1. **Current Regulation**

The recent developments in autonomous vehicle technology has not just raised the discussion of the need for regulations, but has also resulted in varying degrees of actual federal and state regulatory action. These initial decisions set the stage for future regulatory decisions and hence carry significant weight behind them.

* 1. *NHTSA 2013 Regulation*

The National Highway Traffic Safety Administration (NHTSA) serves as the nation’s primary regulatory body in the realm of motor vehicles. A federal actor, NHTSA has the power and responsibility to set motor vehicle safety standards along with possessing the power to enforce regulations that fall under its jurisdiction[[28]](#endnote-28). These regulatory powers and responsibilities center on NHTSA’s mission to “save lives, prevent injuries, and reduce economic costs due to road traffic crashes,” which makes autonomous vehicles a very relevant issue to its work30. In 2013, NHTSA released a “Preliminary Statement of Policy Concerning Automated Vehicles” which represented its first significant official regulatory discourse on the matter. The document does not actually create any regulations for autonomous vehicles, but rather presents a discussion of the topic to include descriptions of much of the benefits and challenges described earlier along with recommendations for areas of research and potential regulatory action. Not intended as an actual federal regulation, the NHTSA report was created for the purpose of helping “states implement this [autonomous vehicle] technology safely so that its full benefits can be realized”30. Overall, NHTSA “is encouraged by the new automated vehicle technologies being developed” and spares no expense at expressing the benefits that it offers society, but also takes a decidedly hands-off approach to regulation30. Careful to acknowledge that “premature regulation can run the risk of putting the brakes on the evolution toward increasingly better vehicle safety technologies,” NHTSA uses that delightful pun to express its reasoning for delaying the release of regulations at the time30. Rather, it stands content to conduct further research into the matter to better inform itself while taking a federalist approach and placing the onus on states to develop their own regulations concerning autonomous vehicles for the time being.

* 1. *California*

By October 2015, six states had enacted legislation that applies to autonomous vehicles, with 2015 ushering in legislation relating to autonomous technology within 16 states[[29]](#endnote-29). California in particular is being observed as it nears the release of regulations set to be the most significant legislature on autonomous vehicles to date. The regulations will prove important in that they will “establish the requirements that manufacturers must meet to certify that their autonomous vehicle has been successfully tested, meets certain safety requirements, and is ready for the general public to operate on public roads”[[30]](#endnote-30). These regulations will ultimately allow for the public deployment of autonomous vehicles within the state of California by giving manufacturers specific standards that, once met, certify their vehicles ready for public use. While specifically only applying to California, this regulation’s effect will foreseeably extend past its borders, serving as a framework that will likely influence other state and federal regulations concerning autonomous vehicles.

* 1. *Benefits and challenges of current regulatory strategy*

This current state of regulatory affairs presents some potential benefits as well as issues that must be overcome. As readily noted in NHTSA’s report on autonomous vehicles, premature regulation for a relatively uncertain technology can create barriers to its growth and development. In some cases, this hindrance might be desired and intentional if the technology suggests greater risks than reward to such a degree that policymakers do not wish to encourage it. In the case of autonomous vehicles, however, NHTSA regulators appear enamored with the promise of the increased safety they believe autonomous cars will bring, and as such desire to facilitate its growth rather than demise. In free market economic theory, lack of external regulation allows for greater efficiency and growth as firms are not hindered by burdensome policies – this efficiency and growth for the autonomous car market is what NHTSA seems to want to accomplish with its current hands-off approach. Another advantage to the federalist regulatory approach is that policymakers at the state and federal level have the opportunity to observe and learn from the real-life case study of California. Once the legislation for California passes, stakeholders will be watching to see how new autonomous technology fares in widespread public use, along with how well the regulations work at promoting the benefits of the technology while mitigating its risks. While problems and issues will most certainly arise, these will be lessons that regulators at the state and federal level can learn from.

Perhaps the first useful lesson offered by California is that developing regulations for autonomous vehicles is difficult. In 2012, California enacted legislation that required state lawmakers to create rules for autonomous vehicles by January 1, 2015. However, nearly a year past that deadline, those rules have yet to see the light of day[[31]](#endnote-31). One reason for this delay is that regulators do not possess unlimited insight and understanding of the new technological matters they must regulate. Brian Soublet, deputy director of the California DMV offers a glimpse into their struggle, expressing that “We didn’t ask to be in the business of regulating a technology. We haven’t been in that business before. It was forced upon us by legislation”[[32]](#endnote-32). Soublet does not only provide an inside look into the frustrations of California regulators, but also goes on to explain the deeper reason for the frustration by claiming that “We’re not an agency that is filled by automotive engineers. We’re not an agency that is filled with automotive safety experts, and so how do we go about doing that?”34. These comments demonstrate that policymakers are not necessarily technical experts in this field, and finding ways to become educated enough to make informed and effective decisions is a difficult process.

A foreseeable outcome of the state-based approach to regulating autonomous vehicles is a patchwork of regulations that vary from state to state. From an auto firm’s perspective, this creates a cumbersome environment for releasing technology into society, as a wide array of different and potentially incompatible standards and regulations may need to be satisfied. From the consumer’s perspective, vehicles that can be used in some states and not others may lose much of their utility value, thus reducing individual desire for an otherwise desirable product. These problems for both producers and consumers collectively result in a potentially significant hinderance to the advancement and implementation of autonomous vehicles. Earlier this year, Samuelsson of Volvo expressed his concern at the lack of federal guidelines due to the problem presented about automakers having to meet different guidelines in each of the 50 states19. Federal regulation will eventually be necessary to prevent disparate standards from crippling automakers, and many share the sentiments expressed by Daniel Lipinski, an Audi senior engineer, “We’re all waiting on federal regulation”33.

1. **Regulatory Capture**

Similar to concentrated individual costs and diffuse benefits, the opposite scenario of concentrated interests and diffuse costs can also create potential for market failure. Coined by George Stigler as “regulatory capture,” the idea theorizes that firms often bend regulations to their will at the cost of the public[[33]](#endnote-33). This political influence comes into play when firms stand to gain concentrated benefits from potential regulations, resulting in lobbying policymakers to pursue those beneficial policies. Even if regulations might harm the public, this harm will typically be minimal enough that collective action issues preclude counter lobbying, in turn leading to regulations that inherently favor interests of the outspoken firms. While this theory may take a rather cynical view of the regulatory process, it nonetheless has historical backing and mechanisms should be in place to mitigate its occurrence.

The automotive industry constitutes a powerful economic and, consequently, political entity, having contributed over $43 million in lobbying efforts on Capitol Hill in 2015 alone[[34]](#endnote-34). Similarly, Google presents a very active presence in D.C., having contributing over $13 million to lobbying in 2015[[35]](#endnote-35). Adding to the potential for regulatory capture in the realm of autonomous vehicles, NHTSA’s literature on autonomous vehicles to date seems to be overly optimistic about the benefits that autonomous vehicles will provide. As stated in their policy document on autonomous vehicles, NHTSA “looks forward to working with other stakeholders to engender that cooperation and chart a steady course forward”14. As will be discussed in the next section, the future of autonomous vehicles may not be as certain as some would believe, and policymakers should be wary of “looking forward” to such an extent that it creates blinding biases that favor pursuing the best pathway for firms rather than society.

1. **Are Driverless Cars a Pipe Dream?**

To reiterate, the term “autonomous vehicles” encompasses a wide range of possibilities from the use of automation for a single application within a car (like automatic braking) to full, driverless autonomy. NHTSA attempts to characterize these varying levels of automation by defining a five-part continuum from level 0, where the driver is in complete control of primary vehicular functions, to Level 4, where the car drives itself without any need for a human driver14. NHTSA, as well as others like individuals from the RAND Corporation who created a detailed “Guide for Policymakers” on autonomous vehicle technology, freely admit that technology will not jump suddenly from Level 0 to Level 4, but regulatory considerations must also be made for in-between, partial autonomy within cars. Their policy documents urge policymakers to find ways to maximize social benefits of autonomous vehicles while minimizing potential costs and not hindering the development to Level 4 autonomy where the full benefits of autonomous vehicles will be realized. This mindset positions that although initial autonomous vehicle technology will likely not produce all of the benefits hoped for, policies should be shaped in a forward looking manner to assist technological development towards achieving the ultimate goal of driverless autonomy. An underlying bias clouds this way of thinking, however. It assumes that, given enough time and nurturing, technology will indeed achieve fully driverless cars. It neglects to consider that driverless cars may not be a desirable or even achievable reality.

* 1. *MIT Disbelievers*

David Mindell, engineering historian and Professor of Aeronautics and Astronautics at MIT, holds a very strong stance on the topic of driverless cars: namely, they will never work. At first glance, such a claim might seem laughable; one can clearly see that Google has already created a driverless car and proven him wrong. Yet closer examination of Mindell’s logic behind his opinion shows that it is built upon substantiated ideas which he lays out in his recently published book, *Our Robots, Ourselves: Robotics and the Myths of Autonomy*. Mindell first points to history as a means of illustrating his point by looking at examples of autonomy in undersea exploration, space, and commercial flight. These examples show that autonomous technology does not follow a “linear progression” from human to autonomous control, but rather show that “human, remote, and autonomous are evolving together”[[36]](#endnote-36). On a 1-10 scale with 1 representing full human control and 10 full autonomy, this evolution invariably converges towards attaining the “perfect five,” or rather, the perfect combination of autonomy enhancing human capabilities for greatest system effectiveness[[37]](#endnote-37). Mindell stresses that he is not arguing against “technological progress,” but rather is seeking to redefine progress as the most effective combination of human and autonomous control as opposed to full automation[[38]](#endnote-38). While empirical examples may illuminate present situations and predict certain futures, empirics do not dictate what must happen in the future. Cars operate in different environments, along with having different users and objectives than other technically advanced vehicles that operate in the sea, air, or space; additionally, computer technology and capability has increased drastically since the lunar landing of the 60s and 70s (a cited historical example of Mindell’s) allowing for unprecedented technological developments. Critics might sensibly seek to discredit an opinion like Mindell’s if it is based solely on empirical evidence; however, technical dimensions exist as well.

Specifically addressing Google, Mindell contends that its engineers are “succumbing to naïve automation” by defining the problem of autonomous cars simply as one of “navigation and collision avoidance”38. Such a problem foreseeably could very well be solved by technology, yet it fails to consider the full spectrum of driving, which includes “geographic, economic, cultural, and other components” that complicate the problem tremendously38. The late Seth Teller, former MIT roboticist, offered an insightful perspective of urban driving as a social endeavor that involves “short-lived social contracts between people, as we scan the streets, make eye contact, let people in and wave ‘thank you.’”38. If such social interaction is actually a necessary part of driving throughout a city, it raises the question whether this sociality can be programmed into an algorithm of impersonal machine.

Mindell’s doubts concerning the future of autonomous vehicles are shared by another MIT professor, John Leonard. A key member of an MIT team that competed in the Defense Advanced Research Project Agency’s (DARPA) 2007 Urban Vehicle challenge, and developer of widely used techniques for autonomous vehicle navigation, Leonard also seeks to convey to the public the limitations of autonomy[[39]](#endnote-39). Rather than hypothesizing about potential scenarios, Leonard physically took to the streets with a video camera to document situations that would prove challenging for any algorithm to handle, which he encountered while driving around the greater Boston area 40. Highlighted scenarios include merging into traffic from an intersection with traffic flowing from both directions, an officer directing traffic at a crosswalk even though the traffic lights are green, and roadways devoid of markings due to freshly fallen snow40. These situations would be very difficult, if not impossible, for current autonomous technology to handle, and illustrate Leonard’s assertion that “there are major, unsolved, difficult issues” in the realm of autonomous driving which should caution the public and media to not “overhype how well it works”. As far as predicting the future of driverless cars, Leonard claims that “I do not expect there to be taxis in Manhattan with no drivers in my lifetime”29.

Google’s cars, much like any developing technology, have real limitations and bugs to address. One key aspect of these cars is that they rely heavily on detailed maps that have been preloaded into the cars before use. These maps contain intricate details from locations of stoplights and their heights above ground, to exact positioning of curbs along with their actual height[[40]](#endnote-40). This detailed information allows the cars to focus on detecting objects and movement within a preinstalled digital landscape. These maps require specialized crews to drive future paths of the autonomous cars before deployment along with consistent updating of the environment if it should change so the cars know what to expect42. When Google released reports that their cars had traveled over 1 million miles of roadways, most of this traveling has occurred over the same several thousand miles of pre-mapped roadway over and over again, mainly in Mountain View, CA and more recently expanding to Austin, TX42. In addition to these geographic constraints, Google has yet to test its cars in snow, safety concerns exist with heavy rain, and their video cameras can be blinded when the sun is directly behind a traffic light[[41]](#endnote-41). Its sensors also struggle to detect elementary obstacles like potholes and uncovered man holes along with not being able to differentiate between certain objects like a rock and a crumpled piece of paper43.

* 1. *Toyota’s Example*

Although they are individual voices as skeptics in the public discourse of autonomous vehicles, Professors Mindell and Leonard do not stand alone on this issue. In fact, over half of 500 experts attending a 2014 conference on autonomous vehicles did not expect driverless cars to “take their children to school” until 2030, with roughly 1 in 10 claiming that they never will[[42]](#endnote-42). Perhaps these skeptics represent an assortment of enlightened individuals on the matter. Conversely, these potentially erroneous and biased academics seem to present a naïve and inconsequential voice when compared with the contradicting assertions of billion dollar corporations like Google and major automakers. At least one powerful corporation shares views with the Mindell line of thinking, however: the world’s largest automaker, Toyota.

In September of 2015, Toyota announced a $50 million research project seeking to develop “intelligent” cars that do not replace humans, but rather watch over them[[43]](#endnote-43). Acting as a “guardian angel” that watches human drivers and intervenes as necessary to correct errors or prevent accidents, Toyota envisions “parallel” autonomy where the technology observes rather than replaces45. This focus seems very similar to Mindell’s ideal of a “perfect five” combination for humans and automation. Proponents for pursuit of driverless technology cite human error as the reason for taking humans out of the loop and preventing accidents, yet Toyota’s project also seeks to prevent accidents and save lives but through mitigating mistakes as they occur45. Toyota has placed this project into the hands of Dr. Gill Pratt, a former program director at DARPA and previous MIT professor, with $25 million of the investment budget allocated to MIT’s Computer Science and Artificial Intelligence Laboratory (CSAIL)[[44]](#endnote-44). A friend of Mindell[[45]](#endnote-45), Pratt clearly shares a similar vision for the future of autonomous vehicles as evidenced by the research focus at MIT’s CSAIL, which also happens to include John Leonard as a lead researcher46.

* 1. *Assessment of claims of safety*

Many tout the 30,000+ lives lost to accidents a year with over 90% of the accidents caused by human error as justification for pursuing driverless cars. In his argument against self-driving cars, Mindell does not question that people make “stupid mistakes,” but he also points out that humans are remarkably adept at making corrections and responding to unpredictable events[[46]](#endnote-46). He contends that the 30,000 fatalities only show the times that humans messed up, but it also leaves out the other side of the story where human reaction and skill *prevented* accidents48. There are ways that humans can perceive and interact with the world that machines cannot replicate, and as Mindell questions: “Who has demonstrated a fully autonomous car that is safer?”48. Is there a chance that autonomous cars could save those 30,000 while dooming a far greater number that otherwise would have been saved by the replaced humans? The answer to this assessment of risk remains uncertain, yet it provides regulators with an important balancing argument to the potentially overly optimistic view of driverless vehicles.

While the future of fully autonomous cars may be uncertain, partial autonomy is, and will continue to be, a very real automotive feature. Furthermore, unlike fully autonomous systems, we have many more tangible examples of human interaction with partially autonomous systems and the associated risks. Returning to the air, commercial aviation and the transition to glass cockpit and automation technology provide useful insight into the realm of human-automation interaction. Glass cockpits sought to improve system functionality by increasing human capability and efficiency through automation of flight operations and ultimately allowed the crew composition of commercial aircraft to be reduced from three to two members[[47]](#endnote-47). As noted by Endsley, however, these benefits from automation also came with changing the pilot’s role from flying to monitoring an automated system, a “role people are not ideally suited to”[[48]](#endnote-48). Accidents like those found at Nagoya, Strasbourg, and Cali offer examples that highlight failures in human-automaton interaction, ultimately leading to tragedy[[49]](#endnote-49),[[50]](#endnote-50). Cognitive issues like automation bias, complacency, and mode error can be found in those examples, and do not show deliberate negligence by the pilots, but rather unintentional consequences brought about by the presence of automation. The Air France 447 disaster of 2009 highlights the challenging problem of how to effectively transfer control from automation to the driver when vehicle’s autonomous systems either fail or prove incapable38. As with most any technology, new capabilities are closely paired with new pathways to failure. The addition of autonomy in cars is no exception, and failure to learn from the aviation industry and mitigate those potential failure pathways, especially those introduced through human-automation interaction, could prove a costly and negligent mistake.

1. **What now? Uncertainty and the need for Planned Adaptation**

Up until this point, this paper has sought to present the topic of autonomous vehicles in such a way that readers may understand the intricacies and challenges that regulators must handle. The area of autonomous vehicles is ripe with uncertainty concerning potential risks and benefits, yet regulators must dig through this uncertainty to the best of their abilities in order to create policies that maximize social benefits while minimizing risk. In the end, whenever high uncertainty surrounds a new technology, policymakers’ regulatory decisions represent a “best scientific guess” for the best solution[[51]](#endnote-51). Such an issue presents regulators with a dilemma, much like California DMV officials are finding. The dilemma is that even though regulators seek to maximize benefit and minimize risk, any decision they make will undoubtedly not accomplish either of those fully and could even lead to greater harm than good. Although perfection is unrealistic, the alternative is acceptable as long as means exist to improve upon imperfect decisions. For regulatory improvements to occur, new information must be available to inform the improvement, and secondly, mechanisms must exist to change existing policies and regulations. McCray et al. specifically address this issue of risk regulation under uncertain conditions through a term called “Planned Adaptation”53. Planned Adaptation acknowledges the fact that mistakes will be made when creating regulations under uncertainty, but rather than fatalistically accepting this fact, also seeks to actively mitigate and improve upon mistakes made. Rather than changing policies in a reactionary manner, organizations committed to Planned Adaptation must have a “prior commitment to subject an existing policy to de novo re-evaluation” in addition to creating a “systematic effort […] to mobilize new factual information for use when the re-evaluation takes place”53. Such mechanisms for planned and informed change, if committed to, create a means for policymakers to continue pushing towards the ever-elusive goals of maximized social benefit and minimized risk.

While reasonable and readily accepted in theory, McCray et al. observe that planned techniques of regulatory adaptation have struggled to receive substantial implementation within the United States53. Many possible reasons exist for this reluctance of policymakers to pursue Planned Adaptation, to include preference for the status quo, fear of losing credibility, and the challenges of enforcing constantly changing regulations53. Additionally, money can prove a significant detriment to Planned Adaptation if organizations lack proper funding to consistently review and update regulations. Indeed, situations where new knowledge may not be readily available or useful may rightly favor stability as more valuable than costs associated with updating regulations. McCray et al. propose that Planned Adaptation may be most effective and appropriate when “major factual uncertainties are preset, or when very large public benefits and costs are at stake”53 – criteria that certainly apply to the realm of autonomous vehicles.

* 1. *Relationship between NTSB and NHTSA*

The uncertainty inherently surrounding autonomous vehicles is exacerbated by the contradicting voices of “experts” in the field. These differing sources of opinion and information create a need for evaluating and discerning the various forms of knowledge that ultimately shape policymakers’ decisions. Effective and unbiased evaluation of knowledge is crucial for the successful implementation of Planned Adaptation, which relies upon making decisions based on the best information available. In their study of several successful examples of Planned Adaptation, McCray et al. observe they all feature a “deliberate segregation of organizational roles” where the “learning” function of the organization is intentionally separated from the “changing” function53. Such isolation suggests the importance for preventing regulators (those in the “changing” role) from allowing preconceived notions to bias their collection and assessment of uncertain, yet policy-influencing knowledge.

The National Transportation Safety Board (NTSB) offers an example of a credible knowledge-assessing body that does not possess any regulatory powers. In its “Strategic Plan Fiscal Years 2013 through 2016,” the NTSB expresses its principal objective of “promoting transportation safety,” also making it quite relevant to the discussion of autonomous vehicles[[52]](#endnote-52). The NTSB in and of itself does not hold any regulatory power, but promotes “transportation safety” by serving as an independent, knowledge-assessing body that presents recommendations to policymakers54. A well-established federal agency, the NTSB by 2013 had issued “over 13,700 safety recommendations to more than 2,300 recipients”54. Indeed, the NTSB touts its separation from direct regulatory power not as a weakness, but rather a credibility builder in that its “effectiveness depends on [its reputation] for conducting thorough, accurate, and independent investigations and for producing timely, well-considered recommendations to enhance transportation safety”54. Essentially, the NTSB’s relevancy and ability to positively impact safety relies upon evaluating information gained through accident investigations and presenting unbiased and effective recommendations, thus incentivizing quality work. This is exactly the type of knowledge-assessing body that allows Planned Adaptation to be possible, as evidenced by NTSB’s symbiotic relationship with the FAA, which annually releases updates to its Federal Aviation Regulations.

NHSTA is the clear regulatory actor responsible for future regulations concerning autonomous vehicles in America, and thus also an essential player for the success of Planned Adaptation in that field. Organizational buy-in and commitment are required for any implementation of Planned Adaptation, attributes that NHTSA already seems to possess. NHTSA recognizes the importance of updating regulatory measures as evidenced by its self-proclaimed responsibility to not only set vehicle safety standards, but also to review “existing ones to determine if they can be improved”31. In its Preliminary Statement of Policy Concerning Automated Vehicles, NHTSA also makes it clear that it willingly accepts and seeks to accomplish the responsibility of generating new knowledge about the subject through research. Returning to the definition of Planned Adaptation, NHTSA’s current organizational leaning towards autonomous vehicles seems to satisfy the requirements for planned review and updating of regulations based on earnestly gathered new information. The goal, however, is not to “satisfy” prerequisites for Planned Adaptation of autonomous car policy, but rather to create actual, effective implementation. As discussed earlier, NHTSA exhibits a strong bias towards a preconceived future of autonomous vehicles that idealizes driverless cars as the end goal, an outcome that is quite uncertain when considering the differing voices in the field of study. McCray et al. promote the separation of the “learning” functions of an organization from its “changing” functions, which effectively serves to mitigate the negative impacts of biases by putting the responsibility of assessing uncertain knowledge into the hands of an independent and credible third party. NTSB has proven itself as a very effective and credible knowledge assessor whose recommendations have assisted with consistent adaptation of regulations within the FAA. While preconceived notions of technological development and associated biases could open the door for regulatory capture and exploitation by firms of NHTSA autonomous vehicle regulation, NTSB could serve as an unbiased guard to this potential market failure.

 NHTSA claims to “[consider] recommendations offered by [NTSB],” however, this relationship appears to be fairly limited. In a Special Investigation Report on Forward Collision Avoidance Systems, NTSB decries “slow and insufficient action on the part of the National Highway Traffic Safety Administration (NHTSA)” to develop standards and create manufacture requirements for collision avoidance technologies[[53]](#endnote-53). NTSB cites several examples where recommendations were insufficiently acted upon by NHTSA, earning a mark of “Unacceptable Response”56. To further illustrate this frustration, the NTSB report describes a recommendation concerning autonomous emergency braking (AEB) and electronic stability control (ESC) systems made in 2008 that did not receive a response from NHTSA until 2014 saying that it would “make a decision regarding the implementation of these systems in 2015”56. To be clear, this report only presents NTSB’s side of the story, and NHTSA may very well have justifiable explanations for its delays. While the two organizations share the same goal of promoting transportation safety, clear tension exists concerning how that goal should most effectively be pursued. To combat potentially significant recommendations being overlooked or disregarded, oversight may be needed to ensure NTSB and NHTSA work as effective partners rather than rivals. In an encouraging development, however, just five months following the release of the NTSB report in June of 2015, NHTSA released regulation closely aligning with AEB recommendations made by NTSB[[54]](#endnote-54). Such cooperation on this matter indicates a potential for continued positive collaboration between the organizations.

One cannot disregard finances when considering barriers to successful Planned Adaptation approaches to regulation. Without proper funding, organizations will not have the ability to collect new information and take the time to update regulations even if they desire to do so. Some issues may not warrant approaches like Planned Adaptation, yet the significant and highly uncertain future of autonomous vehicles more than justifies increased funding to seek the promotion of Planned Adaptation for autonomous vehicle regulation. Policymakers should explore ways for enabling NHTSA and NTSB to create specialized mechanisms that will promote the continued drive towards achieving the most effective and beneficial regulation for autonomous vehicles.

1. **Conclusion**

The impact of autonomous vehicle technology on our society remains yet to be seen. While autonomous technology encompasses a wide range of possibilities, the course of discussion invariably merges towards the future of driverless capabilities. Proponents of driverless vehicles predict a near future where self-driving vehicles provide society with numerous benefits; none more significant than saving thousands of human lives by removing human error from driving. Many technical, legal, and ethical challenges exist, however, when considering the infusion of autonomous vehicles into the complexities of society, and critics argue that the driverless visions of companies like Google are naïve and unrealistic. With the end goal of maximizing public benefit and minimizing risk, policymakers must strive to discern the uncertainty surrounding the issue and decide what their role should be. Overregulation could hinder the development of the technology at the risk of preventing potential benefits. If the technology achieves the high expectations of its proponents, a collective action issue may exist where social benefits would be hampered by individuals unwilling to incur high costs of buying the more expensive vehicles. Risk of regulatory capture by firms seeking to bend regulation to their will at the public’s detriment presents another potential source of market failure. Ultimately, policymakers will not be able to create the perfect solution to these uncertain issues, creating a need for planned regulatory adaptation. Planned Adaptation requires mechanisms to gather new information to inform policymakers who must then be willing to update regulations as needed. While state legislatures may address initial forms of localized autonomous vehicle regulation, the federal policymakers at NHTSA have the responsibility to ensure the safety of national transportation and will eventually need to make their own decisions on the matter. NHTSA appears to be well-inclined to the ideals of Planned Adaptation, yet it exhibits potentially biased viewpoints on autonomous vehicles that could lead to market failures. NTSB presents an example of a credible, third-party knowledge-assessing organization that has enjoyed a long and beneficial relationship with the FAA. Such a relationship with NHTSA could not only serve as a check to any preconceived biases, but also capitalize upon NTSB’s capabilities with assessing highly automated technology within aircrafts. NTSB’s experience in knowledge-assessing coupled with the desire of both NTSB and NHTSA to promote transportation safety offer a promising framework for Planned Adaptation of autonomous vehicle regulations for the years to come.

**Future Research**

The following, non-exhaustive areas of study could continue to supplement this discussion on autonomous vehicles:

* Current FAA regulation of drones and lessons learned that could benefit the study of autonomous vehicles.
* Role of public fear and perception on advancement of technology – could historical examples illuminate means for influencing public opinion?
* Regulatory strategies to most effectively introduce autonomous vehicles into society and inform Planned Adaptation with a consideration for the pros/cons of different strategies.
* Examining private organizations that exhibit strong Planned Adaptation of self-imposed policies. What incentivizes them to do it so well when governmental organizations struggle?
* Analysis of the impact NHTSA’s initial policy document on autonomous vehicles has had on state legislature decisions concerning autonomous vehicles.
* The historical relationship between the FAA and NTSB compared to NHTSA and NTSB – examining roles the different organizations have played in their interactions together, along with lessons that can be learned for creating effective Planned Adaptation.

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