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PUBLIC INTEREST COMMENT

COMMENT ON THE FEDERAL AUTOMATED VEHICLES POLICY

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INTRODUCTION

The Technology Policy Program of the Mercatus Center at George Mason University is dedicated to advancing knowledge about the effects of regulation on society. As part of its mission, the program conducts independent analyses to assess agency rulemakings and proposals from the perspective of consumers and the public. Therefore, this reply comment does not represent the views of any particular affected party but is designed to assist the agency as it explores these issues.

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We appreciate the opportunity to submit reply comments regarding the National Highway Traffic Safety Administration's (NHTSA) Federal Automated Vehicles Policy.[1] We are also grateful to our Mercatus colleague Oliver Sherouse for his valuable help in the construction of our regulatory delay model.

THE BASELINE IN THE DEBATE OVER AUTOMATED VEHICLE POLICY

"Every single death on our roadways is a tragedy," NHTSA administrator Mark Rosekind noted recently. "We can prevent them. Our drive toward zero deaths is more than just a worthy goal. It is the only acceptable goal."[2]

We agree. Zero fatalities on our roads is a noble goal. But the length of time it takes to reach that goal is just as important as the goal itself. We are concerned that NHTSA's proposed policy for automated vehicles may inadvertently increase the number of total automobile fatalities by delaying the rapid development and diffusion of this life-saving technology.

At every juncture of this ongoing debate over highly automated vehicle (HAV) policy, we must keep in mind the real-world baseline of motor vehicle safety. As NHTSA knows all too well, the current baseline is troubling, with over 35,000 people dying on US roadways in 2015 (roughly 96 people per day) and 94 percent of all crashes being attributable to human error. More disturbing is the fact that, as NHTSA recently noted, "preliminary estimates for the first half of 2016 show an alarming uptick in fatalities—an increase of about 10.4 percent as compared to the number of fatalities in the first half of 2015."[3]

Imagine if everyone who was drunk behind the wheel were instead in the backseat of an HAV. In 2014 nearly 9,100 people were killed in alcohol-impaired-driving crashes (25 people per day), and there was an average of one alcohol-impaired-driving fatality every 53 minutes. And motor vehicle crashes are the leading cause of death for people age 16 through 24. It seems reasonable to assume that the majority of these tragedies could be avoided if autonomous systems took over the job of driving for us.[4]

For these reasons, some have pointed out that "automation on the roads could be the great public-health achievement of the 21st century" if HAV technology can help address this situation and move us closer to a world of zero fatalities.[5] Every policy decision must be judged

1. Request for Comment on Federal Automated Vehicles Policy, 81 Fed. Reg. 65,703 (proposed September 23, 2016). The policy can be found at National Highway Traffic Safety Administration (NHTSA), *Federal Automated Vehicles Policy*, September 2016.
2. National Highway Traffic Safety Administration (NHTSA), "U.S. DOT, National Safety Council Launch 'Road to Zero' Coalition to End Roadway Fatalities," press release, October 5, 2016.
3. Ibid. See also NHTSA, "Early Estimate of Motor Vehicle Traffic Fatalities for the First Half (Jan–Jun) of 2016," Traffic Safety Facts, October 2016.
4. As the chief executive of Nvidia Corp put it, "We can recognize objects better than humans can. The beautiful thing about a car doing perception, using our computers, is that it never gets tired. It has eyes all around the car. It's never intoxicated. And it's never angry. It has no emotions. So once you train and test the car, it gets better and better as more and more experiences accumulate." Jen-Hsun Huang, interview by Jason Anders, "Inside the Brain of the Driverless Car," *Wall Street Journal*, October 30, 2016.
5. Adrienne LaFrance, "Self-Driving Cars Could Save 300,000 Lives per Decade in America," *Atlantic*, September 29, 2015.

by how rapidly it can help us advance that goal and move us away from the current baseline in terms of both lives lost and other costs to citizens and the economy.

Indeed, the toll in terms of human lives is not the end of the story. The estimated economic cost of all motor vehicle traffic crashes in the United States in 2010 (the most recent year for which cost data is available) was $242 billion.[6] Lowering the frequency of accidents will, therefore, have many beneficial effects on the economy.

If HAV technology eliminates the need for households to own vehicles altogether, the economic implications will be profound for a typical family. In his recent book, *Humans Need Not Apply*, computer scientist Jerry Kaplan observes that, with the average car costing owners $9,151 per year to drive 15,000 miles (2013 data) and with most households owning two cars, American households spend $18,000 annually on their vehicles.[7] Because driverless cars will help bring down transportation costs, and because fewer Americans may need to own cars at all, Kaplan estimates a potential 75 percent drop in the cost of personal transportation—a savings roughly equal to a typical family's entire annual food budget.[8]

The NHTSA should keep these numbers in mind as it contemplates public policy for HAVs. Any policy that would slow HAV innovation would likely have profoundly deleterious implications for society.

THE OPPORTUNITY COSTS ASSOCIATED WITH PRIOR RESTRAINT

In this section, we identify the most worrisome portion of the NHTSA's proposed HAV guidance: the agency's suggestion that some sort of premarket approval authority might be needed for these technologies.

Generally speaking, wise policy that encourages innovation avoids prior restraints on trial-and-error experimentation. Prior regulatory restraints on innovative activities stifle the sort of creative, organic, bottom-up solutions that will be needed to solve problems that may be unforeseeable today.[9] Attempting to preemptively plan for every hypothetical worst-case scenario and then requiring it to be addressed through a regulatory process means that many *best-case* scenarios will never come about.[10]

When commercial uses of an important resource or technology are arbitrarily prohibited or curtailed, the opportunity costs of such exclusion may not always be immediately evident. Nonetheless, those unseen effects are very real and have profound consequences for individuals, the

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6. NHTSA, "The Economic and Societal Impact of Motor Vehicle Crashes, 2010 (Revised)," Report No. DOT HS 812 013, May 2015.
7. Jerry Kaplan, *Humans Need Not Apply: A Guide to Wealth and Work in the Age of Artificial Intelligence* (New Haven, CT: Yale University Press, 2015), 196.
8. Ibid.
9. Adam Thierer and Andrea Castillo, "Preparing for the Future of Artificial Intelligence" (Public Interest Comment, Mercatus Center at George Mason University, Arlington, VA, July 22, 2016).
10. Adam Thierer, *Permissionless Innovation: The Continuing Case for Comprehensive Technological Freedom*, 2nd ed. (Arlington, VA: Mercatus Center at George Mason University, 2016), 2.

economy, and society. The Internet itself provides a good example of the profound opportunity costs associated with misguided regulation. Initially, commercial development of the Internet was prohibited. But when this mistake was corrected in the early 1990s through the commercial opening of the Internet, the true opportunity costs of the original prohibitions become evident. E-commerce exploded following commercialization, and a vibrant array of new sites and services emerged rapidly—and in ways that no one could have predicted just a few years earlier. New and better digital services continue to emerge rapidly thanks to America's "permissionless innovation" approach to Internet policy.[11]

This is why NHTSA should keep opportunity costs in mind as the agency looks to formulate policy for a fast-moving technology like HAVs. This principle is particularly true in the case of HAVs because the opportunity costs include human lives. If policymakers discount unseen potential future gains or opportunities of HAVs and focus only on the immediate potential risks—and then impose prior regulatory restraints to deal with them—the costs could be catastrophic in terms of human life.

It is helpful to think about this issue in terms of "error costs," which is a term that antitrust lawyers and economists use when referring to the costs of bad decisions about innovation and competition policy.[12] These scholars are concerned with two types of errors: Type I (false positive) and Type II (false negative) errors. Type I and Type II errors are not equivalent because "false positives are more costly than false negatives, because self-correction mechanisms mitigate the latter but not the former."[13]

Stated differently, "in the second (Type II error) case, society can witness the effects of the technology" but "in the first (Type I error) case, consumers will never know what they are missing," observes Michael A. Carrier of Rutgers Law School.[14] "We can only see the tip of the innovation iceberg, and a technology's abandonment will forever deny consumer its possibilities," he argues. "The error-cost asymmetry is another reason for erring on the side of not quashing the technology."[15]

Error-cost analysis provides a useful framework for exploring innovation policy issues and explains why NHTSA's discussion of premarket approval authority is so troubling. Beginning on page 71 of the *Federal Automated Vehicles Policy*, NHTSA suggests,

> A pre-market approval approach—used either in conjunction with or as a replacement for DOT's existing self-certification and compliance testing process—might have potential for expediting the safe introduction and public acceptance of HAVs. Such a regulatory approach could also contribute to public acceptance

11. Adam Thierer, "Embracing a Culture of Permissionless Innovation," *Cato Online Forum*, November 2014.
12. Geoffrey A. Manne and Joshua D. Wright, "Innovation and the Limits of Antitrust," *Journal of Competition Law & Economics* 6, no. 1 (2010): 153–202.
13. Ibid., 157.
14. Michael A. Carrier, *Innovation for the 21st Century: Harnessing the Power of Intellectual Property and Antitrust Law* (Oxford: Oxford University Press, 2011), 131.
15. Ibid.

> of and confidence in HAVs, because it would involve affirmative approval by the federal government of the safety of HAVs and new safety technologies.[16]

More specifically,

> NHTSA adoption of a full pre-market approval approach for HAVs would entail replacing the self-certification process with at least two new statutory provisions. The first provision would prohibit the manufacture, introduction into commerce, offer for sale and sale of HAVs unless, prior to such actions, NHTSA has assessed the safety of the vehicle's performance and approved the vehicle.[17]

NHTSA admits that "substitution of pre-market approval for all standards for which manufacturers currently self-certify would be a wholesale structural change in the way NHTSA regulates motor vehicle safety and would require both fundamental statutory changes and a large increase in Agency resources."[18] The agency also suggests that the Federal Aviation Administration (FAA) might provide a model for how such premarket approval of HAVs by NHTSA could work.[19]

However, in a short appendix to its HAV guidance document, NHTSA notes that "the duration of the [FAA] certification processes varies. Typically, they last three to five years."[20] Moreover, "the most recent FAA certification process for a new commercial aircraft design, the one for the Boeing 787 Dreamliner, lasted considerably longer. It consumed an estimated 200,000 hours of FAA staff time and lasted eight years."[21]

That fact alone should foreclose any further discussion about the wisdom of NHTSA employing an FAA-like premarket approval regime for HAVs. Even the *average* duration of FAA premarket certifications (three to five years) is far too long if we hope to get life-saving HAV technologies deployed on a timely basis.

One way of comparing the costs of the FAA's premarket approval regime and NHTSA's current postmarket approval regime is by looking at the cost to produce automobiles versus civilian aircraft over time. If the lengthy premarket approval process used by the FAA significantly increases the time and cost of getting new civilian aircraft onto the market, we would expect that to appear in the long-term costs of production as measured by the Producer Price Index (PPI). While there may be too much noise to pick up a clear trend over a short period of time, the long-term data should reveal any difference between the two regulatory structures.

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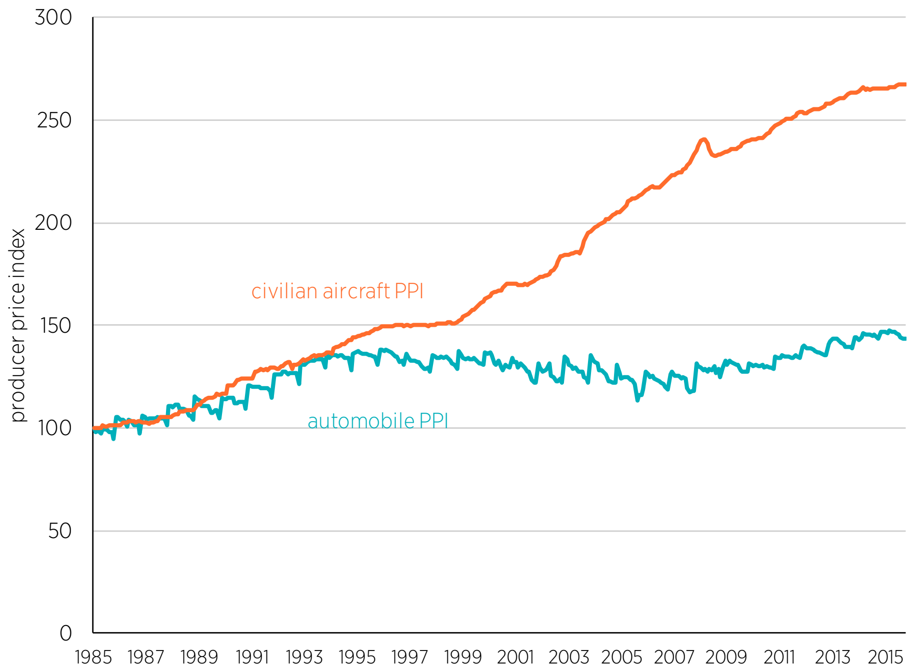
16. NHTSA, *Federal Automated Vehicles Policy*, 72.
17. Ibid.
18. Ibid., 73.
19. "For example, the Federal Aviation Administration (FAA) uses pre-market approval processes to regulate the safety of complex, software-driven products like autopilot systems on commercial aircraft, and unmanned aircraft systems." Ibid., 71.
20. Ibid., 95.
21. Ibid., 95–96.

Figure 1 shows a clear divergence in the cost of producing civilian aircraft[22] and automobiles[23] since 1985, which is the earliest year data is available for both. After chaining both indices to 1985, we can see that the cost of production has risen 43 percent for automobiles and 167 percent for civilian aircraft over the last 31 years.

FIGURE 1. RELATIVE COST TO PRODUCE AUTOMOBILES AND CIVILIAN AIRCRAFT



While there are undoubtedly many factors at play in determining the costs of production for both industries, it seems unclear what could cause such a large differential in the costs of production. Some of the potential explanations hold no water. Automobiles and airplanes are made out of similar materials, and while aircraft use much more aluminum than automobiles, the price of aluminum has been relatively stable over the last 30 years.[24] The increase in economies of scale should actually benefit aircraft over this period because there has been larger growth in miles flown than miles driven since 1985.[25] And by focusing on the cost for producers rather than consumers, we avoid any confounding variables relating to collusion in the airline industry to charge consumers higher prices. Given the lack of other explanations, it seems likely that the large differential must be at least partially attributable to the FAA's more complicated and time-consuming regulatory approach.

22. To measure the production costs for civilian aircraft, we used PPI series PCU3364113364113.
23. To measure the production costs for automobiles, we used PPI series PCU3361103361102.
24. InfoMine, InvestmentMine, "Historical Aluminum Prices and Price Chart," accessed November 21, 2016, http://www.infomine.com/investment/metal-prices/aluminum/all/.
25. US Department of Transportation, Bureau of Transportation Statistics, "Table 1-40: U.S. Passenger-Miles (Millions)," *National Transportation Statistics*, July 2016.

Regulation predicated on premarket approval has real costs to industry that may be too small to measure in any given year but can add up significantly in the long run. There will also be serious costs associated with any attempt to apply traditional vehicle regulatory standards to emerging HAV systems. Paul Brubaker, a former administrator of DOT's Research and Innovative Technology Administration and the current president and CEO of the Alliance for Transportation Innovation, recently noted that NHTSA's guidance document "still requires that autonomous vehicles must demonstrate compliance with Federal Motor Vehicle Safety Standards (FMVSS)."[26] Brubaker describes the problem with this requirement:

> These standards include 286 references to human drivers and mandate traditional design features such as steering wheels, displays and pedals. Any fully self-driving vehicle would violate more than one-third of those standards, not to mention half of the Series 100 Crash Avoidance standards built into the compliance structure.[27]

"This is 2016, not 1966 when the Highway Safety Act that laid out this governance process passed," Brubaker notes. "Today, innovation cycles are measured in months but temporary exceptions can take a year or more and the rulemaking process will take considerably longer."[28]

Brubaker is correct. It is highly unlikely that regulation will be able to evolve fast enough to make this approach work because of the so-called pacing problem, which refers to the "the gap between the introduction of a new technology and the establishment of laws, regulations, and oversight mechanisms for shaping its safe development."[29] Technology policy expert Larry Downes has shown how lawmaking in the information age is inexorably governed by the "law of disruption," meaning that "technology changes exponentially, but social, economic, and legal systems change incrementally."[30] "Emerging technologies change at the speed of Moore's Law," Downes notes, "leaving statutes that try to define them by their technical features quickly out of date."[31]

This is a particular problem in the field of automated systems and machine learning, which are advancing at an astonishing pace.[32] Carl Tobias, a product liability law professor at the University of Richmond, comments on self-driving technology: "Technology is always running ahead

26. Paul Brubaker, "Innovators Must Speak Out on U.S. DOT Autonomous Vehicle Policy," *The Hill*, October 5, 2016.
27. Ibid.
28. Ibid.
29. Wendell Wallach, *A Dangerous Master: How to Keep Technology from Slipping beyond Our Control* (New York: Basic Books, 2015), 251.
30. Larry Downes, *The Laws of Disruption: Harnessing the New Forces That Govern Life and Business in the Digital Age* (New York: Basic Books, 2009), 2.
31. Ibid., 60.
32. "First, regulatory promulgation is fundamentally an iterative and slow process, given the cycles of proposals, requests for comments, reviews, and lobbying that precede rulemaking. Second, with AV technologies in particular, their newness and rapid evolution create uncertainty in both rulemaking effects and of the technology itself. Moreover, with rapid technology changes, it can be challenging to prescribe rules that will remain relevant and appropriate through the development process." James M. Anderson et al., *Autonomous Vehicle Technology: A Guide for Policymakers* (Santa Monica, CA: RAND Corporation, 2016), 103.

of the law, but in this case, it is running way ahead of the law."[33] Thus, if HAV innovators must constantly apply for exemptions from older rules or even newer guidelines in order to move forward, life-saving innovation in this sector will stagnate or perhaps even completely derail.

For these reasons, NHTSA should abandon the idea of premarket approval as a dangerous prior restraint on HAV innovation—a restraint that would put lives at risk. Instead, the agency should focus on best practices and *postmarket* oversight with the specific goal of monitoring the marketplace for gross negligence. Of course, this is already the "regulatory" model at work in our court system, as will be discussed further below.

ALGORITHMIC REGULATION: AVOIDING A FEDERAL CODE COMMISSION

In terms of the dangers of premarket approval, we are also particularly concerned about NHTSA's claim that it "has authority to regulate the safety of software changes provided by manufacturers after a vehicle's first sale to a consumer" and the suggestion that the agency "may need to develop additional regulatory tools and rules to regulate the certification and compliance verification of such post-sale software updates."[34]

It is unclear whether NHTSA's currently regulatory authority can be read so broadly as to include software changes under its regulatory purview.[35] Regardless, such postsale regulation of software changes represents an extension of the sort of prior restraint or premarket approval approach that we diagnosed and critiqued above. Regulation of this sort raises the specter of potentially endless technocratic meddling with the design specifications for future code.

For example, NHTSA notes,

> To address problems and to improve and expand performance capabilities in the coming years, manufacturers and other entities will likely provide software updates for motor vehicles well after they are manufactured and certified. Some of those changes will substantially alter the functions and technical capabilities of those vehicles.[36]

NHTSA seems to imply that this is a problem when, in reality, it is a benefit. The reality is that there is no such thing as perfectly "safe" code, and there is no end point when it comes to security. Rather, security is a dynamic and rapidly evolving process.[37] Systems have to be

33. Mike Ramsey, "Regulators Have Hands Full with Tesla's Plan for Hands-Free Driving," *Wall Street Journal*, March 27, 2015.
34. NHTSA, *Federal Automated Vehicles Policy*, 76.
35. NHTSA argues that "the statute underlying the FMVSS provides for manufacturer certification of a motor vehicle prior at the time of its manufacture. Subsequent software updates could affect the basis for that certification. In addition, such updates would themselves constitute new items of motor vehicle equipment, subject to the certification requirement and verification, to the extent there are applicable FMVSS." Ibid., 77. But Congress has not yet granted the agency the authority to treat HAV software updates as the equivalent of traditional motor vehicle equipment.
36. Ibid., 76–77.
37. Adam Thierer, "Don't Hit the (Techno-)Panic Button on Connected Car Hacking & IoT Security," *Technology Liberation Front*, February 10, 2015.

devised and refined in real time to address vulnerabilities. It is only through ongoing real-world experimentation with actual technologies that we will discover better ways to optimize autonomous technologies for safety, security, privacy, and so on.

HAV system are dynamic by design, and any attempt to preemptively limit innovation based on short-term security concerns will, ironically, undermine the longer-term possibility of creating safer and more secure systems. "Dynamic systems are not merely turbulent," observes Virginia Postrel, author of *The Future and Its Enemies*. "They respond to the desire for security; they just don't do it by stopping experimentation."[38]

It also is vital to remember that "manufacturers have powerful reputational incentives at stake here, which will encourage them to continuously improve the security of their systems."[39] No automaker wants the bad publicity that accompanies car "hacks" or deficient code that leads to problematic outcomes. Innovators in this arena have a great incentive to understand and quickly deal with these issues because the future of their companies is at stake.

Moreover, it is worth noting that courts and class action lawsuits will quickly enter the picture at the first sign of serious trouble with HAV systems.[40] The automotive sector already attracts a disproportionately large amount of litigation activity when compared to other sectors, and that trend is certain to continue. "When confronted with new, often complex, questions involving products liability, courts have generally gotten things right," observes Brookings Institution scholar John Villasenor.[41] "Products liability law has been highly adaptive to the many new technologies that have emerged in recent decades, and it will be quite capable of adapting to emerging autonomous vehicle technologies as the need arises," he concludes.[42]

In sum, there is no reason to believe that common law will not adapt to new technological realities, especially since firms have powerful incentives to improve the security of their systems and avoid punishing liability, unwanted press attention, and lost customers. These facts counsel patience by policymakers, rejection of prior restraint on innovative activities, and ongoing trial-and-error experimentation to improve systems and technologies.

MODELING THE POTENTIAL COSTS OF PREEMPTIVE REGULATION

In an effort to show how important a rapid deployment of HAV technology is, we have constructed a model to project the expected number of lives lost as a result of regulatory delay. It's impossible to predict exactly how much slower the diffusion rate of HAVs will be with a cumbersome premarket approval regime, so we have forecasted the expected loss of life at three different slowdown rates: 5 percent, 10 percent, and 25 percent. Table 1 illustrates these predictions.

38. Virginia Postrel, *The Future and Its Enemies: The Growing Conflict over Creativity, Enterprise, and Progress* (New York: Simon & Schuster, 1998), 199.
39. Adam Thierer and Ryan Hagemann, "Removing Roadblocks to Intelligent Vehicles and Driverless Cars," *Wake Forest Journal of Law & Policy* 5, no. 2 (2015), 40.
40. Adam Thierer, "When the Trial Lawyers Come for the Robot Cars," *Slate*, June 10, 2016.
41. John Villasenor, "Who Is at Fault When a Driverless Car Gets in an Accident?," *Atlantic*, April 25, 2014.
42. Ibid.

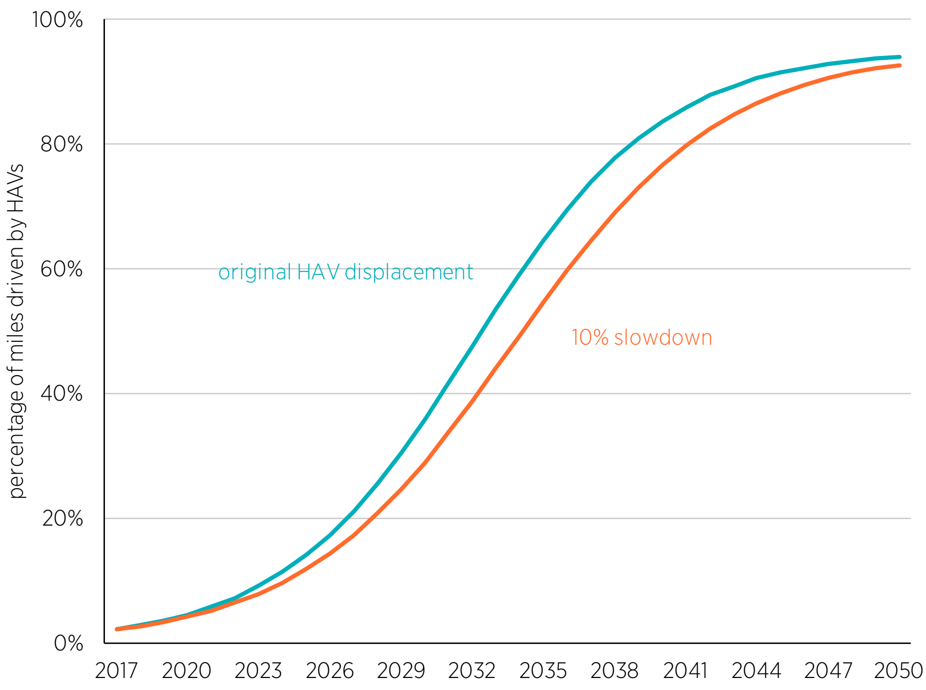
If NHTSA's proposed premarket approval process slows the deployment of HAVs by 5 percent, we project an additional 15,500 fatalities over the course of the next 31 years. At 10 percent regulatory delay, we project an additional 34,600 fatalities over 33 years. And at 25 percent regulatory delay, we project an additional 112,400 fatalities over 40 years.

TABLE 1. ESTIMATED ADDITIONAL FATALITIES AT VARIOUS LEVELS OF REGULATORY DELAY

Regulatory delay	Additional fatalities	Time until HAV saturation
5 percent	15,500	31 years
10 percent	34,600	33 years
25 percent	112,400	40 years

This model works by first estimating the diffusion curve along which HAVs will be adopted, then slowing the slope of that curve by the rate of regulatory delay. In order to illustrate how the model works, we will specify the rate of regulatory delay as 10 percent.

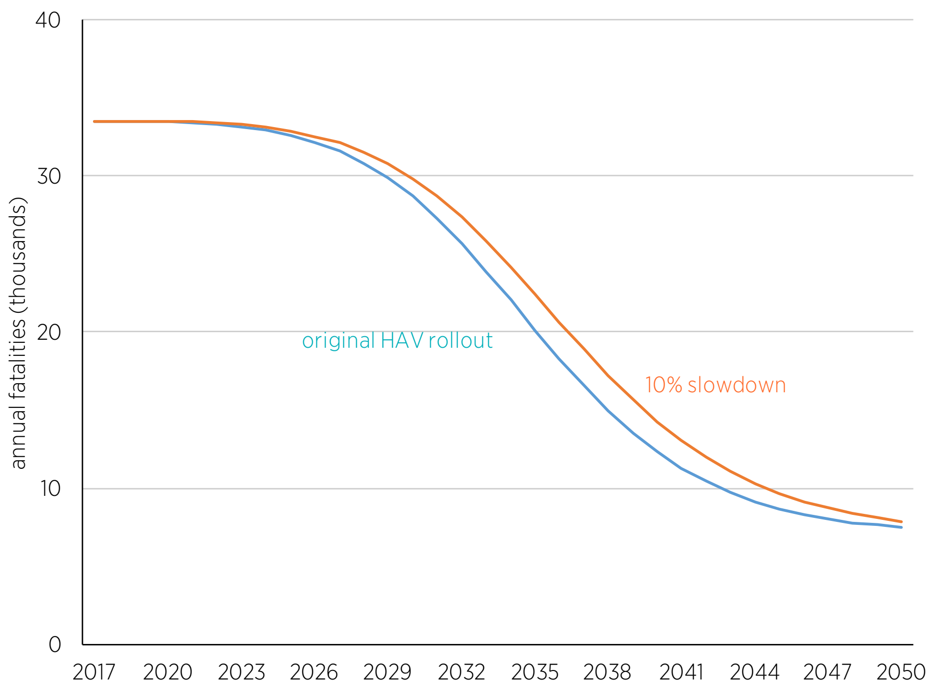
FIGURE 2. ESTIMATED DISPLACEMENT OF NONAUTONOMOUS MILES DRIVEN



The first step is projecting the expected displacement of nonautonomous miles by HAVs and semiautonomous vehicles. In figure 2, the blue line shows our projected timeline for the percentage of total miles driven that has been displaced by autonomous miles. In red is the revised timeline with a 10 percent slowdown as a result of regulatory delay. Although both scenarios eventually reach the same level of adoption, the total number of human-driven miles over the time frame is significantly larger with regulatory delay.

With a slower HAV rollout comes a larger number of yearly fatalities as human drivers remain on the road for longer periods of time. Figure 3 shows these fatality projections.

FIGURE 3. ESTIMATED ANNUAL AUTOMOBILE FATALITIES

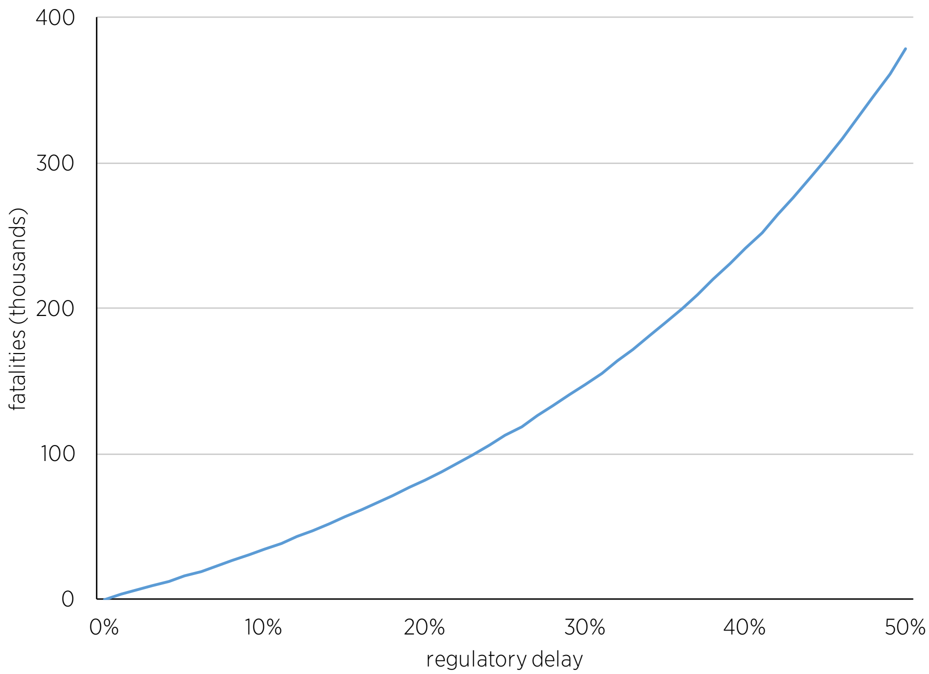


As with figure 2, the blue line in figure 3 represents the yearly automobile fatalities during the adoption period for HAVs, and the red line shows how the number of fatalities is affected by a 10 percent slowdown. The space between the two curves represents the estimated number of fatalities owing to regulatory delay. While the space may look small, the huge number of fatalities each year adds up quickly. In the event of a 10 percent slowdown, an additional 34,600 people will die over the rollout period.

Because of the inherent uncertainty surrounding the actual level of regulatory delay, we wanted to show how the fatalities vary over a wide spectrum from a 1 percent to a 50 percent slowdown. Figure 4 illustrates these results.

Even with only a 1 percent slowdown, we would expect an additional 3,000 fatalities. On the upper end of the projection, with a 50 percent slowdown, we could see as many as 378,500 fatalities.

FIGURE 4. ADDITIONAL FATALITIES CAUSED BY REGULATORY DELAY



Note that these fatalities projections are not annual but include the entire adoption period for HAVs. The adoption period varies based on the level of regulatory delay, between 30 years with no slowdown and 60 years with a 50 percent slowdown.

Our hope is that this model can give NHTSA and other commentators a baseline from which to compare a premarket approval regime and other regulatory approaches. The "cost of caution" is often difficult to quantify, but this model should give NHTSA some insight as to just how costly a delay in HAV technology can be. We detail the assumptions underlying our model in the appendix.

ETHICAL CONSIDERATIONS

In this section we comment on an area that the NHTSA mentioned in the guidance document and that has been a larger topic of conversation in the industry for the past several years: the ethical considerations of driverless cars. More specifically, how should a self-driving car be programmed to act during an unavoidable accident?

While we do not intend to give a robust analysis of all aspects of this debate, we do want to counsel the agency against requiring a solution to this thorny moral problem before allowing driverless cars on the market. And on a more fundamental level, it might be the wrong question to ask.

The *MIT Technology Review* sets up the following scenario:

> Imagine that in the not-too-distant future, you own a self-driving car. One day, while you are driving along, an unfortunate set of events causes the car to head

> toward a crowd of 10 people crossing the road. It cannot stop in time but it can avoid killing 10 people by steering into a wall. However, this collision would kill you, the owner and occupant. What should it do?[43]

Should the car be programmed to save its passengers at all costs? Or maximize the number of lives saved? These are difficult questions that don't have clear and obvious answers. But it may be counterproductive to force the industry to answer them at this time.

Let's begin with how likely these kinds of situations may be in the first place. It's easy to imagine the situation painted above because human drivers are faced with similar situations frequently. But the whole point of driverless cars is to reduce the frequency of the "unfortunate set of events" that leads to these ethical dilemmas. With 360-degree visibility around the vehicle and millisecond response time, it's difficult to imagine a scenario where this might actually occur. By eliminating most of the routine traffic accidents, HAVs will encounter only those accident scenarios in the tail-end of the probability distribution, which are the most difficult to foresee and plan for. In short, it's unclear whether situations like these will actually arise, and the only way to find out is to allow more experimentation, see what problems arise, and then find solutions to address them ex post.

Second, NHTSA's priority has to be getting driverless cars onto the streets as quickly as possible, using a combination of regulatory restraint and the sort of best practices and postmarket oversight described above. Anything that slows this process down has to be weighed against the significant costs of delay outlined in the model above. Requiring all members of the industry to get on board with a single solution to this complex problem is likely to be a time-consuming endeavor. And given the relative infrequency of these situations, the cost of delay seems likely to dwarf any gains from a unified solution, assuming one could be agreed on. Additionally, the engineers and leadership at HAV companies have an opportunity cost. The more time they are required to spend contemplating ethical quandaries that will rarely occur in real life, the less time they can spend setting up failsafe systems for the brakes, improving cross-platform communication between different HAV manufacturers, or refining the software identification system—all things that can prevent crashes in the first place.

Finally, the government can focus on alternative measures to further decrease the likelihood of these problems arising. As our colleague Brent Skorup has highlighted, having smarter infrastructure like roadside sensors can allow "driverless cars to 'see' some information that's blocks or miles away in real time—such as a dog running into the street, a speeding ambulance, or a swerving driver."[44] With this kind of situational awareness delivered to all, it is our opinion that trying to prevent these ethical dilemmas from occurring in the first place is preferable to planning for every conceivable permutation of the driverless car trolley problem.[45]

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43. Emerging Technology from the arXiv, "Why Self-Driving Cars Must Be Programmed to Kill," *MIT Technology Review*, October 22, 2015.
44. Brent Skorup, "Driverless Cars Need Just One Thing: Futuristic Roads," *BackChannel*, October 10, 2016.
45. Joel Achenbach, "Driverless Cars Are Colliding with the Creepy Trolley Problem," *Washington Post*, December 29, 2015.

As driverless cars continue to improve and evolve, so will our intuitions about the best thing to do in any given situation. But we can't let ourselves be so paralyzed by the fear of making the wrong decision that we slow the deployment of driverless cars and inadvertently kill more people as a result.

Again, it is important that policymakers not get too caught up in attempts to preemptively resolve every potential hypothetical scenario. The problem with that approach was nicely summarized by the late political scientist Aaron Wildavsky when he noted, "If you can do nothing without knowing first how it will turn out, you cannot do anything at all."[46] The goal of zero fatalities on the road will be even more elusive if policymakers are paralyzed by fear of the unknown and refuse to allow real-world experimentation with HAV technologies. Only ongoing trial-and-error experimentation will help us find answers to the truly hard questions about how to radically improve the safety of motor vehicles.

Are there risks with such an approach? Of course, but there are far greater risks associated with the operation baseline of the human-driven vehicles that populate our roads today. Some advocates of preemptive regulation of HAV technology argue that allowing real-world experimentation on the roads means that innovators "are essentially making the commuters the guinea pigs," as Joan Claybrook, a consumer-protection advocate and former head of the National Highway Traffic Safety Administration, has argued.[47]

But arguments such as these ignore the reality that members of the general public are already guinea pigs in an ongoing real-world experiment with human-driven vehicles, and that experiment continues to produce very troubling results. Human abilities haven't radically improved in recent years, and we certainly aren't getting significantly better at driving. Most of the safety improvements in recent decades came about because of improvements in other systems, materials, and technologies in and around vehicles. But these improvements can only go so far to counter the fact that humans are fallible, and mistakes will always lead to problems, for both themselves and others around them on the road.

HAV systems offer the nation the first opportunity to make radical near-term improvements in terms of accidents avoided and lives saved. But that can only happen by allowing real-world HAV experimentation today. "If you don't develop the technology and deploy it, it never gets better," argues Jen-Hsun Huang, chief executive of Nvidia Corp., whose chips are used to power autonomous driving and other artificial-intelligence applications.[48] "At some level, you have to put it on the road." These systems can only "learn" how to become safer and more secure through ongoing real-world experiments. "The software becomes better and better over use," Huang observes.[49]

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46. Aaron Wildavsky, *Searching for Safety* (New Brunswick, NJ: Transaction Publishers, 1989), 38.
47. Elizabeth Dwoskin and Brian Fung, "For Some Safety Experts, Uber's Self-Driving Taxi Test Isn't Something to Hail," *Washington Post*, September 11, 2016.
48. Jen-Hsun Huang, interview by Jason Anders, "Inside the Brain of the Driverless Car."
49. Ibid.

Again, at the end of the day, the safety and security considerations surrounding these technologies must be compared to the current real-world baseline of excessive accidents attributable to human error. As Tom Vanderbilt of *Wired* correctly concludes,

> Every scenario you can spin out of computer error—What if the car drives the wrong way—already exists in analog form, in abundance. Yes, computer-guidance systems and the rest will require advances in technology, not to mention redundancy and higher standards of performance, but at least these are all feasible, and capable of quantifiable improvement. On the other hand, we'll always have lousy drivers.[50]

CONCLUSION

It is vital that NHTSA realizes that its policy deliberations and decisions in this matter are not happening in a vacuum. We increasingly live in a world where "global innovation arbitrage" is a reality.[51] Just as capital moves seamlessly around the globe seeking out hospitable regulatory treatment, the same is increasingly true for cutting-edge innovations. Innovators can and will move to countries and continents that provide a legal and regulatory environment that is hospitable to entrepreneurial activity.[52] If HAV entrepreneurs feel that America's approach to innovation policy stacks the deck against them, they will seek out alternative venues where experimentation can continue in a relatively unabated fashion. Some entrepreneurs are already threatening to do so.[53]

To avoid that fate and ensure that America remains at the forefront of HAV innovation worldwide, to the maximum extent possible NHTSA should attempt to make its default policy position "Innovation Allowed." Prior restraint must be avoided as much as possible. Just as policymakers did not preemptively foreclose innovation with previous digital technologies such as the Internet, NHTSA should avoid artificially restricting new forms of HAV innovation today with overly prescriptive regulations. Considering the lives at stake in this matter, the burden of proof rests on those who favor precautionary regulation to explain why ongoing experimentation with new and better ways of doing things should be prevented.

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50. Tom Vanderbilt, "Five Reasons the Robo-Car Haters Are Wrong," *Wired*, February 9, 2012.
51. See Ted Ullyot, interview by a16z, "When Software Eats the Physical World, Startups Bump up against Regulations," *Andreessen Horowitz*, April 22, 2015; Adam Thierer, "Global Innovation Arbitrage: Commercial Drones & Sharing Economy Edition," *Technology Liberation Front*, December 9, 2014.
52. "Entrepreneurs can take advantage of the difference between opportunities in different regions, where innovation in a particular domain of interest may be restricted in one region, allowed and encouraged in another, or completely legal in still another." Marc Andreessen, "Turn Detroit into Drone Valley: How to Build Innovation Clusters beyond California," *Politico*, June 15, 2014.
53. Kyle Stock, "NHTSA Scared This Self-Driving Entrepreneur off the Road," *Bloomberg Technology*, October 28, 2016; Brad Templeton, "Comma.ai Cancels Comma-One Add-On Box after Threats from NHTSA," *Robohub*, October 31, 2016.

APPENDIX: ASSUMPTIONS BEHIND THE MODEL

In the interest of transparency, we wanted to clearly state our assumptions in building this model. We intentionally tried to err on the side of overly modest assumptions in order not to inflate the number of additional lives lost as a result of regulatory delay.

In this model we have assumed a number of parameters:

HAVs will be adopted along a normal logistic function. The academic literature has shown that new technologies are typically adopted along an "S" type logistic function.[54]

The deployment process for driverless cars will begin in 2017. Automated vehicles with human supervision are currently operating in Pittsburgh with Uber,[55] and all Tesla cars currently in production have hardware capable of autonomous driving at SAE-5 levels.[56] Additionally, both Ford[57] and Lyft[58] have stated publicly that they plan to have significant fleets of consumer HAVs ready by 2021. These timelines are consistent with the projection of the model.

The estimated initial transition time for the rollout of driverless cars is 30 years. This is consistent with NHTSA's proposed "Road to Zero" goal of having zero traffic fatalities in 30 years. The only realistic way of reaching anywhere close to this ambitious goal is a speedy rollout of driverless cars, with the vast majority of consumers using driverless cars by the end of this 30-year window. It can be argued that the rollout of HAVs will take longer than 30 years, but extending the rollout time frame in the model would only increase the number of lives lost due to regulation over a longer time span.

The average growth rate in miles driven per year is 2 percent. This has been the average increase in total miles driven in the United States over the past five years.[59]

The fatalities per hundred million miles driven by nonautonomous vehicles will continue at a rate of 1.106. This has been the average rate of the five most recent years for which we have data, from 2010 to 2014.[60] Note that this rate does not include data from 2015 or 2016; in both of these years, the auto fatality rate in the United States has been higher than in previous years.

Autonomous vehicles will initially be 2 times safer than human drivers and grow to be 10 times safer by the end of the original 30-year period. This assumption mirrors those made by professors Daniel J. Fagnant and Kara Kockelman in a paper for the Eno Center for Transportation.[61]

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54. Paul Geroski, "Models of Technology Diffusion," *Research Policy* 29, no. 4–5 (2000): 603–25.
55. Signe Brewster, "Uber Starts Self-Driving Car Pickups in Pittsburgh," *TechCrunch*, September 14, 2016.
56. "All Tesla Cars Being Produced Now Have Full Self-Driving Hardware," *Tesla Blog*, October 19, 2016.
57. "Ford Targets Fully Autonomous Vehicle for Ride Sharing in 2021; Invests in New Tech Companies, Doubles Silicon Valley Team," Ford Motor Company Media Center, August 16, 2016.
58. Darrell Etherington, "Lyft's Ambitious Future Vision Includes Self-Driving Dominance by 2021," *TechCrunch*, September 18, 2016.
59. US Department of Energy, "Annual Vehicle Miles Traveled in the U.S.," Alternative Fuels Data Center, Chart 10315, August 2016.
60. NHTSA, "Fatalities and Fatality Rates, 1994–2014—State: USA," Fatality Analysis Reporting System (FARS) Encyclopedia, accessed November 21, 2016, http://www-fars.nhtsa.dot.gov/Trends/TrendsGeneral.aspx.
61. Daniel J. Fagnant and Kara Kockelman, "Preparing a Nation for Autonomous Vehicles; Opportunities, Barriers and Policy Recommendations," *Transportation Research Part A: Policy and Practice* 77 (2015): 167–81.

Additionally, Tesla has driven over 222 million miles in autopilot mode, according to Elon Musk's statement of the most recent figures.[62] With only one US fatality as a result of autopilot to date,[63] HAV technology is more than twice as safe as the average human-driven US automobile. While this figure is still unreliable because of a small sample size, it represents the best real-world estimate we have to date about the relative safety of HAVs.

Every HAV on the road will drive 1.5 times as many miles as a human driver. This assumption accounts for the decreased marginal cost of driving an extra mile using an HAV and the corresponding increase in miles driven we would expect as a result. The actual displacement effect is impossible to know beforehand, but we thought it was important to assume a generous rate to ensure our final projections were not artificially high.

The maximum crowd-out of HAVs in the market is 95 percent. While HAVs are likely to be widely adopted once they are available, there are holdouts with every technology. Unless HAVs become federally mandated to use when driving on highways, we will not reach 100 percent HAV market crowd-out.

62. Elon Musk, Twitter status update, October 7, 2016, 4:15 p.m., https://twitter.com/elonmusk/status/784487348562198529.
63. "A Tragic Loss," *Tesla Blog*, June 30, 2016.