Autonomous Vehicles and Federal Safety Standards: An Exemption to the Rule?

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Autonomous vehicles (AVs) will revolutionize how people travel, live, work, and interact with others. But there is also a quieter revolution occurring as AV technology forces a reconsideration of how road safety is conceptualized, measured, and regulated.

Although AVs will not eliminate crash risk (Smith, 2015), current estimates suggest that this technology will greatly reduce it. Data are still highly limited regarding exposure (vehicle miles traveled) and generalizability (in terms of both AV systems and the environment to which the vehicle is exposed). However, early reports suggest a possible reduction, but not elimination, of crash risk, especially for nonsevere crashes. Additionally, these vehicles are rarely at fault in a crash (Teoh and Kidd, 2017; Virginia Tech Transportation Institute, 2016; Schoettle and Sivak, 2015).

Currently, automotive safety regulations are split between driver safety (generally regulated by the state through licensure and driving behavior laws) and vehicle safety (generally regulated on the federal level by Federal Motor Vehicle Safety Standards [FMVSS]). FMVSS specify how vehicles must be designed before they can be sold in the United States. There are 73 FMVSS on vehicle crash avoidance (e.g., FMVSS 105 Hydraulic and Electric Brake Systems), crashworthiness (e.g., FMVSS 214 Side Impact Protection), and post-crash survivability (e.g., FMVSS 301 Fuel System Integrity) (National Highway Traffic Safety Administration [NHTSA], 2011).

Many innovative AV designs would not comply with FMVSS, including those central to realizing the promised benefits of the AV revolution (Anderson et al., 2016). For example, in 2015, Google's AV division (which has since spun off as Waymo) asked the NHTSA for clarification in certifying its AV designs (NHTSA, 2016b). Driverless AVs such as these would not need the FMVSS-required steering wheels, mirrors, brake and accelerator pedals, and other mechanisms that allow a human to drive.

Revising FMVSS will ultimately be necessary to accommodate

AVs (NHTSA, 2016a). However, revisions to FMVSS will probably take years, not only because the modification process requires considerable time, but also because the right changes are not yet clear—the technology is too new. Indeed, the response letter from NHTSA to Google elaborated on this:

> As self-driving technology moves beyond what was envisioned at the time when standards were issued, NHTSA may not be able to use the same kinds of test procedures for determining compliance . . . . Unless and until NHTSA has a standard and testing procedures to confirm compliance with these provisions, it cannot interpret Google's SDV (self-driving vehicle) as compliant with these standards and requirements. In order to determine what requirements would be appropriate, and to establish procedures for testing compliance with those standards, using its existing regulatory tools, NHTSA would be required to conduct a rulemaking. (NHTSA, 2016b)

NHTSA identified 11 of the 17 FMVSS for which Google sought interpretation as possibly requiring further rulemaking in the long term (NHTSA, 2016b).

Fortunately, there is already a path to facilitate innovation without, or as a precursor to, FMVSS rulemaking. Automakers can apply for exemptions to FMVSS under different bases, including "make[ing] easier the development or field evaluation of a new motor vehicle safety or impact protection features providing a safety or impact protection level at least equal to that of the standard" (U.S. Department of Transportation, 2013). Manufacturers can sell up to 2,500 vehicles per year for two years under each such exemption, with the potential for renewal (U.S. Department of Transportation, 2013). Exemptions made under this basis could facilitate deployment of innovative AV designs.

Yet such exemption requests are rare. Per the Federal Register, since 1994, there have been only eight requests on the basis of developing or evaluating new safety features.[1] Generally, NHTSA denied exemptions because the petition failed to show that the new safety feature provided a safety level equal to that of the FMVSS, that the exemption would facilitate testing, or both (NHTSA, 2006b; NHTSA, 2010; U.S. Department of Transportation, Federal Motor Carrier Safety Administration, 2015).

The existing exemption process seeks to bound the potential risks posed by the deployment of vehicles that do not conform to FMVSS on safety-related bases. The process first bounds risk by limiting the sale of nonconforming vehicles to 2,500 per exemption per year. However, the AV industry is seeking an increase to this limit to facilitate testing and deployment of the technology. Proposed increases include an immediate increase to 100,000 vehicle sales per exemption per year or a graduated increase with an initial cap of 25,000 vehicles followed by higher caps in subsequent years. These represent between a ten- to 40-fold increase in the exposure to risk relative to the current 2,500-vehicle limit. If even half of the companies registered for AV testing in California each sell 100,000 vehicles, within one year, almost 1 percent of the current U.S. passenger vehicle fleet will be exempt from portions of the FMVSS.[2]

The current process also seeks to bound risk by requiring developers to demonstrate that their nonconforming-vehicle design is just as safe as vehicles that do conform to FMVSS. Traditionally, this has applied to relatively straightforward design changes. For example, in 2004, NHTSA granted an exemption for three manufacturers to sell motorcycles in which the rear brake is controlled by the left handlebar, rather than the right foot control as FMVSS requires (NHTSA, 2004). The manufacturers provided a range of evidence showing how the alternative, nonconforming designs were as safe as or safer than conforming designs. NHTSA has also granted temporary exemptions without safety data to obtain said data. In these cases, evidence of ample laboratory and other off-road testing was provided in the application, and only 5,000 vehicles (2,500 over two years) could be sold under each exemption (NHTSA, 2006a).

Considering Proposed Changes to Standards and Exemptions

AV champions argue that standards and the existing exemption process will stifle deployment of lifesaving technologies. In response, Congress is discussing legislation to remove regulatory roadblocks and encourage development and deployment of AVs by consolidating regulation at the federal level, enhancing cybersecurity, and other measures. For example, one proposal revises the exemption process by (a) raising by a set amount the limit on the number of vehicles that can be sold or allowing an incremental increase over time, and (b) allowing a new basis for an exemption, predicated on the existing exemption basis of developing and field-testing new safety features. The new basis entails developing or testing AV technology that either provides "a safety level at least equal to the safety level of the standard for which exemption is sought … (or) providing an overall safety level at least equal to the overall safety level of nonexempt vehicles" (House Committee on Energy and Commerce, 2017a).

However, it is unclear whether the approaches for assessing equivalent safety for FMVSS make sense when it comes to AVs. Assessments of equivalent safety typically ask, "Can a nonconforming vehicle be as safely driven by a human as a conforming vehicle?" For example, traditionally, if an automaker would like an exemption for a vehicle that has alternative rear and side mirror designs (e.g., a camera system), the automaker would likely have to show that its proposed designs provide the same degree of persistent visibility to the human driver. Some have suggested an analogous approach for AVs: If the AV's cameras and other sensors provide the same degree of visibility as mirrors do for a human driver, that could qualify as "a safety level at least equal to the safety level provided in nonexempt vehicles (or) … of the standard for which the exemption is sought," for the purposes of granting an exemption (NHTSA, 2016a). This approach might make sense if the AV and the driver of the AV remained separate—e.g., if the technology was just a driver surrogate. Then the vehicle could be evaluated as a traditional FMVSS-compliant vehicle and the self-driving technology as a human driver—e.g., with a Department of Motor Vehicles road test.

However, it is not possible to compare the vehicle components of an AV with an FMVSS-compliant vehicle, while separately comparing the control components of an AV with human drivers: The two are completely integrated. The absurdity of this approach becomes clear when considering the following hypothetical situation: An AV could be designed to (a) conform to all FMVSS and (b) drive headfirst into the nearest wall, and such a vehicle would not require any exemptions to be sold in the United States. In other words, an AV could be completely compliant and still unsafe. Granted, NHTSA's investigative protocols would be quickly called to the scene and the vehicle would be taken off the market. But the fact remains: The FMVSS would have been no help in judging the safety of the vehicle.

Therefore, equivalent safety becomes a general concept rather than the measurable benchmark that has historically been used by regulators granting FMVSS exemptions. The real question is: How well does the vehicle perceive its environment and respond? Or, more broadly, "Can the AV drive itself safely?"

The challenge of determining equivalent safety also highlights the large bureaucratic burden this approach places on NHTSA, which has responsibility for reviewing and granting each application. As noted, exemption applications on safety-related bases are rare, but as AVs mature, the number of FMVSS for which auto manufacturers must request exemptions will grow rapidly. A 2016 report from the John A. Volpe National Transportation System Center, Review of Federal Motor Vehicle Safety Standards (FMVSS) for Automated Vehicles, noted that 32 of the standards (44 percent) present a challenge to vehicle certification as "they contain performance specifications, test procedures, or equipment requirements that present potential barriers to the certification of one or more AV concepts" (Kim et al., 2016). Thirty-three of the standards (45 percent) present a certification challenge because they reference the driver (Kim et al., 2016). As of June 27, 2017, 36 manufacturers applied to test AVs in California (California Department of Transportation, 2017). If even half of these companies apply for FMVSS exemptions, the resultant burden on the companies and NHTSA is unlikely to speed deployment of AVs as legislation appears to intend. Additionally, the 2016 NHTSA letter to Google suggests that petitions for exemptions may only act as a stopgap measure until rulemaking around FMVSS relating to AVs is revised (NHTSA, 2016b). So, the exemption process does not preclude the need to revise FMVSS. At a time when there is intense political emphasis on minimizing bureaucracy and easing barriers to doing business, this legislation may, in practice, move in the opposite direction.

The fundamental difficulty is that FMVSS has nothing to say about the "autonomous" in AV. Indeed, per NHTSA's own statement, most statutes and regulations were developed when AVs were "only a remote notion, (hence) these tools may not be sufficient to ensure that HAVs [highly automated vehicles] are introduced safely and to realize the full safety promise of new technologies … the speed with which HAVs are advancing, combined with the complexity and novelty of these innovations, threatens to outpace the Agency's conventional regulatory process and capabilities" (NHTSA, 2016a). Risk-management efforts, such as FMVSS, that are too deeply led by the past can result in a lack of preparation for the unanticipatable and unknowable (Beck, 2006). The existing exemption process and the requirement of equivalent safety are largely inapplicable to AVs.

A Graduated Approach Balancing Innovation, Risk, and Uncertainty

A new approach may be warranted for this innovative technology. Rather than creating an exemption-based path through the FMVSS, there may be certain advantages to developing a parallel system with oversight centralized in the federal government for allowing any vehicle that can drive itself without human intervention or supervision some or all the time (level 4 or level 5 automation level, as set by the Society of the Automotive Engineers), including vehicles that do comply with FMVSS (International Transport Forum, 2015). Such a parallel system cannot be design-based (as many but not all aspects of the FMVSS currently are)[4] because no one yet knows enough about what makes for successful AV design. Rather, the parallel system should be performance-based: AVs could be allowed on the road when their safety performance has been demonstrated to a standard.

At this time, the only way to prove AVs' safety performance is to drive them in real traffic and observe the number and types of crashes and other dangerous events that occur (Kalra, 2017b; Kalra, 2017a). But the number of miles that would have to be driven to fully prove safety is almost certainly too high to accomplish prior to widespread deployment. Traffic fatalities and injuries are rare events compared with vehicle miles traveled in the current vehicle fleet, and they likely to be even more rare among AVs. Even with aggressive testing, it would take tens and sometimes hundreds of years for existing test fleets to drive the hundreds of millions of miles and sometimes hundreds of billions of miles necessary to demonstrate AV performance prior to releasing them on the roads for consumer use. Such a burden of proof is overcautious and could halt innovation and industry; in the meantime, human drivers may continue to cause avoidable crashes (Teoh and Kidd, 2017; Schoettle and Sivak, 2015; Virginia Tech Transportation Institute, 2016) and harm to people and property (Stirling, 2003). Manufacturers and regulators have finite resources and time, and the opportunity costs of an unwillingness to accept some measure of uncertainty around safety (Eichler et al., 2013) could be measured in lives.

We and others have theorized a graduated approach wherein levels 4 and 5 AVs are allowed on the roads through a set of incremental, performance-based gateways with vehicle caps (Sivak and Schoettle, 2015; Danks and London, 2017; NHTSA, 2016a; Kalra, 2016). Rather than a one-time increase in the ceiling of vehicle sales numbers, this option balances the benefits in terms of encouraging and enabling AV technology by raising the ceiling with the need for more information around how these vehicles function and interact with the U.S. vehicle fleet and varying road environments. In a graduated approach, manufacturers would first provide meaningful evidence of safety for NHTSA's review and certification. The proposed safety assessment certification (House Committee on Energy and Commerce, 2017b) is a useful starting point, but sets of evidence that are more clearly delineated, potentially wider, and possibly independently certified may be needed.

Such evidence could include vehicles overseen by trained drivers in specific locales around the country, with a set number of miles driven without incident in certain conditions, such as in heavy traffic; in varying terrain; in highly urban areas; in pedestrian, motorcyclist, and bicyclist-heavy areas; through rolling hills; and through fog, snow, ice, and rain (Sivak and Schoettle, 2015; NHTSA, 2013; Shen and Neyens, 2017; Anderson et al., 2016; Millard-Ball, 2016). As further or alternative evidence, vehicles may pass certain on-road or track-based tests, pass computer-based simulation tests, or show system performance data gleaned from AV programs running in the background as the vehicle is driven by a human (e.g., Tesla's "shadow mode" testing) (Hull, 2017). Such measures as the number of miles driven before human intervention is requested, or "occurrence of malfunctions, degradations, or failures" (NHTSA, 2016a) would also be informative, although there are no comparable measures for human drivers. There is the additional possibility for performance assessments of specific system elements (e.g., sensor range). A wide range of evidence and outcome measures engenders an inclusive, pluralistic, and, integrated understanding of safety performance and risk assessment (Stirling, 2008;

Stirling, 2003; Renn, 1998; Fischhoff, Watson, and Hope, 1984), allowing the manufacturer to make a case for its product's safety (Smith, 2015). This initial set of requirements provides a baseline or lower safety threshold for commercially available AVs.

Following such initial evidence, a small number of vehicles could be sold or deployed commercially. This initial deployment would be used to further gather data about and demonstrate some additional degree of safety. AV systems are likely to improve in safety and function as they are exposed to more environments due to machine-based learning methods; therefore, regular updating of safety performance data is necessary. Meeting these requirements would not generate sufficient information to measure safety performance, but doing so could be a necessary compromise between fostering innovation (with a lowered burden of proof) and managing risk (with fewer vehicles deployed), allowing time for the public to acclimatize to AV systems, and ensuring that consumers do not act as "beta test(s)" or "human guinea pigs" for the technology (Kelley, 2017).

After safety thresholds are met for a period, the cap could increase. Eventually, the cap would be removed, and while AVs would still be required to meet safety standards of performance, their sale would be permitted without restrictions on quantity or duration and without makers having to apply for exemptions.

This graduated approach raises two key questions that remain unanswered in existing literature for such deployment: What should the performance requirements be, and how many vehicles should be allowed? When viewed in isolation, the answers to both questions seem uncertain and arbitrary. In terms of performance requirements, current human-driver road safety is a reasonable point of comparison. AVs are not expected to eliminate crashes, so outcome metrics of crash reduction could include different types of crash rates (total crashes, fatal crashes, crashes involving injuries, and crashes that result only in property damage), as well as non-crash safety incident rates (e.g., lane departures). Specific weight could be given to crashes involving vulnerable road users, such as pedestrians, bicyclists, and motorcyclists. However, whether AVs should be merely better than the average driver, or much better—or even worse—is a policy question still to be determined (Kalra, 2017b; Kalra, 2017a; Pratt, 2017).

Importantly, there is a link between these two questions: Greater precision in measuring AV safety requires that more vehicles need to be deployed, thereby increasing exposure to risk. (Stirling, 2003). This trade-off between risk and uncertainty is not unique to AVs (Stirling, 2003); it applies to other domains, such as geoengineering or personalized medicine. Within pharmaceutical licensing, drugs face a multistage "discovery and screening phase" undertaken by their creators or sponsors, then a three-stage set of clinical trials, with the number of participants, oversight, and statistical ability to detect effectiveness and side effects in a range of situations and population growing through each stage. Finally, drugs undergo a New Drug Application review to ensure safety and labeling (to confirm necessary information is communicated) before approval (U.S. Food and Drug Administration, undated). This progressive process allows the U.S. Food and Drug Administration to weigh risk tolerance with risk-aversion, balancing uncertainty as to the drug's effectiveness and side effects with risk (and ability to measure the risk) of the drug's effects and side effects (Eichler et al., 2013).

Specific to AVs, if society wants to peg how safe an evolutionary, hard-to-predict technology is, then society may have to accept more exposure-based risk in deploying it to find out (International Risk Governance Center, 2016). Therefore, the answers to both questions could be addressed simultaneously: The desired benchmark can determine how many vehicles should be deployed—or, conversely, the number of vehicles one wishes to deploy can inform the benchmark.

This relationship between risk and uncertainty can be expressed mathematically. Figure 1 is from Kalra and Paddock (2016). It shows the number of miles that would need to be driven (vertical axis) to detect a particular difference in safety performance measures between human drivers and AVs (horizontal axis). The difference can be measured in terms of crashes, injuries, and fatalities. The smaller the difference in human and AV safety, the more miles needed to detect that difference. Moreover, the rarer the event, the more miles needed to detect that difference.

Figure 1 shows, for example, that a high risk would have to be accepted to detect modest improvements in AV fatality rates over human driver fatality rates. Indicators of 20-percent improvement in fatalities would require 5 billion miles of driving, a distance that would take hundreds of years to drive in premarket on-road testing.

This relationship can inform the question of benchmarks and numbers of vehicles. Suppose, for example, that the first cap permitted 5,000 vehicles. If these vehicles drive 12,000 miles each in the first year (the average for a privately owned vehicle) (Deaton and Winebrake, 2000; Greenblatt and Saxena, 2015), the fleet will have driven a total of 60 million miles in the first year. This would be sufficient to determine whether the AV fleet is at least 10 percent safer than human drivers in terms of crashes, and at least 15 percent safer in terms of injuries. Because fatalities are rare, one would have to wait until the next cap to assess whether fatal injury rates were affected, unless AV system performance is extreme (either much safer or much less safe than human drivers).

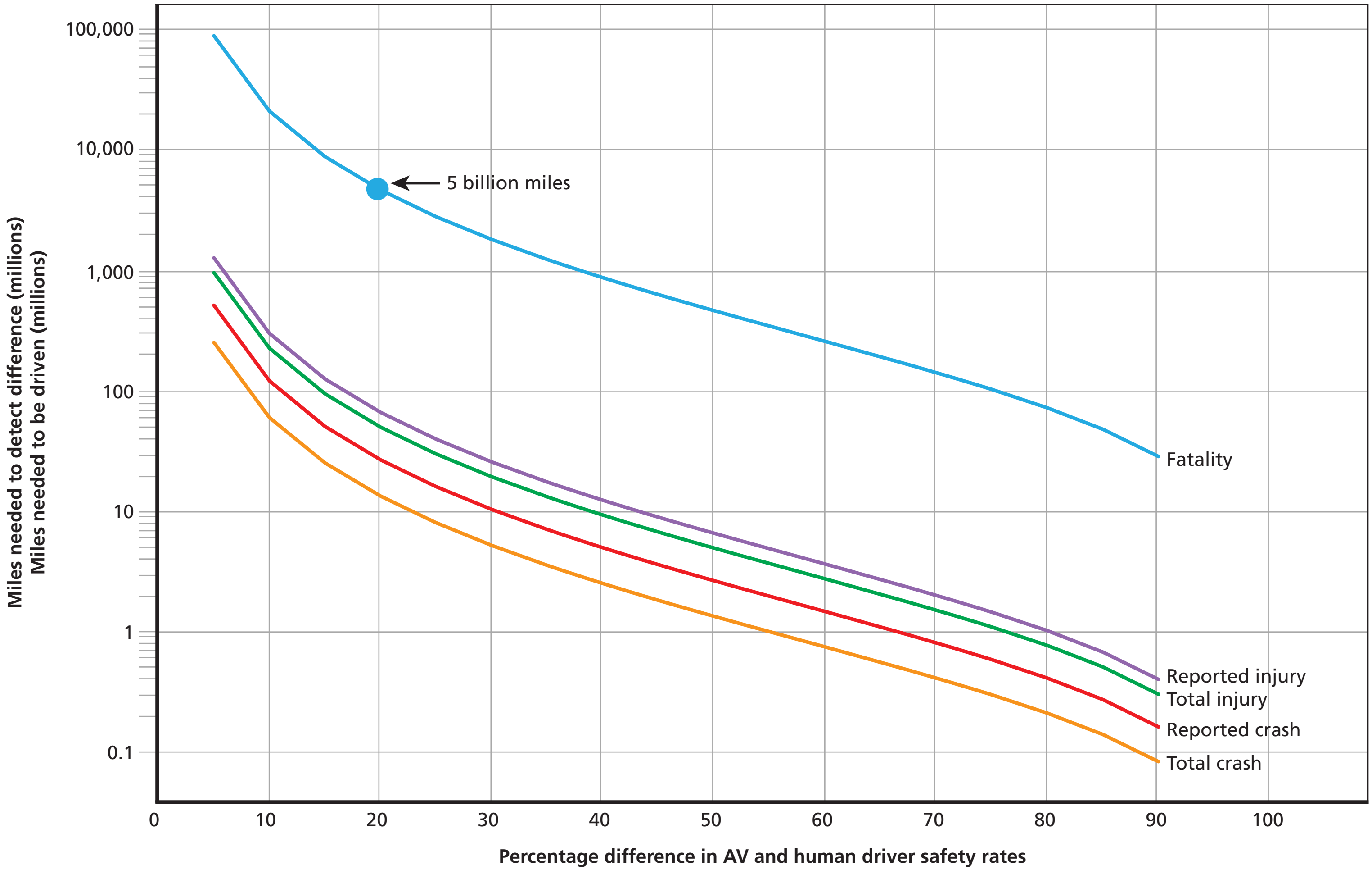
Suppose, for example, that the first cap instead permits 20,000 vehicles, perhaps because the tolerance for uncertainty is less or the appetite for risk is greater. At 12,000 miles per year, the fleet would drive 240 million miles in its first year. That is enough to detect almost any difference in safety in terms of crashes and injuries, and to detect a difference in fatalities above 55 percent. Alternatively, this might form the basis of the second gate, after the fleet of 5,000 vehicles meets the first performance thresholds. The caps could continue upward to, for example, 50,000 vehicles, then 100,000, and then without a ceiling. By tying vehicle sales caps to performance limits rather than years, we can use implementation to more fully understand AV system function and incentivize safety performance while limiting exposure.

A Policy Discussion

The numbers in the previous sections are for illustration—they are not meant to represent a specific policy recommendation. Nor is Figure 1 meant to represent forecasting of the relationships among crash fatalities, injuries, and all crashes in AVs compared with human-driven vehicles. Rather, with Figure 1, we explain an approach that has several advantages over the current alternative of existing FMVSS exemptions. First, by generating a separate set of rules, which NHTSA already acknowledges is needed (NHTSA, 2016b), the federal government can avoid spending resources on reviewing and monitoring an ongoing cycle of design-based exemption petitions.

Second, the approach is evidence-based in its design, and designed to generate new evidence. This is consistent with practices

Figure 1. Miles Needed to Demonstrate AV System Improvement in Safety Rates Compared with Human Drivers



NOTE: This figure shows the variation between AV and human driver safety rate measures along the horizontal access. The comparison can be made across a variety of outcomes, including fatalities (blue), reported injuries (purple), estimated total injuries (green), reported crashes (red), and estimated total crashes (orange) (Kalra and Paddock, 2016). Because AVs may not underreport crashes (Kalra and Paddock, 2016) and have lower reporting thresholds (NHTSA, 2016a), comparisons with reported total injuries and crashes caused by human drivers may be conservative.

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of adaptive regulation that may be a best practice in regulating uncertain technology (International Risk Governance Center, 2016).

Third, this approach applies equally well to business models that provide AVs as a service (e.g., autonomous Ubers and Lyfts) rather than for sale for personal ownership. In this case, the exposure is defined as the number of miles that can be driven (which is a more precise measure than the number of vehicles sold). Overall, this approach balances the lack of knowledge regarding the performance of new, innovative technology with exposure to this technology, while also fostering innovation.

This graduated approach does not eliminate all the complexities in regulating AV safety. Developers, for example, may limit AVs to a particular geography, usage (e.g., rideshares), climate, speed, or other constraint. Evaluating performance requires having data for human drivers in the same constrained contexts. Collection and management of performance data for human-driven vehicles may have to improve to generate comparisons with AVs.

Effectively communicating limitations of the AV system to consumers will be an ongoing challenge. Current legislation from the House proposes ongoing research on this issue (House Committee on Energy and Commerce, 2017b). Concurrently, NHTSA must balance protecting confidential business data with disseminating safety data, including data on design, validation, testing, cybersecurity, and crashes to a variety of audiences, including the general public, researchers, and watchdog groups. Making such data available and accessible may speed up safety development and public acceptance.

Additionally, evidence of safety and crossing safety thresholds should not be construed as a liability waiver for either the driver or the manufacturer. For example, the legislation reported out of the House of Representatives Energy and Commerce Committee in July 2017 states that compliance with safety standards "does not exempt a person from liability at common law" (House Committee on Energy and Commerce, 2017a).

Also, developers are expected to update AV software regularly remotely (Nelson, 2017; Taub, 2016), and rapid improvement is one of the promises of the technology (Kalra and Paddock, 2016; Anderson et al., 2016). Yet improvement from an upgrade is not guaranteed—as everyone has experienced with cell phones and computer software updates, some changes make technology worse. The existing FMVSS exemption process might require an exemption revision or reapplication each time a change is made, adding to the bureaucratic burden for both industry and regulators. In the proposed alternative, a statistical method would need to be developed that defines how data collected before and after an upgrade can be combined to reflect an overall and statistically sound safety measure.

A last concern arises if a fleet performs worse than the benchmark at a given gate. Under traditional exemptions, renewal requests may be denied (e.g., NHTSA's denial of Mercedes Benz's application to continue its headlight research) (NHTSA, 2010). However, with potentially hundreds of thousands of exempt vehicles on the road, regulators may face the proverbial situation of trying to close the barn door once the horse has bolted. The proposed alternative provides a built-in safeguard: multiple, well-designed barn doors. In extreme situations, NHTSA could consider a vehicle recall, a process made easier when the number of vehicles is limited.

Conclusion

Early reports of the safety benefits of AV technology are highly encouraging, but the benefits are not yet proven and may not be known until there is widespread deployment (Teoh and Kidd, 2017; Schoettle and Sivak, 2015; Virginia Tech Transportation Institute, 2016). History is littered with the ways technology performance has surprised us, from the realization in the 1990s that frontal airbag deployments were causing infant fatalities (Wetmore, 2008) to the recent fatal Tesla Autopilot crash resulting from an unforeseen technical glitch in conjunction with user error (NHTSA, undated). Because the road environment and connections between crashes, causes, and outcomes are so complicated (Reason, 2000), it is not possible to fully anticipate AV safety (Beck, 2006). Road safety policy can acknowledge and find comfort with this unknown (Beck, 2006) by balancing uncertainty over crash risk with bounded exposure to this risk (Office of the Best Practice Regulation, 2016).

Unlike the majority of revolutionary innovations that go through existing structures (e.g., birth control pills and the Food and Drug Administration) or incite the need for regulation after their introduction (e.g., Uber and taxi regulation [Wyman, 2017]), FMVSS must be revised before AVs can even enter the marketplace. Effective revisions square support for innovation with the need for knowledge and protection of all road users. Federal agencies have a long history of being encouraged to evolve existent rules based on current impact (McCray, Oye, and Petersen, 2010; NHTSA, undated). Now, these rules must evolve to support future innovation while safeguarding against undesirable consequences.

We believe that the existing FMVSS exemption policy and proposed modifications do not adequately strike this balance, may be burdensome for government and manufacturers, and leave few tools with which to manage the uncertain risks of AVs. Moreover, attempting to rejigger and reapply current standards to accommodate this revolution is like attempting to apply rules of safe horsemanship (M******, 1842) to the Ford Model T. An alternative regulatory set of evolving standards specifically engineered around AVs, with introduction to the vehicle fleet organized around a graduated approach based on the measured impact on public safety, may be far more promising.

Notes

[1] A request around FMVSS 121, Air Brake Systems, was denied (NHTSA, 2006b), as was a request for exemption for FMVSS 111, Rearview Mirrors (U.S. Department of Transportation, Federal Motor Carrier Safety Administration, 2015). A request for exemption from FMVSS 108, Lamps, Reflective Devices, and Associated Equipment was accepted (NHTSA, 2006a), but the renewal was denied (NHTSA, 2010). Four exemptions, including two renewals, were granted around FMVSS 122, Motorcycle Systems (NHTSA, 1997; NHTSA, 1998; NHTSA, 1999; NHTSA, 2001).

[2] Eighteen companies each selling 100,000 vehicles each constitutes 0.75 percent of the total 240,155,238 passenger vehicles registered in 2014 (Bureau of Transportation Statistics, 2017).

[3] This includes Mercedes Benz's 2006 exemption from FMVSS 108, Lamps, Reflective Devices, and Associated Equipment, to investigate light technology (NHTSA, 2006a).

[4] FMVSS may also include test-performance requirements, e.g., FMVSS 208, Occupant Crash Protection's Criteria Around Vehicle Protection in Crash Tests (U.S. Department of Transportation, 2013).

References

Anderson, James M., Nidhi Kalra, Karlyn Stanley, Paul Sorensen, Constantine Samaras, and Oluwatobi A. Oluwatola, *Autonomous Vehicle Technology: A Guide for Policymakers*, Santa Monica, Calif.: RAND Corporation, RR-443-2-RC, 2016. As of September 6, 2017:
https://www.rand.org/pubs/research_reports/RR443-2.html

Beck, Ulrich, "Living in the World Risk Society," *Economy and Society*, Vol. 35, No. 3, 2006, pp. 329–346. As of September 6, 2017:
http://www.tandfonline.com/doi/abs/10.1080/03085140600844902

Bureau of Transportation Statistics, *2017 Pocket Guide to Transportation*, Washington, D.C.: U.S. Department of Transportation, May 2017. As of September 6, 2017:
https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/bts-publications/202411/pocketguide2017revised.pdf

California Department of Transportation, "Application Requirements for Autonomous Vehicle Tester Program," last updated September 1, 2017. As of September 6, 2017:
https://www.dmv.ca.gov/portal/dmv/?1dmy&urile=wcm:path:/dmv_content_en/dmv/vehindustry/ol/auton_veh_tester

Danks, David, and Alex John London, "Regulating Autonomous Systems: Beyond Standards," *IEEE Intelligent Systems*, Vol. 32, No. 1, January-February 2017, pp. 88–91.

Deaton, Michael L., and James J. Winebrake, *Dynamic Modeling of Environmental Systems*, New York: Springer, 2000.

Eichler, Hans-Georg, Brigitte Bloechl-Daum, Daniel Brasseur, Alasdair Breckenridge, Hubert Leufkens, June Raine, Tomas Salmonson, Christian K. Schneider, and Guido Rasi, "The Risks of Risk Aversion in Drug Regulation," *Nature Reviews Drug Discovery*, Vol. 12, No. 12, 2013, pp. 907–916.

Fischhoff, Baruch, Stephen R. Watson, and Chris Hope, "Defining Risk," *Policy Sciences*, Vol. 17, No. 2, October 1984, pp. 123–139.

Greenblatt, Jeffery B., and Samveg Saxena, "Autonomous Taxis Could Greatly Reduce Greenhouse-Gas Emissions of U.S. Light-Duty Vehicles," *Nature Climate Change*, Vol. 5, September 2015, pp. 860–863.

House Committee on Energy and Commerce, "Amendment in the Nature of a Substitute to H.R. 3388," U.S. Congress, 115th Congress, 1st Session, Washington, D.C., July 2017a. As of September 6, 2017:
http://docs.house.gov/meetings/IF/IF00/20170727/106347/BILLS-115-HR3388-L000566-Amdt-9.pdf

House Committee on Energy and Commerce, "Safely Ensuring Lives Future Deployment and Research In Vehicle Evolution Act (H.R. 3388)," U.S. Congress, 115th Congress, 1st Session, Washington, D.C., September 6, 2017b. As of September 11, 2017:
https://www.gpo.gov/fdsys/pkg/BILLS-115hr3388eh/pdf/BILLS-115hr3388eh.pdf

Hull, Dana, "The Tesla Advantage: 1.3 Billion Miles of Data," Bloomberg, December 20, 2017.

International Risk Governance Center, "Conference Report: Planning Adaptive Risk Regulation," London: University College London, January 2016.

International Transport Forum, *Automated and Autonomous Driving Regulation Under Uncertainty*, Paris, April 30, 2015. As of September 6, 2017:
https://www.itf-oecd.org/automated-and-autonomous-driving

Kalra, Nidhi, *Shaping the Future of Autonomous Vehicles: How Policymakers Can Promote Safety, Mobility, and Efficiency in an Uncertain World*, Santa Monica, Calif.: RAND Corporation, CT-459, 2016. As of August 22, 2017: https://www.rand.org/pubs/testimonies/CT459.html

———, C*hallenges and Approaches to Realizing Autonomous Vehicle Safety*, Santa Monica, Calif.: RAND Corporation, CT-463, 2017a. As of August 22, 2017: https://www.rand.org/pubs/testimonies/CT463.html

———, *Challenges and Approaches to Realizing Autonomous Vehicle Safety and Mobility Benefits*, Santa Monica, Calif.: RAND Corporation, CT-475, 2017b. As of August 22, 2017: https://www.rand.org/pubs/testimonies/CT475.html

Kalra, Nidhi, and Susan M. Paddock, *Driving to Safety: How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?* Santa Monica, Calif.: RAND Corporation, RR-1478-RC, 2016. As of September 06, 2017: https://www.rand.org/pubs/research_reports/RR1478.html

Kelley, Ben, "Public Health, Autonomous Automobiles, and the Rush to Market," *Journal of Public Health Policy*, Vol. 38, No. 2, January 2017, pp. 167–184.

Kim, Anita, David Perlman, Dan Bogard, and Ryan Harrington, *Review of Federal Motor Vehicle Safety Standards (FMVSS) for Automated Vehicles Preliminary Report*, Cambridge, Mass.: U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, March 2016.

M******, Captain, *The Handbook of Horsemanship*, London: Printed for Thomas Tegg, No. 73, 1842.

McCray, Lawrence E., Kenneth A. Oye, and Arthur C. Petersen, "Planned Adaptation in Risk Regulation: An Initial Survey of U.S. Environmental, Health, and Safety Regulation," *Technological Forecasting & Social Change*, Vol. 77, No. 6, July 2010, pp. 951–959. As of September 6, 2017: http://www.sciencedirect.com/science/article/pii/S0040162509001942

Millard-Ball, Adam, "Pedestrians, Autonomous Vehicles, and Cities," *Journal of Planning Education and Research*, October 27, 2016. As of September 6, 2017: http://journals.sagepub.com/doi/abs/10.1177/0739456X16675674?journalCode=jpea

National Highway Traffic Safety Administration, "Timeline of Federal Motor Vehicle Safety Standards," Washington, D.C., U.S. Department of Transportation, undated. As of September 11, 2017: https://www.nhtsa.gov/staticfiles/communications/pdf/Lives-Saved-Tech-Timeline.pdf

———, "American Honda Motor Company, Inc., Grant of Application for Temporary Exemption from Federal Motor Vehicle Safety Standard No. 122," *Federal Register*, Vol. 62, No. 194, October 1997. As of September 6, 2017: https://www.gpo.gov/fdsys/pkg/FR-1997-10-07/pdf/97-26491.pdf

———, "American Honda Motor Company, Inc.; Grant of Renewal of Temporary Exemption from Federal Motor Vehicle Safety Standard No. 122," *Federal Register*, Vol. 63, No. 227, November 1998. As of September 6, 2017: https://www.gpo.gov/fdsys/pkg/FR-1998-11-25/pdf/98-31534.pdf

———, "American Honda Motor Company, Inc.; Grant of Application for Second Renewal of Temporary Exemption from Federal Motor Vehicle Safety Standard No. 122," *Federal Register*, Vol. 64, No. 156, 1999. As of September 6, 2017: https://www.gpo.gov/fdsys/pkg/FR-1999-08-13/pdf/99-20961.pdf

———, "Honda Motor Company, Ltd: Grant of Application of Temporary Exemption from Federal Motor Vehicle Safety Standard No. 122," *Federal Register*, Vol. 66, No. 7, 2001. As of September 6, 2017: https://www.gpo.gov/fdsys/pkg/FR-2001-01-10/html/01-699.htm

———, "Grant of Applications of Three Motorcycle Manufacturers for Temporary Exemptions and Renewal of Temporary Exemptions from Federal Motor Vehicle Safety Standard No. 123," *Federal Register*, Vol. 69, No. 196, October 2004.

———, "Mercedes-Benz, U.S.A. LLC; Grant of Application for a Temporary Exemption from Federal Motor Vehicle Safety Standard No. 108," *Federal Register*, Vol. 71, No. 19, January 2006a. As of September 6, 2017: https://www.federalregister.gov/documents/2006/01/30/E6-1079/mercedes-benz-usa-llc-grant-of-application-for-a-temporary-exemption-from-federal-motor-vehicle

———, "InterModal Technologies, Inc.; Denial of Petition for a Temporary Exemption from Federal Motor Vehicle Safety Standard No. 121," *Federal Register*, Vol. 71, No. 29, February 2006b. As of September 6, 2017: https://www.federalregister.gov/documents/2006/02/13/E6-2001/intermodal-technologies-inc-denial-of-petition-for-a-temporary-exemption-from-federal-motor-vehicle

———, "Mercedes-Benz, U.S.A. LLC; Denial of Application for Renewal of Temporary Exemption from Federal Motor Vehicle Safety Standard No. 108," *Federal Register*, Vol. 75, No. 98, May 2010. As of September 6, 2017: https://www.gpo.gov/fdsys/pkg/FR-2010-05-21/pdf/2010-12190.pdf

———, "Quick Reference Guide (2010 Version) to Federal Motor Vehicle Safety Standards and Regulations," Washington, D.C., U.S. Department of Transportation, February 2011. As of September 6, 2017: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/fmvss-quickrefguide-hs811439.pdf

———, “National Highway Traffic Safety Administration Preliminary Statement of Policy Concerning Automated Vehicles,” Washington, D.C., U.S. Department of Transportation, 2013.

———, “Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety,” Washington, D.C., U.S. Department of Transportation, 2016a.

———, “Letter to Chris Urmson, Director, Self-Driving Car Project,” Washington, D.C., U.S. Department of Transportation, 2016b.

Nelson, Gabe, “Over-the-Air Updates on Varied Paths,” *Automotive News*, January 25, 2017.

NHTSA—*See* National Highway Traffic Safety Administration.

Office of the Best Practice Regulation, “Risk Analysis in Regulation Impact Statements,” Australian Government, Department of the Prime Minister and Cabinet, February 2016. As of September 6, 2017: https://www.pmc.gov.au/resource-centre/regulation/risk-analysis-regulation-impact-statements-guidance-note

Pratt, Gill, “Statement of Gill Pratt, CEO, Toyota Research Institute, on ‘Self-Driving Cars: Road to Deployment’ before the U.S. House of Representatives Committee on Energy & Commerce Subcommittee on Digital Commerce and Consumer Protection,” Washington, D.C., February 14, 2017. As of September 6, 2017: http://docs.house.gov/meetings/IF/IF17/20170214/105548/HHRG-115-IF17-Wstate-PrattG-20170214.pdf

Reason, James, “Human Error: Models and Management,” *British Medical Journal*, Vol. 320, March 2000, pp. 4–6.

Renn, Ortwin, “Three Decades of Risk Research: Accomplishments and New Challenges,” *Journal of Risk Research*, Vol. 1, No. 1, 1998, pp. 49–71.

Schoettle, Brandon, and Michael Sivak, *A Preliminary Analysis of Real-World Crashes Involving Self-Driving Vehicles*, University of Michigan Transportation Research Institute, 2015. As of September 6, 2017: http://umich.edu/~umtriswt/PDF/UMTRI-2015-34.pdf

Shen, Sijun, and David M. Neyens, “Assessing Drivers’ Response During Automated Driver Support System Failures with Non-Driving Tasks,” *Journal of Safety Research*, Vol. 61, 2017, pp. 149–155.

Sivak, Michael, and Brandon Schoettle, *Should We Require Licensing Tests and Graduated Licensing for Self-Driving Vehicles?* University of Michigan Transportation Research Institute, October 2015. As of September 6, 2017: http://umich.edu/~umtriswt/PDF/UMTRI-2015-33.pdf

Smith, Bryant Walker, “Regulation and the Risk of Inaction,” in Markus Maurer, J. Christian Gerdes, Barbara Lenz, and Hermann Winner, eds., *Autonomous Driving*, New York: SpringerOpen, 2015, pp. 571–587.

Stirling, Andy, “Risk, Uncertainty and Precaution: Some Instrumental Implications from the Social Sciences,” in F. Berkhout, M. Leach and I. Scoones, eds., *Negotiating Change: New Perspectives from the Social Sciences*, United Kingdom: University of Sussex, 2003.

———, “‘Opening Up’ and ‘Closing Down,’” *Science, Technology, and Human Values*, Vol. 33, No. 2, 2008, pp. 262–294.

Taub, Eric A., “Your Car’s New Software Is Ready. Update Now?” *New York Times*, September 8, 2016.

Teoh, Eric R., and David G. Kidd, “Rage Against the Machine? Google’s Self-Driving Cars Versus Human Drivers (in Draft),” Insurance Institute for Highway Safety, April 2017.

U.S. Department of Transportation, “Motor Vehicle Safety Title 49, United States Code, Chapter 301 and Related Uncodified Provisions Administered by the National Highway Traffic Safety Administration,” Washington, D.C., May 2013. As of September 6, 2017: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/motor_vehicle_safety_unrelated_uncodified_provisions_may2013.pdf

U.S. Department of Transportation, Federal Motor Carrier Safety Administration, “Parts and Accessories Necessary for Safe Operation; Denial of an Exemption Application from Atwood Forest Products,” *Federal Register*, Vol. 80, No. 234, December 7, 2015. As of September 6, 2017: https://www.gpo.gov/fdsys/pkg/FR-2015-12-07/pdf/2015-30803.pdf

U.S. Food and Drug Administration, “Drug Approval Process,” undated. As of September 6, 2017: https://www.fda.gov/downloads/drugs/resourcesforyou/consumers/ucm284393.pdf

Virginia Tech Transportation Institute, “Automated Vehicle Crash Rate Comparison Using Naturalistic Data,” January 8, 2016. As of September 6, 2017: http://www.vtti.vt.edu/featured/?p=422

Wetmore, Jameson M., “Engineering with Uncertainty: Monitoring Air Bag Performance,” *Science and Engineering Ethics*, Vol. 14, No. 2, 2008, pp. 201–218.

Wyman, Katrina M., “Taxi Regulation in the Age of Uber,” *New York University Journal of Legislation and Public Policy*, Vol. 2, No. 1, 2017, pp. 1–100.

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About This Perspective

RAND has a long history of objective, evidence-based research examining how society can harness the benefits and manage the risks of intelligent, transformative technologies. RAND's work on autonomous vehicles builds on this firm foundation. The flagship report, *Autonomous Vehicle Technology: A Guide for Policymakers*, published in 2014 (and revised in 2016) and the subsequent *Driving to Safety: How Many Miles of Driving Would It Take to Demonstrate Autonomous Vehicle Reliability?* in 2016 examined the policy landscape and safety concerns surrounding these technologies.

As the technology nears commercial deployment, policymakers face pressing questions about encouraging the technology while minimizing its potential safety risks. This Perspective directly informs this policy issue by contributing to the debate around how Federal Motor Vehicle Safety Standards processes should be shaped to accommodate autonomous vehicles.

During the development of this Perspective and at the time of publication, Nidhi Kalra's spouse, David Ferguson, served as co-founder and president of Nuro, a machine learning and robotics start-up engaged in autonomous vehicle development. He previously served as a principal engineer for Google's driverless car project. Neither her spouse nor the companies he has worked for had any influence on this work.

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