# Competing Notions of Autonomous Vehicle Safety

An STS Research Paper
presented to the faculty of the
School of Engineering and Applied Science
University of Virginia

by

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March 27, 2020

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**Competing Notions of Autonomous Vehicle Safety**

On March 18, 2018, Elaine Herzberg was struck and killed by a self-driving car being tested by Uber, becoming the first fatality of the technology. Five days later, Walter Huang was killed when his semi-autonomous Tesla left its lane and crashed into a highway barrier. Uber grounded their vehicles to investigate, while Tesla adjusted their driver monitoring (Siddiqui & Laris, 2018; Laris, 2020). The National Transportation Safety Board (NTSB) investigated these crashes and recommended policies, however neither Congress nor the U.S. Department of Transportation (DOT) mandated regulations.

These tragedies are dwarfed by the 36,558 other United States roadway deaths in 2018, many of which caused by human error (NHTSA, 2019). Proponents anticipate autonomous vehicles (AVs) will prevent many, if not most, road fatalities. Many are skeptical of this promise, including pedestrians, other road users, and some technical researchers. With many lives at stake, it is crucial to understand why groups disagree about the safety implications of AVs. A difference in technical knowledge plays a role, however it does not fully explain the different perspectives. Groups disagree because they must reconcile their notions of safety with varying ideas towards rapid development and user convenience. Skeptics are often more cautious due to mistrust toward developers and regulators.

SAE International (2018) has defined five levels of driving automation. An important cutoff is from Level 2, where the driver must remain normally attentive, to Level 3, where the driver is only needed when notified. Level 2 systems, such as Tesla's Autopilot or Cadillac's Super Cruise, are often called partially autonomous or advanced driver-assistance systems (ADAS). These Level 2 systems will be examined as forms of automation; however, they are usually not included in the term autonomous vehicles (AVs).

**Review of Research**

Social and psychological factors significantly influence roadway safety. Peltzman (1975) found that mandates requiring safety devices on vehicles have not reduced highway deaths. The regulations are offset by market demand for safety and driver behaviors, possibly causing fewer driver deaths in exchange for more nonfatal injuries and pedestrian deaths. Norton (2007) found that early twentieth century social campaigns against “jaywalkers,” in conjunction with the physical imposition of automobiles, secured the street for automobiles and shifted blame for accidents to pedestrians.

The deployment of AVs comes with uncertainty and risk. Rowe (1994) proposed four classes of uncertainty: temporal, in future or past states; structural, in complexity; metrical, in measurement; and translational, in explaining uncertainty. Structural and metrical uncertainty contribute to temporal uncertainty, such as in AV safety. Translational uncertainty affects the communication and mitigation of risk, due to differing perspectives and agendas. Geenhuizen & Nijkamp (2003) claim this uncertainty may cause over-optimistic predictions, such when forecasting an infrastructure project’s costs and traffic effects (Skamris & Flyvbjerg, 1996). “Technology watchers,” analyzing technology and stakeholder perspectives, or innovating in an experimental niche, may reduce this uncertainty and inform policy (Geenhuizen & Nijkamp, 2003).

The nature of a risk affects how one responds to it. Slovic (1987) found public risk perception is highest for risks that are harder to observe and dreadful or uncontrollable. Such outcomes are seen as signals for worse to come. Starr (1969) found the public accepts voluntary risks that are about 1000 times more dangerous than involuntary risks, and acceptability of a risk is directly related to awareness of the benefits.

An individual's response to risk is closely related to their personal relationship to the risk. Sjöberg (2000) found that risk perception depends on attitude (i.e. beliefs and values), risk sensitivity, and specific fear towards the risk. One's feelings towards a risk can conflate high benefits with low risks, or low benefits with high risks (Slovic & Peters, 2006). Otway & Von Winterfeldt (1982) contend social acceptability depends on more than an "objective" acceptable risk level, but also on trust in expert authority and social context of the risk. Wilde (1982) contends people compare their perceived risk level to a target risk level, adjusting behavior until they match. People offset the improvements of safety innovations by taking more risks for other benefits (e.g. mobility), and only "motivational" changes in target risk can affect safety. A group's agenda and vulnerability may explain differences in how safe they perceive AVs to be.

Different groups appraise new technologies based on different heuristics. Scheufele & Lewenstein (2005) found the public forms opinions of innovations regardless of technical or policy knowledge, and thus often within framings supplied by the media. When researchers propose regulations, Corley et al. (2009) found they prioritize risks over benefits, and are prone to political and economic biases. Rayner (2004) found that proponents often acclaim innovations as revolutionary, then retreat in response to public criticism.

People interacting with automation show biases. Dietvorst, Simmons, & Massey (2014) found people are less confident in algorithms than humans after observing the algorithm perform, even if it performs better than the human. However, slight control over the algorithm's outputs increases trust (Dietvorst, Simmons, & Massey, 2016). Parasuraman & Manzey (2010) found people trusting automation too much causes poor attention allocation, complacency, and bias when monitoring the automation. Bonnefon et al. (2016) found people prefer AVs that make decisions to minimize total deaths, even if sacrificing their passengers. However, people would rather purchase AVs that prioritize the passengers' lives over others (Bonnefon et al., 2016).

## Visions of Safety

AV developers advertise the systems' safety in a misleading or exaggerated manner. In its mission, Google's Waymo cites, "2 out of 3 people will be involved in a drunk driving crash," before claiming "94% of crashes involve human choice or error in the US" (Waymo, 2020). Waymo conflates drunk-driving as the most significant cause of crashes, although it is a less significant (albeit still troublesome) fraction of from 6.4% to 28% of crashes (Dingus et al., 2016; U.S. DOT, 2018). GM asks the reader to "imagine a world with no car crashes," before citing the same "94% of crashes" statistic (GM, 2020). In their guiding document "Autonomous Vehicles 3.0," the U.S. Department of Transportation (DOT) attributed the statistic to "impaired driving, distraction, and speeding" (U.S. DOT, 2018). However, the original National Highway Traffic Safety Administration (NHTSA) report attributed the 94% of crashes to those that weren't a strictly mechanical or environmental issue. The report also warned the statistic was "not intended to be interpreted as the cause of the crash nor as the assignment of the fault to the driver" (Singh, 2015). The uncritical use of this statistic implies once the human is taken out of "human choice or error," there will be a 94% reduction of crashes.

AV researchers are more cautious than manufacturers when discussing safety, although they are still optimistic. Phil Koopman believes AVs can reduce crash deaths closer to in half, although even less in the short term due to AVs making different errors than people and deployment being limited to cities (Koopman, 2018b; Casualty Actuarial Society, 2014). Thomas Winkle (2016) claims that to make useful predictions of safety improvements, researchers need a sophisticated model based on crash data, with assumptions about an AV's performance and deficiencies.

Researcher's apprehensions are often from concerns that some problems cannot be solved in the near term. Koopman (2018a) claims AVs are just as prone to "human" errors in perception and decision-making in ambiguous situations. Lex Fridman entertains that AVs may need a theory of mind, treating other drivers and pedestrians as agents, before human-level interactions are achieved (Fridman, 2020). Researchers do not have a clear or standardized way to prove the safety of AVs (Koopman & Wagner, 2016). One metric required for California's safety report is "disengagements," or how often a human overrides the system. However, researchers view disengagements as an inaccurate indicator of safety and detrimental to improvement (Vogt, 2020; Marshall, 2018). The gap between testing, production, and regulation makes safe deployment difficult (Palanisamy & Miailhe, 2017).

AV proponents believe being too cautious with safety is counterproductive, since an imperfect AV can still be safer than human drivers and save lives overall. Elon Musk claims it would be "morally reprehensible to delay release" of partial automation since it is safer than humans in its operational domain, and has gone further to say "If […] you effectively dissuade people from using autonomous vehicles, you're killing people" (Musk, 2016; Batuik, 2016) Rodney Brooks, a robotics and AI researcher, predicts, "we will delay adopting levels 4 and 5 autonomy, at the cost of more overall lives lost, rather than have autonomous driving systems cause many deaths at all" (Brooks, 2017). AV enthusiasts similarly claim "should we put off saving 99.5% of lives to fight over these differences," and "self driving cars killing people won't be making things worse […] with a future potential of improving beyond status quo" (trex005, 2018; td__30, 2018). RAND Corporation predicts that manufacturers deploying AVs at a 10%

improvement in safety over humans would save more lives than waiting for 75% or 90% improvements in almost all scenarios; they acknowledge such a utilitarian view must be balanced by social factors (Kalra & Groves, 2017).

Developers' target level of automation affects their safety assurances. Waymo, Uber, and Nvidia, none of whom are in the conventional car market, have thorough safety reports discussing their approaches to safe development (Waymo, 2018; Uber ATG, 2018; Nvidia, 2018). General Motor's Cruise, also attempting to develop full autonomy, has a similarly detailed report (GM, 2018). Tesla's safety report is more understated: assuring their vehicles and systems are better than average, but not discussing their principles (Tesla, 2020b). This may reflective of Tesla's gradual implementation of automation of the road; their crash statistics indicate this, graded by level of driver assistance with Autopilot at the top. Many manufacturers have driver assistance systems, such as collision avoidance and lane-departure warnings, in their new models. Toyota has such a system with "Safety Sense," and is developing a driver-assisting autonomous system in "Guardian," however does not have a safety report for either (Toyota, 2020; Toyota Newsroom, 2019). As the technology becomes less disruptive, developers make fewer safety assurances.

**Convenience**

Developers selling automated systems often advertise convenience ahead of safety. On its Autopilot page, Tesla advertises self-parking and self-navigating before safety (Tesla, 2020a). Cadillac's Super Cruise advertises the "ease and convenience of hands-free driving," mentioning safety only as a disclaimer (Cadillac, 2020). Developers not directly selling AVs, however, emphasize safety. GM's self-driving car page almost exclusively focuses on safety (GM, 2020).

Uber’s Advanced Technology Group’s page features safety and the technology (Uber, 2020). Automated driving systems are generally limited to luxury cars, such as Tesla’s Model 3 and Cadillac’s CT6, which may explain the advertising.

Consumers tend to value convenience and safety similarly, depending on the framing. Nielsen and Haustein (2018) found that AV enthusiasts anticipate safety benefit and relaxation opportunities similarly, while neutral or skeptical people anticipate relaxation significantly more than safety improvements. König and Neumayr (2017) found time and relaxation are larger perceived benefits of AVs, but safety concerns are similarly significant. Expected safety is the greatest predictor of use for AVs (Zmud, Sener, & Wagner, 2016). Safety is a prerequisite for use, but convenience is often more anticipated.

AV developers make tradeoffs between convenience and safety, as is evident in driver monitoring. Current systems monitor the driver’s attention, since Level 2 automation requires driver vigilance to take control at any point. To monitor drivers, Tesla’s Autopilot senses steering wheel pressure, and Cadillac’s Super Cruise tracks eye movement.

Tesla negotiates safety features with user experience. A Tesla spokesperson said, “we make decisions based on what will improve safety and provide the best customer experience, not for any other reason” (Higgins, 2018). In two Autopilot crashes, the National Transportation Safety Board (NTSB) found drivers placed their hands on the wheel only to stop system warnings; the Board determined the system does not ensure attention (NTSB, 2017; NTSB, 2019a). Tesla has increased warning frequency, particularly after crashes, but has not introduced new monitoring features (Lambert, 2016). According to the Higgins (2018), Tesla rejected eye-tracking, fearing it "would annoy drivers with overly sensitive sensors.” CEO Elon Musk says eye-tracking was rejected as ineffective, and that Tesla's high safety record makes these criticisms a moot point (Musk, 2018).

Drivers often agree monitoring is annoying. Some Tesla drivers call the monitoring system the "Nanny Nag," an intrusive detraction from driving (mark.grablin, 2018; Redmiata98, 2018). Some drivers bypass the systems, such as by jamming an orange or custom phone-holder against the wheel's pressure sensor (Lindeman, 2018; Autopilot Buddy, 2020). One Super Cruise user described the eye-tracking as "effective – albeit annoying" (Lambert, 2018). When drivers' annoyance leads them to bypass the system, it degrades safety, but such systems may be only moderately effective anyway. Seat belt reminder systems modestly increase compliance by 3-5%, with the least increases among those who disapprove of the system (Williams & Wells, 2003; NHTSA, 2007).

## Safety Regulations

Federal regulation of self-driving cars is minimal. The U.S. Department of Transportation (DOT) and National Highway Traffic Safety Administration (NHTSA) promote continuity and modernization of existing car regulations (King, 2019; Szabat, 2019). The groups promote innovation through largely voluntary safety guidance, as in "Autonomous Vehicles 4.0" (Owens, 2019; U.S. DOT, 2020). Developers do not all oblige; of 66 AV developers permitted to test in California, only 18 have completed NHTSA's voluntary safety self-assessment (California DMV, 2020; NHTSA, 2020). Bills, such as the AV START act, have been proposed to standardize testing between states. These bills have failed because they have not satisfactorily accounted for risks and have not provided for sufficient oversight of AV development (Feinstein et al., 2018).

Safety advocates claim the federal government is too lax in regulating AVs, risking safety in favor of development. Jason Levine, executive director of the Center for Auto Safety, claims U.S. DOT believes AV developers' "marketing assurances" too much and is failing to fulfill its safety responsibilities (Levine, 2020). Cathy Chase, the President of Advocates for Highway and Auto Safety, calls for "robust regulations that prioritize public safety over AV manufacturers' profit" (Chase, 2020). The Insurance Institute for Highway Safety calls existing regulations a "decidedly pro-technology approach that lacks adequate safeguards to protect other road users" (IIHS, 2018).

NTSB, an independent investigatory agency, agrees current oversight is insufficient, and proposes new safety regulations. The board concluded an inadequate safety culture was a contributing cause to Uber's 2018 crash, and recommended NHTSA implement mandatory safety reports with a formal review process (NTSB, 2019b; Sumwalt, 2019). U.S. DOT recognizes NTSB's role in recommending policy after incidents, but has not adopted any proposals (U.S. DOT, 2020).

AV developers benefit from lax safety regulations. AVs must be tested in situations in which they have not already been proved safe. Tesla CEO Elon Musk said, "All input is error," meaning the system learns from disengagements (Fridman, 2019b). Tesla allows Autopilot nearly anywhere outside of its operational design domain (ODD), despite NTSB recommendations, which likely yields substantial data (Sumwalt, 2019). Uber CEO Dara Khosrowshahi aims for gradual implementation, hoping to "feather it in a live network and gather a lot of data" (NYT, 2017). Chris Urmson, CEO of Aurora, says reducing the number of system disengagements is "inversely correlated with progress" when training (Marshall, 2018).

However, commercial deployment of full autonomy requires minimizing disengagements. Without mandatory regulations, how developers will manage this transition is unclear.

## Interaction with Road Users

Many pedestrians and cyclists have negative opinions towards AVs. A 2018 Public Policy Polling (PPP) survey found 79% of road users would be at least somewhat concerned for their safety if AVs were in their city (PPP, 2018). An Advocates for Highway and Auto Safety (AHAS) poll similarly found 64% of people were concerned sharing the road; this rose to 69% following the death of Elaine Hertzberg (AHAS, 2018a; AHAS 2018c). In Arizona, some pedestrians harass Waymo's test cars, standing in front of them, cutting them off, and threatening them. Waymo often avoids the same neighborhoods in response (Randazzo, 2018).

Pedestrians and cyclists are skeptical towards the regulation needed for safe interaction with AVs. The Missouri Bicycle and Pedestrian Federation (MoBikeFed) is concerned AV regulations will require sensors on bicycles, making cycling "more dangerous or more expensive," particularly for low income communities. MoBikeFed calls for public funding to be restricted to "repairing and updating infrastructure to serve all users" (Hugh, 2018). Pittsburghers for Public Transit (PPT) sees public allocations supporting AV-specific infrastructure as a betrayal of communities that have "called for better sidewalks, crosswalks, dedicated bus and bike infrastructure" (Amruthapuri & Bartel, 2019). The League of American Bicyclists and other advocacy groups are concerned there is no minimum "vision test" for pedestrians and cyclists required before public testing (Whitaker, 2018; AHAS, 2018b).

Vulnerable road users are also mistrustful of the companies implementing AVs. Pittsburgh cyclists lost more faith in Uber rather than AV technology following the death of

Elaine Hertzberg, in “the way they tried to shirk responsibility and blame first Elaine” (BikePGH, 2019). Some pedestrians are concerned that companies will deploy unsafe AVs to gain a market share before competitors (Botello et al., 2018). One pedestrian showed distrust after a close call with a Waymo car, saying, “[Waymo] said they need real-world examples, but I don’t want to be their real-world mistake” (Romero, 2018). Douglas Rushkoff generalizes this, saying, “There’s a growing sense that the giant corporations […] do not have our best interests at heart” (Romero, 2018).

When the technology is trusted, road users have less concerns over safety. Cyclists in Pittsburgh feel more safe sharing the roads with AVs than with human drivers, with feeling of safety increasing with exposure to AVs (BikePGH, 2019). Penmetsa et al. (2019) found pedestrians and cyclists who have interacted with AVs are more optimistic for their potential to improve safety. Deb et al. (2017) found a pedestrian’s willingness to cross in front of an AV and their perceptions of safety are correlated. Rothenbucher et al. (2016) observed pedestrians interact normally crossing in front of AVs, except when the vehicles behaved unexpectedly and broke trust.

Still, road users’ trust towards AVs does not completely explain their opinions of, or implications on, safety. Deb et al. (2017) found pedestrians who follow traffic rules less, despite having less confidence in the safety of AVs, are more likely to cross in front of them. Despite clear misgivings, those protesting AVs in Arizona feel safe standing in front of or brake-checking them (Randazzo, 2018). Pedestrians may also be in a similar position to drivers: perceiving AVs as safer than humans may cause complacency, which can increase risk.

Social interactions between pedestrians and AVs exemplify the importance of trust and safety. Technical researchers view these interactions as a major barrier from AV deployment.

Lex Fridman described the problem that AVs “have to not only understand the intent of the movement ... [AVs] also have to assert [themselves]” (Fridman, 2019a). Rodney Brooks claims AVs will attract ire in either being in a “privileged position,” asserting themselves, or more likely, be “very wimpy drivers, slowing down traffic for everybody.” (Brooks, 2017). The Pedestrian and Bicycle Information Center discussed ten problems interacting with pedestrians AVs must solve before being safe for full deployment (Sandt & Owens, 2017).

Some think changing the behavior of pedestrians is the answer to safe interactions, prioritizing rapid deployment. Andrew Ng said, speaking of pedestrian edge cases, “we should partner with the government to ask people to be lawful and considerate” (Brandom, 2018). U.S. DOT noted “improved public and consumer education” as a theme in conversations with stakeholders (U.S. DOT, 2018). Automotive industry officials have considered gates at street corners to control pedestrians (Taub, 2019). This attitude assumes it will be easier to solve the problem, at least in the near term, by changing social behaviors rather than improving the technological capabilities.

**Conclusion**

The reality of AV safety remains uncertain due to the technical problems of proving safety and few mandatory regulations ensuring it. Until these factors are resolved, the standard for safety depends on each participant’s vision. These visions to achieve safety often contradict each other. When a vulnerable group has low trust in development, any assurances of equity will likely fall flat; this is especially true when developers push for rapid deployment or allow their drivers to become distracted. Similarly, when companies advertise a near-term future while technical developers show doubts, even informed consumers will remain skeptical or confused.

Many emerging technologies produce this uncertain environment, where a focus on rapid development and user experience does not fully account for risks or outside perspectives. The current regulatory approach appears to be waiting for uncertainty to decrease with development. Unfortunately, vulnerable participants often become heard only after an incident occurs, such as Elaine Herzberg's death.

It remains a societal challenge of how virtues like safety, privacy, and justice can be held paramount with uncertain, emerging technologies. Investigation into the relationships between developers, regulators, and the public could shed light on this problem. Analyzing further psychological factors may also be useful. Studying AV deployment in other countries and case studies of other emerging technologies may answer how participants can reconcile their visions of safety.

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