The End of Accidents

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In the next decade, humans will increasingly share the roads with autonomous vehicles ("AVs"). The deployment of AVs has the potential to dramatically reduce the frequency and severity of motor vehicle crashes. Existing liability rules give companies developing AVs insufficient incentives to develop that potential. Data from real-world autonomous driving indicates that today's most advanced AVs rarely cause crashes, but often fail to avoid preventable crashes caused by other road users' errors. A growing number of scholars have proposed reforms that would make it easier for plaintiffs injured in crashes with AVs to hold AV companies liable. These reform proposals either ignore the issue of comparative negligence or would preserve some form of the defense. If AV companies avoid liability for crashes in which a human road user was negligent, they will not invest in developing technology that could prevent those crashes. This Article proposes a solution: AV companies should be held responsible for all crashes in which their AVs come into contact with other vehicles, persons, or property — regardless of fault, cause, or comparative negligence. Contact responsibility would cause AV companies to internalize the costs of all preventable crashes and lead them to make all cost-justified investments in developing safer technology. Crashes would no longer be treated as regrettable yet inevitable accidents, but as engineering problems to be solved.

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TABLE OF CONTENTS

INTRODUCTION

Human drivers are a menace to public health. In 2019, 36,096 Americans were killed in motor vehicle crashes.[1] An estimated 2.74 million Americans were injured.[2] The annual economic cost of crashes — from medical bills, property damage, and lost productivity — is over $200 billion.[3] The trend lines aren't promising. In the past few years, the per mile fatality rate has barely declined.[4] Most crashes aren't "accidents."[5] The causes of crashes are predictable. The National Highway Traffic Safety Administration ("NHTSA") estimates that driver error is the critical reason for 94% of crashes.[6]

The deployment of autonomous vehicles ("AVs") — likely in the form of robotaxis — will make transportation safer. AVs will cause fewer crashes than conventional vehicles ("CVs") because software

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1 NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., DOT HS 813 060, OVERVIEW OF MOTOR VEHICLE CRASHES IN 2019, at 1 (2020), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813060 [https://perma.cc/KE4U-P8V8] [hereinafter MOTOR VEHICLE CRASHES IN 2019]. The World Health Organization estimated that crashes killed 1.35 million globally in 2016. WORLD HEALTH ORG., GLOBAL STATUS REPORT ON ROAD SAFETY xi (2018), https://apps.who.int/iris/bitstream/handle/10665/276462/9789241565684-eng.pdf?ua=1 [https://perma.cc/ZU5S-WDN7]. Because many AV companies are developing their technology for U.S. deployment first, U.S. liability rules may affect the safety of AVs deployed abroad.

2 NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., MOTOR VEHICLE CRASHES IN 2019, *supra* note 1.

3 NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., DOT HS 812 013, THE ECONOMIC AND SOCIETAL IMPACT OF MOTOR VEHICLE CRASHES, 2010 (REVISED) 1 (2015), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013 [https://perma.cc/6AWE-5DUM] (estimating that the total economic cost of U.S. motor vehicle crashes in 2010 was $242 billion).

4 *See* NAT'L HIGHWAY TRAFFIC ADMIN., MOTOR VEHICLE CRASHES IN 2019, *supra* note 1, at 2-3. Preliminary data suggests that the per mile fatality rate increased significantly in the second and third quarters of 2020, which NHTSA attributes to the effects of the COVID-19 pandemic. *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., DOT HS 813 053, EARLY ESTIMATE OF MOTOR VEHICLE TRAFFIC FATALITIES FOR THE FIRST 9 MONTHS (JAN–SEP) OF 2020, at 3 (2020), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813053 [https://perma.cc/SNV8-WS3R].

5 Activists have argued that using the word "crash" rather than "accident" will reduce fatalism about road safety. *See* Matt Richtel, *It's No Accident: Advocates Want to Speak of Car 'Crashes' Instead*, N.Y. TIMES (May 22, 2016), https://www.nytimes.com/2016/05/23/science/its-no-accident-advocates-want-to-speak-of-car-crashes-instead.html [https://perma.cc/8JV7-GEFW].

6 NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., DOT HS 812 506, CRITICAL REASONS FOR CRASHES INVESTIGATED IN THE NATIONAL MOTOR VEHICLE CRASH CAUSATION SURVEY 1 (2018), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812506 [https://perma.cc/A64M-W2CF] [hereinafter CRITICAL REASONS FOR CRASHES].

won't make the kinds of errors that human drivers make.[7] AVs won't drive drunk, get drowsy, or be distracted. They won't speed, run red lights, or follow other vehicles too closely. They will drive cautiously and patiently. AVs will consistently drive like the safest human drivers drive at their best.

But AVs could be *even safer*. AVs could be designed not only to avoid causing their own errors, but also to reduce the consequences of errors by human drivers, cyclists, and pedestrians. AVs can monitor their surroundings better and react more quickly than human drivers.[8] AV technology has the potential to make better predictions and better decisions than humans can.[9] AVs could be designed to anticipate when other road users will drive, bike, or walk unsafely and to prevent those errors from leading to crashes or make unavoidable crashes less severe.[10] As long as AVs share the roads with humans, improving AV technology's capability to mitigate the consequences of human error will save lives.

Liability rules will influence how much AV companies[11] invest in developing safer technology. Existing products liability law creates insufficient incentives for safety because AV companies can reduce their liability for a crash by showing that the plaintiff was comparatively negligent.[12] A comparative negligence defense will be a powerful liability shield because the kinds of errors that human drivers make — violating traffic laws and driving impaired — are the kinds of errors that human jurors recognize as negligence. A liability regime with a comparative negligence defense only creates incentives for AV companies to develop behaviors that AV technology has already mastered: driving at the speed limit, observing traffic signals, and maintaining a safe following distance. It won't push AV companies to

[7] For data on the causes of crashes, see *infra* Part I.C.

[8] *See id.* (describing AV capabilities).

[9] *See infra* Part I.D. (reviewing unsolved engineering problems).

[10] *See infra* Part I.C. (analyzing the potential for developing AVs that exceed the safety performance of human drivers).

[11] Companies developing AV technology include conglomerates like Alphabet, traditional automakers like General Motors, ridehailing companies like Lyft, automotive parts suppliers like Bosch, and venture-backed startups like Aurora. I use "AV company" as a shorthand for any business developing AV technology, especially AV software.

[12] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 17(a) (AM. L. INST. 1998) ("A plaintiff's recovery of damages for harm caused by a product defect may be reduced if the conduct of the plaintiff combines with the product defect to cause the harm and the plaintiff's conduct fails to conform to generally applicable rules establishing appropriate standards of care.").

develop software that can reliably anticipate human error and take evasive action.

Data from real-world AV testing shows that AVs are rarely causing crashes but are failing to avoid plausibly preventable crashes. In October 2020, the leading AV company, Waymo, released a report of every contact between its prototype robotaxis and other vehicles, bicycles, or pedestrians during its 6.1 million miles of autonomous driving in 2019.[13] At the current stage of testing, Waymo's AVs usually have a backup driver behind the wheel, ready to take over manual control if necessary.[14] Waymo's report includes every actual contact during autonomous operation and every contact that would have happened, according to Waymo's simulation software, if the backup driver hadn't taken over manual control.[15] If the report is reliable, almost every contact in the 6.1 million miles involved human error.[16] In fact, in most cases, it's not even arguable that the AV made an error that contributed to the contact.

Waymo's report also reveals, however, that its AVs sometimes fail to avoid plausibly preventable crashes caused by human error. Consider the scenario depicted in Figure 1 below.[17] Late one night in 2019, a Waymo AV was travelling in the left lane of a divided road in the suburbs of Phoenix.[18] A CV was traveling in the wrong direction in the right lane veering towards the AV.[19] The backup driver took over manual control.[20] According to Waymo's simulation, if the backup driver hadn't taken over, the CV would have crashed head-on into the AV.[21] The force of the collision would have caused the AV's airbag to deploy.[22] The AV would have braked, but not swerved out of the way.[23]

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[13] *See* MATTHEW SCHWALL, TOM DANIEL, TRENT VICTOR, FRANCESCA FAVARÒ & HENNING HOHNHOLD, WAYMO PUBLIC ROAD SAFETY PERFORMANCE DATA 1-5 (2020), https://arxiv.org/pdf/2011.00038 [https://perma.cc/F49B-7U4F].

[14] *See id.* at 2 (describing Waymo's use of backup drivers, which the company calls "trained operators," during testing).

[15] *See id.* at 3-5 (explaining Waymo's procedure for simulating contacts).

[16] For analysis of Waymo's report, see *infra* Part II.A.

[17] SCHWALL ET AL., *supra* note 13, at 7.

[18] *Id.*

[19] *Id.*

[20] *See id.* at 8.

[21] *Id.*

[22] *Id.*

[23] *See id.* ("In simulation, the [AV] detected the wrong way vehicle, initiated full braking, and was simulated to come to a complete stop in its lane prior to impact.").

The CV's driver likely wouldn't have swerved out of the way either because the driver was likely "significantly impaired or fatigued."[24]

Figure 1: Head-On Collision from Waymo Report

Waymo doesn't clarify whether its backup driver was able to avoid a crash. But it's quite possible that the backup driver was able to avoid it. Evolution has armed humans with a powerful survival instinct. The backup driver should have had room for evasive maneuvers on the wide suburban road late at night. Yet Waymo's AV software — software that would drive 6.1 million miles without causing a crash that same year — wouldn't have prevented an apparently preventable head-on collision.

Consider the simulated crash from a liability perspective. Suppose there had been no backup driver, and the vehicles collided. Assume, consistent with the report, that the driver of the CV was drunk. Would the drunk driver prevail against Waymo in a lawsuit? Almost certainly not. The question itself sounds absurd. Drunk driving that results in a crash is negligence per se.[25] Waymo's comparative negligence defense would all but dispose of the case. Because Waymo would avoid liability

[24] *See id.*

[25] RESTATEMENT (THIRD) OF TORTS: LIAB. FOR PHYSICAL & EMOTIONAL HARM § 14 cmt. h (AM. L. INST. 2010) (explaining that "it may be negligence per se for the defendant to violate a statute by operating a car under the influence of alcohol" if the drunk driving is the factual cause of the crash).

for the crash, it would have little incentive to develop technology that could prevent a similar crash in the future.[26]

Now consider the same simulated crash from a social welfare perspective. Would the social benefits of technology that could prevent a crash like this exceed the cost of development? Likely yes. Drunk driving is common.[27] Drivers, impaired or not, sometimes drive in the wrong direction.[28] AV technology's ability to monitor the environment more consistently and react more quickly gives AVs advantages over CVs in responding to impaired drivers. If AV companies invest in developing better behavior prediction and decision-making capabilities, they could design AVs that would dramatically reduce the social costs of drunk driving. AVs could become superhuman defensive drivers, preventing not only crashes like this one but also crashes that now seem unpreventable.

Investments in developing safer AV software will be highly cost-effective because the software will be deployed at scale. When an AV company develops code that enables its AVs to prevent a crash in a certain kind of traffic scenario — and doesn't make them less safe in other scenarios — it will add the new code to the software that runs on all the AVs in its fleet.[29] The improved code will prevent a crash every time one of the company's AVs encounters a similar traffic scenario *for the rest of history*. As engineers change jobs or share ideas, the fix will spill over to other AV companies' fleets.[30] From a social welfare perspective, the return on investments in developing safer AV technology will be tremendous.

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26 For responses to the objection that market incentives will make up for the lack of liability incentives, see *infra* Part IV.C.

27 *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., MOTOR VEHICLE CRASHES IN 2019, *supra* note 1, at 9 (reporting that drunk driving killed 10,142 Americans in 2019).

28 In fact, a Waymo AV was hit by another driver driving in the wrong direction in 2018. In that case, the driver that hit the Waymo AV had run a red light and swerved into the Waymo AV's lane to avoid traffic in the intersection. *See* Bree Burkitt, *Police: Driver Cited for Running Red Light in Chandler Crash with Waymo Self-Driving Van*, ARIZ. REPUBLIC (May 5, 2018, 2:10 PM), https://www.azcentral.com/story/news/local/chandler-breaking/2018/05/05/driver-cited-crash-waymo-self-driving-van/583815002/ [https://perma.cc/WTY7-RNUK].

29 In other words, the new code must pass the company's regression testing. *See infra* Part I.A.

30 This argument implies that, even under contact responsibility, AV companies will not internalize all of the benefits of developing safer AV technology if (1) the improvements are not patentable or infringement is hard to detect and (2) other AV companies use their improvements to prevent crashes involving their AVs (and not the first company's AVs).

AV companies will only develop AV technology's full crash prevention potential if they internalize the costs of all preventable crashes. But determining which crashes could be efficiently prevented with yet-to-be developed AV technology would be exceedingly difficult for jurors, judges, or regulators. AV technology may achieve safety gains not just by mimicking the behavior of an expert human driver but by exhibiting *emergent* behavior — behavior that would seem alien to a human observer.[31] The better approach is to treat *all* crashes involving AVs as potentially preventable. In this Article, I defend a system of absolute liability for AV companies that I call "contact responsibility." Under contact responsibility, AV companies would pay for the costs of all crashes in which their AVs come into contact with other vehicles, persons, or property.[32] No crash involving an AV would be considered an accident.[33]

Contact responsibility would align the private financial incentives of AV companies more closely with public safety. AV companies will collect massive amounts of data on driver, cyclist, and pedestrian behavior as their fleets of AVs passively record their surroundings. Contact responsibility will push AV companies to sift through that data to find opportunities to prevent crashes efficiently. In many cases, the solution will be developing safer technology. If a company's AVs are frequently being hit in intersections by CVs that run red lights, the company might develop software that can more reliably predict when CVs won't stop at traffic signals. In other cases, the solution may be deploying AVs differently. The company might plan routes for its robotaxis that avoid especially dangerous roads at certain times of day.[34] In still other cases, the solution may be political. The company might use its money to lobby for protected bike lanes, mandatory ignition interlocks, or the development of a vehicle-to-vehicle ("V2V") communication network.[35]

31 *See* Ryan Calo, *Robotics and the Lessons of Cyberlaw*, 103 CALIF. L. REV. 513, 538-45 (2015) (describing emergence in robotics systems).

32 AV companies would only avoid responsibility if they could prove the party seeking payment intentionally caused the crash. For a possible example of such a crash, see SCHWALL ET AL., *supra* note 13, at 10.

33 For crashes *between* AVs, I endorse Steven Shavell's "strict liability to the state" proposal. *See* Steven Shavell, *On the Redesign of Accident Liability for the World of Autonomous Vehicles* 1, 2 (Harvard John M. Olin Ctr. for L., Econ., & Bus., NBER Working Paper No. 26220, 2019). http://www.law.harvard.edu/programs/olin_center/papers/pdf/Shavell_1014.pdf [https://perma.cc/W8LM-4SUL]. For more discussion of this issue, see *infra* Part III.A.

34 For analysis of AV companies' deployment decisions, see *infra* Part IV.B.

35 For analysis of AV companies' political incentives, see *infra* Part III.E.

Contact responsibility may sound radical because it would insulate human drivers from tort liability for crashes they cause negligently or even recklessly. One might worry that it would create a moral hazard. But liability plays at most a modest role in deterring unsafe driving. Human drivers tend to cause crashes by breaking traffic laws and driving impaired.[36] Under contact responsibility, the civil and criminal penalties for those violations would continue to provide deterrence. Drivers would also still face liability for crashes with other CVs, cyclists, and pedestrians. They would still face the possibility that their insurers would raise their premiums after a crash with an AV, even though they weren't held liable, because the crash indicated they had a higher risk of crashing with a CV. Most importantly, drivers would still want to avoid the risk of injuring themselves or others. Contact responsibility wouldn't diminish those deterrents.[37] It would simply target liability incentives where they will be most useful: AV companies' investment decisions.

There's a rich law and economics literature that analyzes the optimal liability rules for motor vehicle crashes.[38] In recent years, several scholars have proposed reforms to adapt tort law to crashes involving AVs. These proposals include a heightened standard of care,[39] a strict liability regime,[40] a no fault system,[41] and a regulatory alternative based on premarket testing.[42] The debate has yielded valuable insights, but it has been conducted almost entirely from the armchair. Earlier research

36 *See infra* Part I.C.

37 For a more detailed response to this objection, see *infra* Part IV.A.

38 For influential early work in this literature, see generally GUIDO CALABRESI, THE COSTS OF ACCIDENTS (1970) (analyzing goals of accident law); WILLIAM M. LANDES & RICHARD A. POSNER, THE ECONOMIC STRUCTURE OF TORT LAW (1987) (discussing the concepts of strict liability and negligence); STEVEN SHAVELL, ECONOMIC ANALYSIS OF ACCIDENT LAW (1987) (reframing accident law under an economic lens).

39 Bryant Walker Smith considered this possibility without endorsing it. *See* Bryant Walker Smith, *Automated Driving and Product Liability*, 2017 MICH. ST. L. REV. 1, 49-50 (2017).

40 *See* David C. Vladeck, *Machines Without Principals: Liability Rules and Artificial Intelligence*, 89 WASH. L. REV. 117, 146 (2014) (proposing a "true strict liability" regime for AV crashes).

41 *See* Kenneth S. Abraham & Robert L. Rabin, *Automated Vehicles and Manufacturer Responsibility for Accidents: A New Legal Regime for a New Era*, 105 VA. L. REV. 127, 147 (2019) (proposing a system of manufacture enterprise liability for AV crashes).

42 *See* Mark A. Geistfeld, *A Roadmap for Autonomous Vehicles: State Tort Liability, Automobile Insurance, and Federal Safety Regulation*, 105 CALIF. L. REV. 1611, 1651-54 (2017) (arguing that NHTSA should require that AV companies prove, based on premarketing testing, that their AVs are twice as safe as human drivers).

lacked analysis of the strengths and weaknesses of AV technology[43] and the characteristics of AV crashes.[44] Now that data on AV safety performance is publicly available, it's possible to make more informed predictions about the real-world consequences of different liability rules.

The data suggest that AV crashes will follow a predictable pattern.[45] AVs will rarely cause crashes. But they will fail to avoid plausibly preventable crashes caused by other road users. Therefore, the most important liability issue is whether AV companies will be responsible when a negligent or reckless human driver causes a crash with an AV. The literature has largely ignored comparative negligence.[46] Scholars who have considered the issue have advocated retaining some form of the defense.[47] In fact, one leading reform proposal expressly rejects AV company responsibility for "injury caused by the egregious negligence of a CV driver, coupled with minimal causal involvement by the [AV]."[48] I argue that absolving AV companies from responsibility for those injuries would be a mistake. Contact responsibility is the only liability regime that will unlock AV technology's full crash prevention potential.

The Article proceeds in four Parts. Part I describes how AV technology works, how AVs will be deployed, and how AVs could be made safer. Part II analyzes AV crash data in the aggregate and two AV

[43] Harry Surden and Mary-Anne Williams offer a helpful explanation of AV technology, though their aim is not to compare AV with human performance. *See* Harry Surden & Mary-Anne Williams, *Technological Opacity, Predictability, and Self-Driving Cars*, 38 CARDOZO L. REV. 121, 137-41 (2016).

[44] Other articles have analyzed crashes involving partially autonomous vehicles. *See, e.g.*, Geistfeld, *supra* note 42, at 1626-27 (discussing a crash involving Tesla Autopilot software). One interesting exception is Bryan Casey's analysis of a crash between a Cruise AV and a motorcycle. *See* Bryan Casey, *Robot Ipsa Loquitur*, 108 GEO. L.J. 225, 239-41 (2019).

[45] *See infra* Parts II.A–B.

[46] Abraham and Rabin briefly discuss the issue. *See* Abraham & Rabin, *supra* note 41, at 166-67.

[47] Mark Lemley and Bryan Casey have argued for retaining comparative negligence defenses in AV crash cases to prevent moral hazard. *See* Mark A. Lemley & Bryan Casey, *Remedies for Robots*, 86 U. CHI. L. REV. 1311, 1383 (2019) ("[W]hile we think moral fault makes little sense in accidents involving autonomous vehicles, and perhaps any consideration of blame is problematic when considering accidents between two autonomous vehicles, we will still need to compare the behavior of humans and autonomous vehicles in order to make sure that we give proper incentives to human drivers.").

[48] Abraham & Rabin, *supra* note 41, at 167. They offer as examples "a rear-end collision while the [AV] is nearly stopped or reckless, intoxicated driving by the CV driver." *Id.*

crashes in detail. Part III makes the case for contact responsibility. Part IV responds to objections.

I. AV TECHNOLOGY AND ECONOMICS

AVs surpass human performance in some driving tasks. AVs excel at following rules, monitoring their surroundings, and reacting quickly. Today, though, they often perform worse than human drivers at tasks that require judgment, like predicting behavior and making complex decisions. AV companies are continuously creating new code, testing it in simulations and on public roads, and identifying flaws in the software to be fixed in the next round of development. With sufficient investment, AV technology could develop superhuman abilities to prevent crashes.

The AV industry has converged on a taxonomy for distinguishing among different "levels" of vehicle automation.[49] Partially autonomous vehicles are known as L1, L2, and L3 vehicles. L1 vehicles have driver assistance technology that can control the vehicle's longitudinal motion (like adaptive cruise control) or lateral motion (like lane assist).[50] L2 vehicles have driver assistance technology that can control both lateral and longitudinal motion, but still requires constant supervision by the driver.[51] Tesla's controversial Autopilot software is an L2 technology.[52] L3 vehicles would be able to drive without human supervision in certain situations, but would still require a human driver to be seated behind the wheel, ready to take over manual control on demand.[53]

Fully autonomous vehicles, capable of transporting passengers between given origin and destination points without any human

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[49] SAE INT'L, SURFACE VEHICLE RECOMMENDED PRACTICE J3016, at 19 (2018) https://www.sae.org/standards/content/j3016_201806/ [https://perma.cc/59P4-LQ8N]. NHTSA has used SAE's taxonomy in its policy statements. *See* U.S. DEP'T OF TRANSP., PREPARING FOR THE FUTURE OF TRANSPORTATION: AUTOMATED VEHICLES 3.0 vi (2018), https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf [https://perma.cc/ZC54-3A7S] (describing SAE's levels of automation, but cautioning that "no terminology is correct or incorrect").

[50] SAE INT'L, *supra* note 49, at 21.

[51] *Id.*

[52] *See* Kirsten Korosec, *Tesla's Full Self-Driving Computer Is Now in All New Cars and a Next-Gen Chip Is Already 'Halfway Done,'* TECHCRUNCH (Apr. 22, 2019, 1:00 PM), https://techcrunch.com/2019/04/22/teslas-computer-is-now-in-all-new-cars-and-a-next-gen-chip-is-already-halfway-done/ [https://perma.cc/GV3H-HQ23].

[53] *See* SAE INT'L, *supra* note 49, at 22 (stating that, in a L3 vehicle, the driver is "receptive to a request to intervene" and take over manual control).

intervention, are called L4 vehicles.[54] L4 vehicles have a limited operational design domain ("ODD").[55] An AV's ODD is the set of operating conditions under which it's designed to function, including "environmental, geographical, and time-of-day restrictions."[56] L4 vehicles, with a limited but gradually expanding ODD, are the vehicles that will stress the tort system and transform society.[57] Partially autonomous vehicles may raise complex or novel issues for tort law. For example, there could be litigation about whether a driver negligently failed to supervise an L2 system or whether the design of a L3 system was defective because it failed to instruct a driver to take over in certain circumstances.[58] L4 vehicles merit special attention because their potential to prevent crashes changes the cost-benefit analysis underlying existing doctrine.

Any predictions about how AV technology will develop are fraught with uncertainty. Although AVs are being tested on public roads, it's difficult to infer their capabilities from publicly available data, because important aspects of their performance are only revealed in rare traffic scenarios.[59] AV companies are usually cagey about their AVs' capabilities. The state-of-the-art in AV technology changes rapidly because AV software is being continually updated. There's a remarkable amount of capital pouring into AV development. An estimated $16 billion had been invested through the end of 2019.[60] But waiting to act

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[54] *See id.* (stating that, in a L4 vehicle, the driver need not perform the dynamic driving task as a fallback).

[55] *See id.* (stating that the automated driving system in a L4 vehicle "[p]ermits engagement only within its [operational design domain]").

[56] *Id.* at 14.

[57] The taxonomy includes a category for "L5" vehicles — L4 vehicles with no ODD constraints — but it is doubtful such vehicles will exist in the foreseeable future. SAE defines an L5 vehicle as one that "[p]ermits engagement of the [automated driving system] under all driver-manageable on-road conditions." *Id.* at 23. It is not even clear that there are CVs on the road today that can operate in *all* conditions in which at least one CV could operate. An SUV, for example, may be great for off-roading but would struggle with narrow alleys in a European city center better suited to a compact car, and vice versa.

[58] *See* Abraham & Rabin, *supra* note 41, at 140-41; Geistfeld, *supra* note 42, at 1625-28.

[59] *See* Philip Koopman, *The Heavy Tail Safety Ceiling*, AUTOMATED & CONNECTED VEHICLE SYS. TESTING SYMP. 1, 1-2 (2018) http://users.ece.cmu.edu/~koopman/pubs/koopman18_heavy_tail_ceiling.pdf [https://perma.cc/37W8-7UJN] (explaining that on-road testing will not ensure that AVs are safe because of the heavy tail distribution of dangerous events).

[60] *See* Amir Efrati, *Money Pit: Self-Driving Cars' $16 Billion Cash Burn*, THE INFO. (Feb. 5, 2020, 7:01 AM), https://www.theinformation.com/articles/money-pit-self-driving-cars-16-billion-cash-burn [https://perma.cc/6KNH-ZKZE].

on liability until we have more certainty about how the technology will develop could be costly.

A. Basics of AV Technology

The driver of a fully autonomous vehicle is a combination of its sensors, computers, and software. Most L4 AVs operating on public roads today use at least three types of sensors: radar, lidar, and cameras.[61] Radar emits radio waves that bounce back when they hit an object. The object's distance from the radar can be calculated from the time it takes the waves to return.[62] Lidar, short for light detection and ranging, emits laser beams. As with radar, the time it takes the beams to reflect back indicates the object's distance.[63] The two sensor modalities are complementary: lidar is more accurate at short ranges,[64] but radar isn't affected by lighting conditions and can have a longer range.[65] Cameras collect images that the system's computer vision software can process.[66] Cameras can detect color,[67] which makes it possible to identify traffic lights. AVs have onboard computers, which run the AVs' software.[68] The AV's software fuses information from the sensors, decides how the vehicle should move, and sends the signal to execute those decisions.

AV software is composed of several systems: mapping, localization, perception, behavior prediction, motion planning, and controls.[69] The mapping system gives the AV an extremely precise guide to the lanes, intersections, buildings, and other static objects it should expect to find at a given location.[70] The localization system enables the AV to determine its present position on the map.[71] The perception system uses

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[61] *See* Ekim Yurtsever, Jacob Lambert, Alexander Carballo & Kazuya Takeda, *A Survey of Autonomous Driving: Common Practices and Emerging Technologies*, 8 IEEE ACCESS 1, 5-7 (2020) https://arxiv.org/pdf/1906.05113.pdf [https://perma.cc/395J-WMT6].

[62] *Id.* at 6.

[63] *See id.* at 6-7.

[64] *Id.* at 7.

[65] *See id.* at 5-7 (classifying lidar's range as "medium" and radar's range as "high").

[66] *See id.* at 5-6 (explaining different types of cameras used in AV systems).

[67] *Id.*

[68] *See id.* at 7 ("Besides sensors, an ADS needs actuators to manipulate the vehicle and advanced computational units for processing and storing sensor data.").

[69] *See id.* at 4 (describing a similar division of systems, except that behavior prediction is referred to as "assessment").

[70] *See id.* at 7-10 (describing technical approaches to localization and mapping).

[71] *See id.* at 8-10 (explaining how lidar is used for localization).

data from the AV's sensors to detect vehicles, cyclists, pedestrians, and other moving and stationary objects and track them in real-time.[72] The behavior prediction system models where other agents are likely to move in the near future.[73] The motion planning system continuously generates and selects trajectories for the AV to take through the world, based on the inputs from the mapping, localization, perception, and behavior prediction systems.[74] The controls system executes these trajectories by sending signals to the steering, throttle, or brakes.[75]

At any given time, each AV in an AV company's fleet will be running the same code. In other words, every Waymo AV has the same driver. Consequently, every Waymo AV should handle the same traffic scenario identically to every other AV in its fleet. Waymo's software may be adapted to local conditions, but, within each local area, each Waymo AV will drive like the others. The uniformity of AV software has an important implication for liability. A misjudgment by a driver could be a fluke — a momentary lapse in attention, not likely to be repeated. A misjudgment by a Waymo AV in a given scenario would be repeated by every Waymo AV presented with the same scenario.

In practice, though, it's unlikely that AVs developed by the same company will crash twice in highly similar scenarios, as long as — *and this is why liability matters* — AV companies have sufficient incentive to avoid that kind of crash again. AV software is being continuously updated. Engineers frequently review data from on-road testing.[76] This includes autonomous driving on public roads and in private closed-course facilities, where more risky scenarios can be tested.[77] Engineers

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[72] *See id.* at 9-14 (describing technical approaches to object detection and tracking and the sensor modalities they use).

[73] *See id.* at 16-17 (describing techniques for "surrounding driving behavior assessment" and "driving style recognition").

[74] *See id.* at 17-19 (describing technical approaches for "global planning" and "local planning").

[75] CLAUDINE BADUE, RÂNIK GUIDOLINI, RAPHAEL VIVACQUA CARNEIRO, PEDRO AZEVEDO, VINICIUS BRITO CARDOSO, AVELINO FORECHI, LUAN JESUS, RODRIGO BERRIEL, THIAGO PAIX O, FILIPE MUTZ, LUCAS VERONESE, THIAGO OLIVEIRA-SANTOS & ALBERTO FERREIRA DE SOUZA, SELF-DRIVING CARS: A SURVEY 1, 23 (2019) https://arxiv.org/pdf/1901.04407.pdf [https://perma.cc/NE2L-BURR] (describing technical approaches to control).

[76] *See, e.g.*, WAYMO, WAYMO SAFETY REPORT: ON THE ROAD TO FULLY SELF-DRIVING 26 (2018) (describing how Waymo's on-road testing feeds back into software development).

[77] *See id.* at 25 (explaining that Waymo uses its closed-course facility in part "to stage challenging or rare scenarios so our vehicles gain experience with unusual situations").

also review the results of computer simulations that model how the AV software will behave in a larger set of traffic scenarios.[78]

Each AV company's software will have driven orders of magnitude more simulated miles than real miles. For example, in January 2020, Waymo announced that its AVs had driven 20 million real-world miles.[79] By comparison, about six months earlier, Waymo had announced that its AVs had driven 10 *billion* simulated miles.[80] Crashes or near misses in real-world testing and in simulation reveal "edge cases" — scenarios that occur infrequently but need "specific design attention to be dealt with in a reasonable and safe way."[81] They also reveal corner cases — "combinations of normal operational parameters" that can become edge cases if the combination "produces an emergent effect."[82]

The software development process is iterative.[83] New edge cases are identified from testing or simulation. New algorithms or fixes to existing algorithms are proposed. The proposed solutions undergo regression testing — simulations that assess whether the new software might perform worse in known traffic scenarios than earlier versions did.[84] If the fix passes regression testing, it goes into the next software release and is evaluated on the road. If it fails, the engineers go back to the drawing board. The process then repeats itself. If the process works, the on-road performance of the company's AVs should improve over time.

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78 *See id.* at 23-24 (describing Waymo's use of simulations in software development).

79 Richard Nieva, *Waymo Driverless Cars Have Driven 20 Million Miles on Public Roads*, CNET (Jan. 6, 2020, 9:47 PM), https://www.cnet.com/news/waymo-driverless-cars-have-driven-20-million-miles-on-public-roads/ [https://perma.cc/3WPH-UQ6C]. Remarkably, half of the 20 million miles were driven in 2019. *See id.*

80 Darrell Etherington, *Waymo Has Now Driven 10 Billion Autonomous Miles in Simulation*, TECHCRUNCH (July 10, 2019, 5:17 PM), https://techcrunch.com/2019/07/10/waymo-has-now-driven-10-billion-autonomous-miles-in-simulation/ [https://perma.cc/M9SW-QYN3].

81 Philip Koopman, Aaron Kane & Jen Black, *Credible Autonomy Safety Argumentation*, SAFETY-CRITICAL SYS. SYMP. 1, 17 (2019), http://users.ece.cmu.edu/~koopman/pubs/Koopman19_SSS_CredibleSafetyArgumentation.pdf [https://perma.cc/VCJ6-AN8R].

82 *Id.*

83 WAYMO, *supra* note 76, at 26.

84 *See* APTIV SERVS. U.S., AUDI AG, BAYRISCHE MOTOREN WERKE AG, BEIJING BAIDU NETCOM SCI. TECH., CONT'L TEVES AG & CO., DAIMLER AG, FCA U.S. LLC, HERE GLOB. B.V., INFINEON TECHS. AG, INTEL & VOLKSWAGEN AG, SAFETY FIRST FOR AUTOMATED DRIVING 95 (2019), https://www.daimler.com/documents/innovation/other/safety-first-for-automated-driving.pdf [https://perma.cc/2X74-ZWR2].

The process of developing AV software takes tremendous time and resources.[85] But the process of implementing fixes to software is almost costless. All it requires is uploading the new code to the AVs' onboard computers. As Brad Templeton, an early advisor to Google's AV team, explains, for AV technology, "failures will almost all be software issues. As such, once fixed, they can be deployed for free. The logistics of the 'recall' will cost nothing. GM would have no reason not to send out a software update once they found a problem."[86]

AV companies are currently testing their L4 vehicles on the road in limited ODDs. Most testing to date has taken place in regions with warm climates because operating in heavy snow remains a hard engineering problem for AV technology.[87] Some AV companies restrict their vehicles to roads with a speed limit below 25 mph.[88] Other limitations on ODD are more subtle and difficult to infer from publicly available information. For example, it's widely known that AVs have encountered trouble with left turns against oncoming traffic without a dedicated left turn arrow.[89] It's possible that some AV companies may be treating these "unprotected" left turns as outside their vehicles' current ODD. Almost all AV companies testing vehicles on public roads are relying on backup drivers, seated behind the steering wheel and ready to take over manual control when necessary. As of September 2020, Waymo had driven 65,000 miles on public roads without a backup driver, but its AVs are

[85] A major contributor to the cost of development is the compensation that AV software engineers and research scientists receive. *See, e.g.*, Alan Ohnsman, *Autonomous Car Race Creates $400k Engineering Jobs for Top Silicon Valley Talent*, FORBES (Mar. 27, 2017, 12:33 PM), https://www.forbes.com/sites/alanohnsman/2017/03/27/autonomous-car-race-creates-400k-engineering-jobs-for-top-silicon-valley-talent/#470d1a8114a3 [https://perma.cc/6AW9-8NBH] ("Salaries in the Bay Area, including annual bonuses and equity, currently average $295,000 a year for top self-driving car engineers, and range from $232,000 to as much as $405,000.").

[86] Brad Templeton, *An Alternative to Specific Regulations for Robocars: A Liability Doubling*, BRAD IDEAS (June 1, 2016, 12:34 AM), https://ideas.4brad.com/alternative-specific-regulations-robocars-liability-doubling [https://perma.cc/B5ZN-7HWX].

[87] *See* Leslie Hook, *Self-Driving Cars Face a New Test: Snow*, FIN. TIMES (Dec. 21, 2017), https://www.ft.com/content/99225360-e071-11e7-8f9f-de1c2175f5ce [https://perma.cc/277L-AEMV].

[88] *See* Aarian Marshall, *A Not-So-Sexy Plan to Win at Self-Driving Cars*, WIRED (Dec. 4, 2018, 3:30 PM), https://www.wired.com/story/may-mobility-win-self-driving-cars/ [https://perma.cc/RDS4-4WV3] (reporting that AV startup May Mobility's vehicles are operating at 25 mph or less on public roads in Rhode Island).

[89] *See* Amir Efrati, *With Waymo Robotaxis, Customer Satisfaction Is Far from Guaranteed*, THE INFO. (Mar. 22, 2019, 6:31 AM), https://www.theinformation.com/articles/with-waymo-robotaxis-customer-satisfaction-is-far-from-guaranteed [https://perma.cc/67ED-WCSN] (reporting that Waymo's AVs are struggling with left turns against oncoming traffic).

still driving several millions of miles each year with backup drivers behind the wheel.[90] As the technology matures, AV companies hope to expand their AVs' ODDs and to rely less on backup drivers. Their ultimate goal is to deploy AVs that don't need backup drivers at all.

The media frequently publishes predictions about when AVs will be deployed at scale. Many have been falsified. In 2015, Chris Urmson, one of the early leaders of Google's AV project, said that his team was aiming to have AVs available by the time that his eleven year old son would take a driver's test four-and-a-half years later.[91] When asked about that prediction in 2019, Urmson said, "I think none of us really understood just how hard this problem was."[92] Recently, a consensus in the industry has developed that initial predictions about timelines were too optimistic.[93] AV companies will likely deploy their AVs as soon they can safely navigate an economically significant OOD, to signal to investors that they're on a path to profitability. The answer to when AVs will be safe enough to deploy depends on solving currently unsolved engineering problems.

B. The Robotaxi Business Model

The earliest deployments of fully autonomous passenger vehicles will likely arrive in the form of a robotaxi. Consumers will purchase rides rather than vehicles. Almost every major company in the industry is either pursuing this business model or has invested in other companies that are pursuing it.[94] Businesses actively developing technology for a

[90] *See* SCHWALL ET AL., *supra* note 13, at 1.

[91] Jane Wakefield, *TED 2015: Google Boss Wants Self-Drive Cars 'for Son'*, BBC NEWS (Mar. 18, 2015), https://www.bbc.com/news/technology-31931914 [https://perma.cc/KXX2-3EYQ].

[92] Dan Costa, *Aurora Is Not Building Autonomous Cars, It's Building Safe Drivers*, PCMAG (Mar. 25, 2019), https://www.pcmag.com/article/367343/aurora-is-not-building-autonomous-cars-its-building-safe-d [https://perma.cc/ZN62-6TAM].

[93] *See* Neal E. Boudette, *Despite High Hopes, Self-Driving Cars Are 'Way in the Future,'* N.Y. TIMES (July 17, 2019), https://www.nytimes.com/2019/07/17/business/self-driving-autonomous-cars.html [https://perma.cc/7Q7T-HD3K].

[94] One possible exception is Apple, which has publicly stated that it is working on AV technology, but has not disclosed how it plans to bring the technology to market. *See* Alex Webb & Emily Chang, *Tim Cook Says Apple Focused on Autonomous Systems in Cars Push*, BLOOMBERG (June 13, 2017, 3:00 AM), https://www.bloomberg.com/news/articles/2017-06-13/cook-says-apple-is-focusing-on-making-an-autonomous-car-system [https://perma.cc/DL5T-W5G6]. It is worth noting that Apple has invested $1 billion in Didi Chuxing, the leading Chinese ride-hailing company. Julia Love, *Apple Invests $1 Billion in Chinese Ride-Hailing Service Didi Chuxing*, REUTERS (May 12, 2016, 7:11 PM), https://www.reuters.com/article/us-apple-china/apple-invests-1-billion-in-

robotaxi service include tech companies like Alphabet's Waymo[95] and Amazon's Zoox[96] and traditional automakers like General Motors ("GM")'s Cruise,[97] Ford's Argo AI,[98] and Hyundai's Motional.[99] Ridehailing companies embraced the robotaxi model early,[100] but found that their cash-hemorrhaging businesses couldn't sustain the R&D expense. Uber spent years trying to develop a robotaxi in house, but it never recovered from a fatal crash in 2018.[101] In 2020, Uber sold its AV program to Aurora, a company that plans to develop robotaxis but is

chinese-ride-hailing-service-didi-chuxing-idUSKCN0Y404W [https://perma.cc/NHD2-4DZU].

95 *See* John Krafcik, *Waymo One: The Next Step on Our Self-Driving Journey*, MEDIUM: WAYMO BLOG (Dec. 5, 2018), https://medium.com/waymo/waymo-one-the-next-step-on-our-self-driving-journey-6d0c075b0e9b [https://perma.cc/WEP8-CNBZ] (announcing the start of Waymo's robotaxi service).

96 Karen Weise & Erin Griffith, *Amazon to Buy Zoox, in a Move Toward Self-Driving Cars*, N.Y. TIMES (June 26, 2020), https://www.nytimes.com/2020/06/26/business/amazon-zoox.html [https://perma.cc/QA8S-9NWM] (reporting that Amazon stated that it hoped to bring Zoox's "vision of autonomous ride-hailing to reality").

97 *See* Dan Ammann, Th*e Next Steps to Scale Start in San Francisco*, MEDIUM: CRUISE BLOG (July 24, 2019), https://medium.com/cruise/the-next-steps-to-scale-start-in-san-francisco-713315f3a142 [https://perma.cc/HZ6Z-K3NC] (reiterating GM's plan to "deploy a fully driverless service in San Francisco" in the context of announcing that deployment will take longer than anticipated).

98 *See* FORD MOTOR CO., A MATTER OF TRUST: FORD'S APPROACH TO DEVELOPING SELF-DRIVING VEHICLES 6 (2018), https://media.ford.com/content/dam/fordmedia/pdf/Ford_AV_LLC_FINAL_HR_2.pdf [https://perma.cc/U95S-JSZX] (stating, "[i]nitially, self-driving vehicles will work best in a different business model: one where vehicles are accessed and shared versus owned and driven.").

99 Andrew J. Hawkins, *Hyundai's Autonomous Vehicle Project with Aptiv Will Now Be Called Motional*, VERGE (Aug. 11, 2020, 8:00 AM), https://www.theverge.com/2020/8/11/21362322/hyundai-aptiv-motional-autonomous-vehicle-joint-venture [https://perma.cc/N587-34H2] (reporting that Motional "plans to test fully driverless vehicles for ride-hailing services").

100 *See, e.g.*, John Zimmer, *The Third Transportation Revolution: Lyft's Vision for the Next Ten Years and Beyond*, MEDIUM: JOHN ZIMMER (Sept. 18, 2016), https://medium.com/@johnzimmer/the-third-transportation-revolution-27860f05fa91 [https://perma.cc/K7HM-QXXS] (outlining Lyft's vision for robotaxis and predicting that "[b]y 2025, private car ownership will all-but end in major U.S. cities").

101 *See* Cade Metz & Kate Conger, *Uber, After Years of Trying, Is Handing Off Its Self-Driving Car Project*, N.Y. TIMES (Dec. 7, 2020), https://www.nytimes.com/2020/12/07/technology/uber-self-driving-car-project.html [https://perma.cc/9HD7-U6HL]. For analysis of the fatal crash, see *infra* Part II.D.

prioritizing automated trucking.[102] In 2021, Lyft followed Uber's lead, selling its AV unit to Woven Planet, a Toyota subsidiary.[103]

Most of the other major automakers are partnering with one of the AV companies. Renault-Nissan announced a partnership with Waymo to develop a robotaxi.[104] Volkswagen has a similar partnership with Argo AI.[105] Honda partnered with Cruise.[106] Even Tesla, which continues to market its L2 Autopilot software, has said it will one day enable owners to rent out their vehicles as robotaxis.[107] In fact, in early 2021, Tesla CEO Elon Musk invoked the possibility of using Teslas as robotaxis to justify the company's $800 billion market capitalization.[108]

The industry has converged on the robotaxi model for both economic and technological reasons. The economic advantage of robotaxis over

102 *See* Metz & Conger, supra note 101; *see also* Dana Hull, *Aurora Partners with Toyota in Bid to Bring Autonomy to Masses*, BLOOMBERG (Feb. 9, 2021, 9:00 AM), https://www.bloomberg.com/news/articles/2021-02-09/toyota-autonomous-vehicle-startup-aurora-enter-self-driving-cars-partnership [https://perma.cc/87YF-C8AH] (explaining that Aurora is interested in developing a robotaxi service but is focusing on commercial vehicles first).

103 Preetika Rana, *Lyft Agrees to Sell Autonomous-Driving Unit to Toyota for $550 Million*, WALL ST. J. (Apr. 26, 2021, 5:08 PM), https://www.wsj.com/articles/lyft-agrees-to-sell-autonomous-driving-unit-to-toyota-for-550-million-11619467500 [https://perma.cc/8VS9-9UB6].

104 *See* Press Release, Renault Nissan Mitsubishi & Waymo, Groupe Renault and Nissan Sign Exclusive Alliance Deal with Waymo to Explore Driverless Mobility Services (June 20, 2019), https://www.alliance-2022.com/news/groupe-renault-and-nissan-sign-exclusive-alliance-deal-with-waymo-to-explore-driverless-mobility-services/ [https://perma.cc/97ES-DWW8] (announcing that the businesses have entered into a partnership "to explore all aspects of driverless mobility services for passengers and deliveries in France and Japan").

105 *See Ford - Volkswagen Expand Their Global Collaboration to Advance Autonomous Driving, Electrification and Better Serve Customers*, FORD MOTOR CO. (July 12, 2019), https://media.ford.com/content/fordmedia/fna/us/en/news/2019/07/12/ford-vw.html [https://perma.cc/UU2K-UHDM] ("Argo AI's focus remains on delivering a SAE Level 4-capable SDS to be applied for ride sharing and goods delivery services in dense urban areas.").

106 *See* Neal E. Boudette, *Honda Putting $2.75 Billion into G.M.'s Self-Driving Venture*, N.Y. TIMES (Oct. 3, 2018), https://www.nytimes.com/2018/10/03/business/honda-gm-cruise-autonomous.html [https://perma.cc/3DDX-8ZXR].

107 Kirsten Korosec, *Tesla Plans to Launch a Robotaxi Network in 2020*, TECHCRUNCH (Apr. 22, 2019, 2:38 PM), https://techcrunch.com/2019/04/22/tesla-plans-to-launch-a-robotaxi-network-in-2020/ [https://perma.cc/5AAC-XTPD] (reporting that Elon Musk said he felt "very confident predicting that there will be autonomous robotaxis from Tesla next year" — a prediction that didn't materialize).

108 *See* Ari Levy & Laura Kolodny, *Elon Musk Explains How Self-Driving Robotaxis Will Justify Tesla's Massive Valuation*, CNBC (Jan. 27, 2021, 8:22 PM), https://www.cnbc.com/2021/01/27/elon-musk-explains-how-self-driving-robotaxis-justify-tesla-valuation.html [https://perma.cc/SPY7-HSD2].

individually-owned AVs is higher utilization rates.[109] Most individually-owned vehicles are lightly utilized. They sit and depreciate in driveways, garages, or parking lots for about 90% of the day.[110] In recent years, new business models have emerged to increase vehicle utilization rates. Car-sharing networks, like Zipcar, allow multiple drivers to use the same car at different times in one day.[111] But car-sharing networks must manage demand carefully, because their cars sit idle between rides. Taxis generally have higher utilization rates than individually-owned vehicles, but they're still limited by the schedule of the human driver. For an AV, when one trip ends, the AV can drive autonomously to where the next trip will begin. An operator of a robotaxi fleet seeking to maximize profits will optimize routes to increase utilization rates. Higher utilization rates mean more transportation demand can be served with fewer vehicles. One recent study estimates that a robotaxi fleet that is 70% of the size of the current taxi fleet "can provide adequate service with current taxi demand levels in Manhattan."[112]

The limits of existing AV technology also favor the robotaxi business model. AVs rely heavily on the detailed maps that their engineers create before they're tested on the road.[113] Maps give an AV information about what lanes are available, which turns are possible, and where traffic lights should be detected. Of course, AVs must rely on their perception systems to determine if new objects, stationary or moving, have altered the map. But trying to navigate without these detailed maps is, at least for now, impractical. Mapping a new geography has a high fixed, upfront cost.[114] Therefore, if an AV company sought to sell vehicles to

[109] *See* Marco Pavone, *Autonomous Mobility-on-Demand Systems for Future Urban Mobility*, AUTONOMOUS DRIVING 2, 12 (Markus Maurer et al. eds., 2016) (explaining that currently "most of the vehicles used in urban environments are overengineered and underutilized").

[110] *Id.* at 2.

[111] Not coincidentally, Waymo hired Avis, Zipcar's corporate parent, to manage its AV fleet. Mark Bergen, *Alphabet Inks Deal for Avis to Manage Self-Driving Car Fleet*, BLOOMBERG (June 26, 2017, 7:00 AM), https://www.bloomberg.com/news/articles/2017-06-26/alphabet-inks-deal-for-avis-to-manage-self-driving-car-fleet [https://perma.cc/5JTX-VRV8].

[112] Pavone, *supra* note 109, at 10.

[113] *See* Leslie Hook, *Driverless Cars: Mapping the Trouble Ahead*, FIN. TIMES (Feb. 20, 2018), https://www.ft.com/content/2a8941a4-1625-11e8-9e9c-25c814761640 [https://perma.cc/2VC2-228A] (explaining the importance of detailed, continually updated maps to AV operation).

[114] *See id.* (explaining that "[b]ecause companies do not share mapping data and use different standards, they must create new maps for each new city that they plan to enter," which will, according to the founder of an AV mapping startup, "delay the deployment in certain geographies").

consumers, it would either have to wait until all destinations where the consumer might want to travel had been mapped or sell a vehicle that could only be driven in a geofenced area. As one AV investor puts it, "since cars are designed to move across multiple geographies, it's hard to sell a consumer vehicle that only works in, say, Phoenix, but cannot take a road trip to San Francisco."[115] For a robotaxi service, being limited to one metropolitan area is no problem. That's how taxis have always been used and how Lyft and Uber are used today.

When an AV company wants to move into a new region, it needs to test its AVs on the roads first to validate them in local conditions. Local driving behavior can be idiosyncratic. For example, in Pittsburgh, it's common for the first driver in the left turn lane at an intersection to turn left immediately after the light turns green, ahead of the traffic going straight through the intersection.[116] Researchers at Carnegie Mellon have adapted the AVs they're testing on Pittsburgh's roads to wait "a full second or longer for an intersection to clear before proceeding at a green light."[117] A new geography can also have novel road features, like New Jersey's jughandles, or novel vehicle types, like London's double-decker buses. As with mapping, the initial testing and validation period has fixed, upfront costs, which makes geofenced deployments more practical.

In the early years, AVs' limited ODDs will also favor a robotaxi business model. Consumers aren't likely to buy a vehicle limited to 45 mph. But they might be willing to buy a ride within an urban area during which the AV will be limited to that speed. Likewise, consumers might be frustrated with a vehicle that would only turn left at intersections with a dedicated left turn arrow, but it's easy to imagine commercially viable robotaxi routes planned to avoid unprotected lefts.

C. *Potential for Superhuman Performance*

AVs should eventually outperform human drivers on safety simply by avoiding common human errors. Recall that NHTSA estimates that

[115] Mike Volpi, *Not So Fast: Driverless Cars Will Change Everything–But Not Anytime Soon*, FAST CO. (Mar. 26, 2019), https://www.fastcompany.com/90324427/not-so-fast-driverless-cars-will-change-everything-but-not-anytime-soon [https://perma.cc/WU8S-9Q9P].

[116] Mike Wereschagin, *'Pittsburgh Left' Seen by Many as a Local Right*, PITTSBURGH TRIB. LIVE (June 14, 2006, 12:00 AM), https://archive.triblive.com/news/pittsburgh-left-seen-by-many-as-a-local-right/#axzz2SAfy5vRK [https://perma.cc/RHT6-J6T4].

[117] *The Problem with Self-Driving Cars Could Turn Out to Be Humans*, CNBC (May 11, 2017, 12:15 PM), https://www.cnbc.com/2017/05/11/the-problem-with-self-driving-cars-could-turn-out-to-be-humans.html [https://perma.cc/66FN-UGDD].

driver error is the critical reason for 94% of all United States motor vehicle crashes.[118] Impaired driving contributes greatly to those errors. NHTSA collects detailed data on fatal crashes from state and local agencies through its Fatality Analysis Reporting System ("FARS").[119] In the 2019 FARS data, there was at least one driver with a blood alcohol concentration ("BAC") of .08 g/dL or higher (the legal limit in every state) in 28% of fatal crashes.[120] It's more difficult to determine whether distraction or drowsiness contributed to a crash. NHTSA was nonetheless able to establish that, of the fatal crashes in the 2019 FARS data, 8.7% were "distraction-affected" and 1.9% involved a drowsy driver.[121] These numbers should be viewed as conservative estimates.

Human drivers, impaired or not, violate the traffic law. Some of those violations lead to crashes. To take one example, in the 2018 FARS data, there was at least one driver speeding in 26% of fatal crashes.[122] AVs will never drive drunk, drowsy, or distracted. AVs will obey the speed limit, respect the right-of-way, and maintain a safe following distance. These basic differences between AV behavior and CV behavior explain much of the safety improvements that AVs can bring. They don't depend on any changes to liability rules. Liability matters because AVs have the potential to drive more safely than even sober, alert, and law-abiding drivers.

AVs will pay better attention to their surroundings because they're not constrained by the limits of human physiology. Drivers are instructed to check side-view and rear-view mirrors frequently. Many recent generation CVs have rear-view cameras to assist. In fact, these cameras prevent enough crashes that Consumer Reports has recommended that drivers install aftermarket backup cameras in older cars to eliminate the rear-view blind zone.[123] AVs have a continuously

118 NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., CRITICAL REASONS FOR CRASHES, *supra* note 6.

119 *See Fatality Analysis Reporting System (FARS)*, NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars (last visited Jan. 22, 2021) [https://perma.cc/GJC3-QUSD].

120 NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., MOTOR VEHICLE CRASHES IN 2019, *supra* note 1, at 9.

121 *See id.*

122 NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., DOT HS 812 932, TRAFFIC SAFETY FACTS: SPEEDING 1 (2020), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812932 [https://perma.cc/SN3J-B9C8].

123 *See Car and Truck Backup Cameras Systems*, CONSUMER REPS., https://www.consumerreports.org/cro/2012/12/car-backup-cameras/index.htm (last updated Jan. 2014) [https://perma.cc/WMP7-TL5T].

updated, 360-degree, three-dimensional view of their surroundings.[124] Consequently, AVs may detect that a car in an adjacent lane is moving too close or that a rear-end collision is imminent more rapidly than a human driver would. When an AV must make a quick decision about braking or swerving, the software will know whether adjacent lanes are clear. AVs' greater awareness of their surroundings doesn't guarantee that they will make the right decisions about how to act on that information. But when the right decision is straightforward, AVs' enhanced situational awareness should lead to fewer crashes.

AVs will also have better reaction times than drivers. Depending on conditions, human drivers have reaction times from 1.6 to 2.5 seconds and AVs have reaction times between 0.5 and 0.75 seconds.[125] When a driver perceives a child darting into the street, the driver must first decide how to act and then mechanically depress the brake pedal or turn the steering wheel, which relays an electronic signal to the brakes or wheels. AVs remove the mechanical step. In certain cases, AVs may also reduce the decision time. AVs' combined potential for paying better attention and reacting faster creates the possibility of dramatically reducing crashes through rapid action.

AVs could eventually develop superhuman abilities to perceive the world. Advances in perception software could enable AVs to reliably detect and classify vehicles, cyclists, and pedestrians earlier and from further away than drivers can. An AV's sensors could have a longer range than human eyes. They could be designed to work better at night, in the glare of the sun, or in inclement weather. Greater perception capabilities could give AVs more time to act and avoid a collision. Existing AV technology still struggles with important perception tasks, like perceiving objects in heavy rain and snow.[126] But experts are

[124] *See, e.g.*, WAYMO, *supra* note 76, at 14 (describing at a high level how Waymo's sensors permit its AV software "to see 360 degrees" and create "a detailed 3D picture of the world").

[125] *See* BRANDON SCHOETTLE, SENSOR FUSION: A COMPARISON OF SENSING CAPABILITIES OF HUMAN DRIVERS AND HIGHLY AUTOMATED VEHICLES 14-15 (2017), http://www.umich.edu/~umtriswt/PDF/SWT-2017-12.pdf [https://perma.cc/P8UP-DHH7] (noting that the study's estimates of human reaction times were based on publicly available sources and estimates for AV reaction times were "based on conversations with individuals who are familiar with AV design and performance").

[126] *See, e.g.*, John Markoff, *A Guide to Challenges Facing Self-Driving Car Technologists*, N.Y. TIMES (June 7, 2017), https://www.nytimes.com/2017/06/07/technology/autonomous-car-technology-challenges.html [https://perma.cc/4WLC-NKKF] (reporting that "[h]eavy rain or snow can confuse current car radar and lidar systems").

optimistic about AV perception, because machine learning solutions have shown promising results.[127]

AVs may also eventually make better decisions than drivers do. Because they pay better attention to their surroundings, AVs will be able to consider more options. AV software will also have had far more experience than any human driver, because the software learns from the experience of every vehicle in the fleet and from the far greater number of miles driven in simulation. AVs may make decisions that would puzzle a lay observer, but sometimes this unpredictable behavior will be useful. Roboticists call this useful, unexpected behavior "emergence."[128] Emergent behavior by AVs may mean finding ways to drive more safely or efficiently than humans regularly do. But right now, AVs are worse than sober, attentive, careful drivers at some decision-making tasks, because it's difficult to automate judgment.

D. Unsolved Engineering Problems

In its current state, AV technology struggles to reliably predict the behavior of other road users and communicate with them. There are, of course, many situations in which AVs will fail to drive safely that don't involve these limitations. Because AV testing has only been conducted in a small number of cities, mostly in the developed world, and generally in favorable weather, it's possible that the most difficult edge cases have yet to be discovered.[129] But failures in automating judgment already create edge cases that are common in real-world testing, such as when an AV plans to turn left against oncoming traffic.

Behavior prediction may be the most important unsolved engineering problem for AVs. As Harry Surden and Mary-Anne Williams have explained, humans, unlike AVs, have a sophisticated "theory of mind"

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127 *See* Lex Fridman, *Drago Anguelov (Waymo) – MIT Self-Driving*, YOUTUBE (Feb. 12, 2019), https://www.youtube.com/watch?v=Q0nGo2-y0xY [https://perma.cc/LDQ7-462Y] (discussing the application of machine learning techniques to engineering problems in autonomous driving, especially perception tasks). *But see* STEVEN E. SHLADOVER, PRACTICAL CHALLENGES TO DEPLOYING HIGHLY AUTOMATED VEHICLES 39 (2018) (claiming that, with machine learning techniques, a 90% accuracy rate for "recognizing objects in a fairly complex environment is considered very good," but that much higher accuracy rates will be required for driving in high density urban environments).

128 *See* Calo, *supra* note 31, at 538-45.

129 *Cf.* Bryan H. Choi, *Crashworthy Code*, 94 WASH. L. REV. 39, 102 (2019) ("[S]oftware developers lean heavily on ex post error removal strategies: testing the code as much as is economically feasible, and fixing any errors discovered thereby. But a well-known truism of software assurance is that testing cannot prove the absence of errors, only their presence.").

— the "ability to extrapolate from our own internal mental states to estimate what others are thinking, feeling, or likely to do."[130] We make inferences about another person's likely future behavior by observing his or her present behavior. Surden and Williams give the interesting example that people often lean slightly in the direction they intend to move.[131] We also make inferences based on our store of knowledge about human behavior. We expect humans to break some rules. We aren't surprised by jaywalking. We expect some humans, like children or intoxicated adults, not to follow rules at all.[132]

When we see someone walking toward the street, we can generally infer that they will stop at the sidewalk's edge. When we see a child or a visibly intoxicated person nearing the edge, though, we would use extra caution. Our expectations about their mental states allow us to infer their likely behavior. It may eventually be possible to develop software that can handle each of these cases. Once an AV's perception system can reliably distinguish children from adults, for example, the software can slow down near children. But there are more subtle edge cases — like a child chasing a ball into the roadway — that would be simple for a human decision-maker but might be complex for AV software.

Behavior prediction can require inferences that are context-sensitive. Suppose, for example, that an ambulance is approaching from behind with its sirens blaring. Waymo claims that its AVs have audio sensors that can detect sirens and that the "audio sensors are designed to discern the direction sirens are likely coming from."[133] But detecting the ambulance isn't the hard problem. It's predicting what other road users will do in response. That behavior may be highly situation-specific. Drivers might move abruptly into an adjacent lane or even onto the shoulder. Clearing a path for the ambulance might require the AV to enter a lane that it wouldn't otherwise consider safe to enter. Suppose instead that the ambulance is driving against the direction of traffic — or that it's riding without its sirens because it's carrying a patient with a heart condition — and the complexity becomes apparent.

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130 Surden & Williams, *supra* note 43, at 124.

131 *Id.* at 155.

132 *See* Philip Koopman & Frank Fratrik, *How Many Operational Design Domains, Objects, and Events?*, SAFEAI (2019), http://users.ece.cmu.edu/~koopman/pubs/Koopman19_SAFE_AI_ODD_OEDR.pdf [https://perma.cc/EEA4-5H67] (listing these examples as events that must be handled safely in AV object and event detection response).

133 WAYMO, *supra* note 76, at 33.

AVs also have a limited ability to detect and interpret communication from other road users. For example, drivers often use hand signals to let another driver, cyclist, or pedestrian know that they're yielding the right-of-way or that they want the other road user to yield.[134] Waymo recently released a video in which one of its AVs navigated an intersection in which a police officer was directing traffic with hand signals.[135] It may seem impressive, but the circumstances made the communication problem easier than it could have been. The traffic light wasn't functioning, and the officer was standing in the middle of the street. These are reliable clues that the AV needs to receive communication. The officer's hand signals may have been easier to detect and interpret than another driver's signals would be. True edge cases will involve more ambiguity about whether communication is intended and what the content of the message is.

Likewise, AVs will struggle to communicate back to other road users.[136] One reason why unprotected left turns have proved so challenging is that "[m]erging into rapidly flowing lanes of traffic is a delicate task that often requires eye contact with oncoming drivers."[137] Engineers are experimenting with different signals that could be broadly understood.[138] But even if AVs could send clear messages, they would also need to determine that they had been received. As with behavior prediction, local knowledge and culture can complicate the communication problem. In the long run, V2V communication — electronic signals transmitted between vehicles — may provide the answer. But V2V communication networks face a collective action problem.[139] AV companies have little incentive to invest in V2V

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[134] *See* Surden & Williams, *supra* note 43 at 156 ("A driver who is trying to merge may wave to get the attention of another driver to move in front.").

[135] Waymo, *Waymo's Autonomous Driving Technology Navigates a Police Controlled Intersection*, YOUTUBE (Feb. 20, 2019), https://www.youtube.com/watch?v=OopTOjnD3qY [https://perma.cc/2SZQ-KWBX].

[136] *See* Surden & Williams, *supra* note 43, at 160-61 (explaining how AVs struggle to communicate their intentions to other road users).

[137] Markoff, *supra* note 126.

[138] *See* Megan Rose Dickey, *Here's How Lyft Envisions Self-Driving Cars Communicating with Pedestrians*, TECHCRUNCH (Dec. 11, 2018, 12:49 PM), https://techcrunch.com/2018/12/11/lyft-self-driving-car-communication-patent/ [https://perma.cc/69R7-VX7T] (linking to patents on AV external communication filed by Google, Uber, and Lyft).

[139] *See* Brad Templeton, *V2V and the Challenge of Cooperating Technology*, BRAD TEMPLETON, https://www.templetons.com/brad/robocars/v2vdata.html (last visited Feb. 10, 2021) [https://perma.cc/73DJ-Y8CN] (describing the "chicken and egg problem" of V2V investment).

capabilities until they can expect that most other vehicles will also be using the V2V system.

AV companies are working to solve some of these engineering problems as they work to bring their AVs' performance up to the level of reasonable human drivers. But they won't have an incentive to develop AVs' full potential for superhuman performance without a change in liability rules.

II. AV CRASHES

Fully autonomous vehicles have been involved in crashes on public roads since at least 2014.[140] In 2021, NHTSA ordered companies developing AVs to start reporting crashes to federal regulators.[141] But until NHTSA's database is populated, the best publicly available sources for data on AV crashes are Waymo's report on its testing in Arizona in 2019 and California's mandatory Autonomous Vehicle Collision Reports. The crash data indicate that existing AV technology rarely causes crashes but sometimes fails to prevent plausibly preventable crashes caused by other road users' errors. More detailed information is available for a few AV crashes that have been the subject of police or regulatory investigations, including a crash between an Uber AV and a CV in 2017 and a fatal crash between another Uber AV and a pedestrian in 2018. These collisions illustrate the difficulty of applying anthropomorphic standards of care to crashes involving AVs.

A. Waymo's Safety Performance Data

In October 2020, Waymo released a report that it called "Public Road Safety Performance Data."[142] It's the most extensive report on L4 AV safety to date. The report includes every contact between Waymo AVs and other objects during 6.1 million miles of autonomous driving with a backup driver in Arizona in 2019.[143] It also covers 65,000 miles of

140 Automotive parts supplier Delphi reported a crash involving an AV operating in conventional mode to the California DMV in 2014. *See* DELPHI AUTO. SYS., LLC, FORM OL 316, at 2 (2014). Google reported that one of its AVs was involved in an autonomous mode crash on April 7, 2015. *See* GOOGLE AUTO, LLC, FORM OL 316, at 7 (2015).

141 *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., INCIDENT REPORTING FOR AUTOMATED DRIVING SYSTEMS (ADS) AND LEVEL 2 ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) 10-14 (2021), https://www.nhtsa.gov/sites/nhtsa.gov/files/2021-08/First_Amended_SGO_2021_01_Final.pdf [https://perma.cc/DHQ4-NLB3].

142 SCHWALL ET AL., *supra* note 13.

143 *Id.* at 3.

fully driverless operation in 2019 and the first nine months of 2020.[144] The total number of miles covered in the report is roughly equivalent to the number of miles driven in eight human lifetimes.[145]

Assessing the safety performance of Waymo's AVs requires accounting for the potential crashes that were prevented by one of its backup drivers taking over manual control.[146] Waymo addresses this problem by including counterfactual "simulated contacts" in its report. A simulated contact occurs if Waymo's simulation software predicts that the AV would have come into contact with another object if the backup driver hadn't taken over.[147] Developing high fidelity simulations is difficult. Waymo's engineers can confidently predict how an AV would behave in the first moment of the counterfactual world with no takeover because they know what the software was programmed to do. But they can't predict with certainty how other agents would behave and what the AV would have done in response. As long as AV companies are testing with backup drivers, though, data from counterfactual simulations must supplement data from real-world driving to accurately measure AV safety performance.

Waymo reports that, during the 6.1 million miles with the backup driver, its AVs were involved in 46 contacts, 17 actual contacts and 29 simulated contacts.[148] During the 65,000 fully driverless miles, there was one (actual) contact.[149] Of the 47 contacts, 30 either didn't result in an injury or weren't expected to result in an injury based on simulation.[150] The remaining 17 were serious enough that there was a probability of some injury.[151] In three of the actual contacts, the vehicle's airbag deployed, and, in five of the simulated contacts, an airbag deployment was predicted to result from the collision.[152] The total number of contacts isn't useful for comparisons with human

[144] *Id.* at 1.

[145] Brad Templeton, *Waymo Data Shows Superhuman Safety Record. They Should Deploy Today*, FORBES (Oct. 30, 2020, 10:00 AM), https://www.forbes.com/sites/bradtempleton/2020/10/30/waymo-data-shows-incredible-safety-record--they-should-deploy-today/ [https://perma.cc/G2YJ-Z73U].

[146] Waymo reports that its simulations predict that, in over 99.9% of takeovers, continued autonomous operation would not have resulted in a contact. SCHWALL ET AL., *supra* note 13, at 4-5.

[147] *See id.* at 3-5 (describing how Waymo models simulated contacts).

[148] *See id.* at 5.

[149] *Id.* at 3.

[150] *See id.* at 5 (classifying crashes according to ISO 26262, a standard widely accepted in the industry).

[151] *See id.*

[152] *See id.*

drivers. Many of the contacts Waymo describes are contacts that most drivers wouldn't report to insurance or law enforcement.[153] The safety performance of Waymo's technology — and Waymo's limited liability exposure — only becomes clear when the contacts are examined in detail. The 47 contacts, both actual and simulated, can be divided into six categories (in rough order of severity): one head-on collision, 15 angled collisions, ten sideswipes, 16 rear-end collisions, two reversing collisions, and three single vehicle collisions.[154]

The head-on collision was the simulated crash discussed in the Introduction. Recall that the CV was travelling the wrong direction late at night and veering toward the AV's lane.[155] The backup driver took over, but the simulation concluded that, if the backup driver hadn't taken over, the vehicles would have collided. Waymo's report infers that "the other driver was significantly impaired or fatigued."[156] Waymo's comparative negligence defense would almost certainly have shielded the company from liability.

The most interesting contacts in the report are the 15 angled collisions. Four of these collisions involve an AV and a CV trying to turn right at the same time. In each of these cases, the AV "was making a right turn from a rightmost lane that was either splitting to an additional lane, or had been the result of two lanes merging to one."[157] A CV "attempted to pass the [AV] on the right while the [AV] was slowing to make the right turn with the right turn signal activated."[158] In each of these collisions, the backup driver took over in the real world, but in simulation, the vehicles collided.[159] Without more detail, it's hard to predict the liability outcome. Overtaking on the right generally

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153 *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., U.S. DEP'T OF TRANSP., DOT HS 812 183, NATIONAL TELEPHONE SURVEY OF REPORTED AND UNREPORTED MOTOR VEHICLE CRASHES 16 (2015), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812183 [https://perma.cc/FSK5-4XLN] [hereinafter NATIONAL TELEPHONE SURVEY OF MOTOR VEHICLE CRASHES] (estimating, based on a phone survey of U.S. adults who had been in a motor vehicle crash in the previous 12 months, that 29.3% of all crashes, and 35.6% of crashes that don't involve an injury, are unreported).

154 SCHWALL ET AL., *supra* note 13, at 11.

155 *See id.* at 7-8.

156 *Id.* at 8.

157 *Id.* at 11.

158 *Id.*

159 *See id.*

violates Arizona's traffic code.[160] But it's not clear how that rule would be applied to a right turn scenario.[161]

In the other 11 angled collisions, the report states that the AV was "traveling straight in a designated lane at or below the speed limit" and "the turning/crossing [CV] either disregarded traffic controls or otherwise did not properly yield right-of-way."[162] The report only provides details on the five events in which the actual contact resulted, or the simulated contact would have resulted, in an airbag deployment. They include: (1) a tractor trailer ignoring a stop sign and turning right onto a road on which an AV was driving straight; (2) a car running a red light and colliding with an AV in an intersection; (3) a vehicle turning right onto a road on which an AV was driving straight; (4) a car making a left across traffic onto a road on which an AV was driving straight; and (5) a car making an unprotected left across an AV's lane, colliding with it in an intersection.[163]

If these five collisions are representative of the rest of the angled collisions, then Waymo would have little liability exposure.[164] The right-of-way isn't always clear. But it's clear when a driver has a stop sign or a red light, and it's usually clear when a driver is turning into or across traffic that has a green light. In fact, Ellen Bublick has found that "in a number of traffic accident cases, courts have refused to permit defendants who run red lights to claim that plaintiffs should have stopped on green."[165] Bublick suggests that courts may not want to allow verdicts that "undermine the normative clarity of the categorical rule that cars should obey traffic signals."[166]

The ten sideswipes follow a distinct pattern. In each of these cases, the AV and the CV were traveling in the same direction. In eight of the ten cases, the AV "was stopped or traveling straight in a designated lane at or below the speed limit," and the CV sideswiped the AV while changing into its lane.[167] In the other two cases, the AV was changing

[160] *See* ARIZ. REV. STAT. ANN. § 28-724 (2021).

[161] These crashes may result from human drivers becoming frustrated that an overly cautious AV is taking too long to turn right.

[162] SCHWALL ET AL., *supra* note 13, at 9.

[163] *See id.* at 9-10.

[164] Simulated collisions (3) and (4) introduce some complexity because vehicles positioned between the CV and the AV obstructed the line-of-sight between them. *See id.* at 10. For more analysis of (3), which Waymo claims its AV would have unsuccessfully attempted to avoid by swerving, see *infra* Part III.B.

[165] Ellen M. Bublick, *Comparative Fault to the Limits*, 56 VAND. L. REV. 977, 1023 (2003). For citations to cases, see *id.* at 1023 n.247.

[166] *Id.*

[167] SCHWALL ET AL., *supra* note 13, at 7.

lanes. In one of those cases, the CV that sideswiped the AV was traveling 30 mph over the speed limit.[168] In the other, the CV "had entered early into a dedicated left turn lane that the [AV] was attempting to merge into."[169] It's unlikely that Waymo would be liable for the eight times a CV entered its lane. There shouldn't be doubt that the AV has the right-of-way. The company might also have a comparative negligence defense in the case in which its AV sideswiped a CV that was speeding 30 mph over the limit. The collision in the left turn lane is more ambiguous. But if the CV entered the lane before the lane markings permitted it, Waymo could have a comparative negligence defense in that case as well.

The 16 rear-end collisions follow a similar pattern. In only one of the 16 events did the AV rear-end the CV. In that case, the CV "swerved into the lane in front of the Waymo and braked hard immediately after cutting in despite lack of any obstruction ahead."[170] The AV's backup driver took over control, but in simulation, the AV would have braked but still come into contact with the rear of the CV at 1 mph.[171] Waymo characterizes the CV driver's behavior as "consistent with antagonistic motive."[172] In other words, Waymo is suggesting that the driver intentionally caused the crash.

In the other 15 rear-end collisions, a CV rear-ended the AV. In eight cases, a CV rear-ended an AV while the AV was stopped or decelerating for traffic controls or traffic ahead.[173] In another four cases, a CV rear-ended an AV while the AV was stationary or near stationary waiting to turn right.[174] In one case, a CV rear-ended an AV while the AV was making a left turn in an intersection.[175] There were two rear-end collisions in which a CV struck an AV while the AV was traveling straight at a slower speed than the CV. In one of those cases, the AV was traveling at the speed limit, and the CV was traveling 23 mph above the limit.[176] In the other, the AV was traveling over a speed bump.[177]

The lopsided ratio of CVs rear-ending AVs to AVs rear-ending CVs is predictable. AVs are programmed to maintain a safe following distance, but human drivers often fail to do so. In a tort case, there's no rule of

168 *Id.*
169 *Id.*
170 *Id.* at 9.
171 *Id.*
172 *Id.*
173 *See id.* at 8.
174 *See id.* at 8-9.
175 *See id.* at 9.
176 *Id.* at 8.
177 *Id.*

law that makes the driver doing the rear-ending liable and the driver being rear-ended not liable. But in practice, the rear-ender is usually liable. According to Laurence Ross's famous study of insurance adjusters, in settlement negotiations for rear-end crashes, there's a "strong presumption of liability on the rear driver."[178] That presumption may be even stronger if the rear-ended vehicle is stationary, waiting to turn, traveling over a speed bump, or hit by a vehicle driving 23 mph over the speed limit.[179]

In the two reversing collisions, the AV "was stopped or traveling forward at low speed and the other vehicle was reversing at a speed of less than 3 mph at the moment of contact to the side of the [AV]."[180] It's unlikely that Waymo would be liable for being struck by a reversing vehicle. Reversing is an especially dangerous maneuver, and drivers are expected to pay close attention while performing it.

In each of the three single vehicle collisions, the AV was stationary. In one case, a pedestrian walked into the right side of the AV.[181] In another case, simulation predicted that a cyclist riding at a low speed would have collided with the right side of an AV that had just decelerated and stopped.[182] In a third case, simulation predicted that a skateboarder would have struck an AV's rear right corner at a low speed.[183] Under existing law, it's difficult to imagine Waymo being held liable for a contact involving a stationary AV. It's not even clear that a court would find that the AV was the factual cause of the injury.[184]

Taken together, most of the contacts described in Waymo's report fit this pattern: a CV violates a traffic law, and the AV fails to prevent a crash. CVs often rear-end AVs, but AVs rarely rear-end CVs. CVs often sideswipe AVs by merging into their lane, but AVs rarely do the reverse. CVs run red lights or stop signs and crash into AVs in intersections. A liability regime that allows AV companies to raise a comparative negligence defense would leave them with little liability exposure, even for many plausibly preventable crashes.[185]

[178] H. LAURENCE ROSS, SETTLED OUT OF COURT: THE SOCIAL PROCESS OF INSURANCE CLAIMS ADJUSTMENT 100 (2d ed. 1980).

[179] *See* SCHWALL ET AL., *supra* note 13, at 8.

[180] *Id.* at 7.

[181] *See id.* at 6-7.

[182] *See id.*

[183] *See id.*

[184] For more on factual cause, see *infra* Part IV.D.

[185] In March 2021, Waymo released a study of how its simulated AVs would have handled a set of 72 fatal crashes in Chandler, Arizona between 2008 and 2017. *See* JOHN M. SCANLON, KRISTOFER D. KUSANO, TOM DANIEL, CHRISTOPHER ALDERSON, ALEXANDER OGLE, TRENT VICTOR, WAYMO SIMULATED DRIVING BEHAVIOR IN RECONSTRUCTED FATAL

B. California's AV Collision Reports

California requires companies to report all collisions "originating from the operation of the autonomous vehicle on a public road that resulted in the damage of property or in bodily injury or death."[186] By 2021, 55 companies held a permit to test AVs in California, though only a fraction of them test at scale.[187] As of December 31, 2020, there had been 271 collisions reported, of which 266 can genuinely be called crashes.[188] The reports indicate whether the AV was operating in either "autonomous mode" or "conventional mode." A collision in "conventional mode" means that the vehicle was "under the active physical control of a natural person sitting in the driver's seat operating or driving the vehicle with the autonomous technology disengaged."[189]

In some cases, drawing a line between autonomous and conventional mode collisions can misleadingly suggest that AV technology didn't contribute to a crash when it did. Suppose that a backup driver anticipates a crash and takes over manual control, but she is unable to avoid the crash. The crash will be labeled a "conventional mode" collision even though the backup driver took over precisely *because* she

CRASHES WITHIN AN AUTONOMOUS VEHICLE OPERATING DOMAIN 5-6 (Mar. 8, 2021), https://storage.googleapis.com/waymo-uploads/files/documents/Waymo-Simulated-Driving-Behavior-in-Reconstructed-Collisions.pdf [https://perma.cc/56GY-7UJL]. The results were broadly consistent with Waymo's October 2020 report. The AVs didn't initiate any crashes — in the sense of violating traffic laws or otherwise deviating from expected driving behavior — and were able to avoid some, but not all, of crashes initiated by other road users. *See id.* at 15-16.

186 CAL. CODE REGS. tit. 13, § 227.48 (2021).

187 *See Autonomous Vehicle Testing Permit Holders*, CAL. DEP'T OF MOTOR VEHICLES, https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-testing-permit-holders/ (last visited Jan. 14, 2021) [https://perma.cc/3MA7-P6ES].

188 Five of the reported incidents were intentional contacts between a pedestrian and an AV. *See* GM CRUISE, LLC, REPORT OF TRAFFIC COLLISION INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (Apr. 11, 2019) (pedestrian attacking an AV with an "foreign object"); GM CRUISE, LLC, REPORT OF TRAFFIC COLLISION INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (July 18, 2018) (pedestrian intentionally stepping onto the AV's hood while it was stopped at a red light); GM CRUISE, LLC, REPORT OF TRAFFIC COLLISION INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (June 26, 2018) (a golf ball from a nearby golf course hit an AV's windshield); GM CRUISE, LLC, REPORT OF TRAFFIC ACCIDENT INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (Feb. 6, 2018) (a taxi driver who got out of his taxi and slapped the AV); GM CRUISE, LLC, REPORT OF TRAFFIC ACCIDENT INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (Jan. 25, 2018) (pedestrian running across the street "against the 'do not walk' symbol, shouting, and str[iking] the left side of [the AV's] rear bumper and hatch with his entire body").

189 CAL. CODE REGS. tit. 13, § 227.02 (2021).

believed that continued autonomous operation would lead to a crash. To address this problem, we can create a third "transitional" collision category for crashes in which the report indicates that the backup driver switched from autonomous to conventional mode in the moments before the contact. Of the 266 collisions, 140 were in autonomous mode, 83 were in conventional mode, and 43 were transitional.[190]

The California reports provide less useful aggregate data than the Waymo report does. The maturity of the AV technology being tested varies significantly from company to company. The California reports also cover a seven year period. AV technology has improved dramatically during that time. California also doesn't require companies to report collisions that were prevented because the safety driver took control. There is no obligation to report counterfactual simulated contacts.

The California reports are useful, however, for corroborating some of the patterns in the Waymo report. Not all of the California reports list traffic citations, but in each of those that do, the CV driver was cited.[191] The lopsided ratio of CVs rear-ending AVs to AVs rear-ending CVs that appears in the Waymo report also appears in the California reports. In 108 of the 140 autonomous mode collisions and in 54 of the 126 conventional mode and transitional collisions, the AV was rear-ended by another vehicle.[192] By contrast, in only three collisions did the AV rear-end another vehicle, and in all three of those collisions, the AV was operating in conventional mode.[193]

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[190] California AV collision reports from 2020 and 2019 are available from the California DMV. *See Autonomous Vehicle Collision Reports*, CAL. DEP'T OF MOTOR VEHICLES, https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-collision-reports/ (last visited Mar. 29, 2021) [https://perma.cc/UR78-K22Q]. Crashes from 2014 to 2018 are available to the public at no cost by emailing the California DMV and are on file with the author.

[191] Some of the collision reports do not include the page of the form that reports whether a citation has been issued. There are four reports that do mention a citation. In three of those four, the human driver of the CV was cited. *See, e.g.*, AIMOTIVE, INC., REPORT OF TRAFFIC COLLISION INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 3 (Oct. 17, 2019) (noting a citation to the CV driver). Cruise filed a report about an incident in which one of its AVs was rear-ended by an electric scooter as the AV was decelerating. *See* GM CRUISE, LLC, REPORT OF TRAFFIC COLLISION INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (Mar. 13, 2019). The report lists a citation, but it does not clarify whether it was the AV's backup driver or the person on the scooter who was cited. *See id.* at 3.

[192] *See Autonomous Vehicle Collision Reports*, *supra* note 190.

[193] *See id.*

What explains this consistent pattern? Rear-end crashes are common.[194] When they don't involve an injury, rear-end crashes are less likely to be reported to the police than other kinds of crashes.[195] AVs may be behaving in unpredictable ways that make them more vulnerable to being rear-ended. AVs are programmed to follow the speed limit, which will make them drive more slowly than the speed of traffic in many situations. AVs also may be more likely to decelerate or stop abruptly when a vehicle, cyclist, or pedestrian stops ahead or moves closer to the roadway. AVs' limited capacity to predict behavior and communicate with other road users may contribute to this problem. If an AV can't accurately predict where a pedestrian walking up to a curb will move next, it might be risk-averse and stop where a human driver wouldn't stop, surprising the human driver behind it.

Several of the California reports are consistent with this theory. In one case, as an AV was nearing an intersection, "a cyclist approached, splitting the lane and riding in the wrong direction on the lane line between the [AV] and a row of parked cars." [196] The AV "slowed as the cyclist approached and passed, and during this time a taxi driving behind the [AV] bumped into the rear of the [AV]."[197] Another report states that an AV had "stopped to yield to another vehicle at the intersection."[198] After being stopped for approximately 1.5 seconds, the AV was rear-ended at approximately 39 mph.[199]

There's at least one reported collision in California in which the AV clearly violated the traffic law. On February 14, 2016, a Google AV — this was before the Google AV program became Waymo — crashed into a public transit bus near the intersection of El Camino Real and Castro

[194] *See* NATIONAL TELEPHONE SURVEY OF MOTOR VEHICLE CRASHES, *supra* note 153, at 41-42 (reporting that, in a phone survey of U.S. adults who had been in a motor vehicle crash in the previous 12 months, there had been damage to the rear of the vehicle in 34.8% of all crashes involving only property damage and in 32.6% of all crashes involving an injury).

[195] *See id.* (reporting damage to the rear of the vehicle in 41.4% of all reported property damage only crashes and 32.4% of all unreported damage only crashes).

[196] GM CRUISE, LLC, REPORT OF TRAFFIC ACCIDENT INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (Apr. 2, 2018).

[197] *Id.*

[198] WAYMO LLC, REPORT OF TRAFFIC COLLISION INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (Feb. 26, 2019).

[199] *Id.*

Street in Mountain View, California.[200] The AV was travelling in the far right lane of El Camino.[201] Google's collision report states:

> As the Google AV approached the intersection, it signaled its intent to make a right turn on red onto Castro St. The Google AV then moved to the right-hand side of the lane to pass traffic in the same lane that was stopped at the intersection and proceeding straight. However, the Google AV had to come to a stop and go around sandbags positioned around a storm drain that were blocking its path. When the light turned green, traffic in the lane continued past the Google AV. After a few cars had passed, the Google AV began to proceed back into the center of the lane to pass the sand bags. A public transit bus was approaching from behind. The Google AV test driver saw the bus approaching in the left side mirror but believed the bus would stop or slow to allow the Google AV to continue. Approximately three seconds later, as the Google AV was reentering the center of the lane it made contact with the side of the bus. The Google AV was operating in autonomous mode and travelling at less than 2 mph, and the bus was traveling at about 15 mph at the time of contact.[202]

Google released a statement in which it admitted "some responsibility" for the crash.[203] After all, its AV had failed to yield the right-of-way. But as AV technology has progressed, it's become more difficult to find examples of L4 AVs unambiguously violating the traffic law.

C. An AV-CV Crash

A typical AV-CV crash today involves a CV driver violating a traffic law and an AV failing to avoid a collision. In some cases, it's clear that the CV driver would be fully liable in tort. In other cases, the liability outcome is more difficult to predict. Consider the crash between an Uber AV and a CV that took place on March 27, 2017, in Tempe, Arizona. Alexandra Cole was driving northbound on McClintock

[200] *Id.*; *See* GOOGLE AUTO, LLC, REPORT OF TRAFFIC ACCIDENT INVOLVING AN AUTONOMOUS VEHICLE (FORM OL 316), at 2 (Feb. 23, 2016). Reports of traffics accidents involving autonomous vehicles dated before January 1, 2019, are archived, but are available upon request. *See Autonomous Vehicle Collision Reports*, *supra* note 190.

[201] *Id.*

[202] *Id.*

[203] David Shepardson, *Google Says It Bears 'Some Responsibility' After Self-Driving Car Hit Bus*, REUTERS (Feb. 29, 2016, 10:25 AM), https://www.reuters.com/article/us-google-selfdrivingcar-idUSKCN0W22DG [https://perma.cc/36N9-6CME].

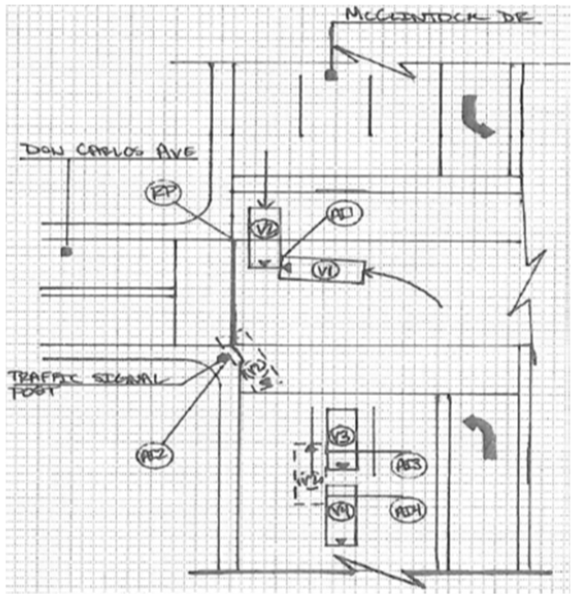
Drive.[204] She approached the intersection of Don Carlos Avenue. She planned to turn left, across three lanes of oncoming traffic.[205] It was rush hour — 6:25 PM on a Monday afternoon.[206] Traffic was heavy. Cars had come to a complete stop in the two southbound lanes closest to her.[207] The third southbound lane was empty. Cole had a green light, and she recalled seeing that there were about five seconds left on the crosswalk timer.[208] Cole described what happened next:

> As far as I could tell, the third lane had no one coming in it so I was clear to make my turn. Right as I got to the middle lane about to cross the third I saw a car flying through the intersection but couldn't brake fast enough to completely avoid the collision.[209]

Cole's vehicle collided with an Uber AV. A report by the Tempe Police, reproduced below as Figure 2, illustrates the crash.[210] Cole's vehicle is V1. The Uber AV is V2. At the time of the collision, the AV was in autonomous mode.[211] There was a backup driver behind the wheel. The backup driver later told the police that he didn't have time to take over manual control.[212] After the initial collision, the Uber AV struck a traffic signal pole, ricocheted, hit two more vehicles — V3 and V4 in the diagram — and rolled over.[213]

204 *See* TEMPE POLICE DEP'T, GENERAL OFFENSE REPORT NO. 2017-34909, at 11 (2017).
205 *See id.*
206 *Id.* at 3.
207 *Id.* at 13.
208 *Id.*
209 *Id.*
210 *Id.* at 9.
211 *Id.* at 2.
212 *Id.*
213 *See id.* at 9, 11.

Figure 2: March 27, 2017 Crash from Tempe Police Report



No one was seriously injured.[214] But there was significant damage to the vehicles.[215] Cole was ticketed for failing to yield the right-of-way.[216] Arizona's traffic code provides that "[t]he driver of a vehicle within an intersection intending to turn to the left shall yield the right-of-way to a vehicle that is approaching from the opposite direction and that is within the intersection or so close to the intersection as to constitute an immediate hazard."[217] Neither Uber nor its backup driver were ticketed.[218] The AV was operating at 38 mph, and the speed limit was 40 mph.[219] The AV had a green light and the right-of-way.

The AV's behavior was puzzling to the humans who saw it. A witness to the crash gave a statement to the police, in which he volunteered that the AV was at fault for "trying to beat the light" and "hitting the gas so hard."[220] Notice how the statement anthropomorphizes the AV.

214 *See id.* at 3-4.

215 *See id.* at 7-8 (diagrams displaying damage).

216 *See id.* at 5.

217 ARIZ. REV. STAT. ANN. § 28-772 (2021).

218 *See* TEMPE POLICE DEP'T, *supra* note 204, at 6 (box checked for "no improper action" for the Uber backup driver).

219 *See id.* at 3. I credit Uber's statement because their log files keep an electronic record of the speed and could be subject to subpoena.

220 *Id.* at 23.

Accelerating to beat the end of a yellow light is a kind of behavior one might expect from a human driver, but Uber wouldn't have programmed its AV to behave that way. Cole may have sincerely recalled the AV "flying" through the intersection. The witness may have sincerely believed he saw the AV accelerating. But their perceptions were mistaken.

Did the Uber AV exercise reasonable care? Would a reasonable driver enter an intersection at the end of a green light, at full speed, in the right lane, with stopped vehicles in the left and center lanes obstructing the view of any vehicle that might be turning left? Was Cole's inference — that no vehicle would enter the intersection at full speed, from the apparently empty third lane, during the last few seconds of the green light — unreasonable?

There's a sign on McClintock Drive not far after Don Carlos Avenue that reads: "THRU TRAFFIC MERGE LEFT."[221] The reason for the sign is that the right lane of McClintock Drive becomes a right turn only lane at the next major intersection. A driver familiar with the area might understand that other drivers who planned to head straight through the second intersection would merge out of the right lane in advance. This would lead the left and center lanes to be crowded — and the right lane to be empty — at rush hour. A local driver in the Uber AV's position might know that vehicles headed in the opposite direction could be turning left ahead and that the drivers of those turning vehicles wouldn't expect a vehicle to appear in the right lane at the last minute.

The crash might have been difficult for Uber's engineers to prevent. The AV had to make a prediction about Cole's likely behavior. The software would have to understand not just that its view of Cole was obstructed, but that *Cole's view* of the AV was obstructed and that she might not consider the possibility of a car heading straight in the right lane at the last minute. Uber could have programmed its AVs to slow down at the end of green lights. But in many situations, that behavior might be dangerous. Because drivers sometimes accelerate to beat a light, an AV that decelerated at the end of a green light might get rear-ended. The right solution for this scenario might be more complicated. It might even require engineers to encode some local knowledge into the software's map, like an instruction for its AVs to merge out of the right lane of southbound McClintock before Don Carlos, unless they were turning right ahead.

[221] *See 1127 S McClintock Drive, Tempe, Arizona*, GOOGLE MAPS, https://www.google.com/maps/@33.4167347,-111.9090356,3a,75y,197.2h,89.26t/data=!3m6!1e1!3m4!1sxs_dhsyGsXcJ286L-SccCw!2e0!7i16384!8i8192 (last visited July 11, 2021) [https://perma.cc/NN64-E7SD] (displaying merge sign).

Eventually, AV companies may be able to develop software that will prevent this kind of crash. But they will need a financial incentive to do so. There's no evidence that Uber incurred any cost from the crash other than the expense of repairing its vehicle. The crash may not have attracted even the modest amount of media attention it did attract if it hadn't led to a dramatic rollover photo and if AV crashes hadn't been such a novelty at the time. The attention to the crash didn't last long because it was overshadowed by a more serious crash less than a year later.

D. A Fatal AV-Pedestrian Crash

On March 18, 2018, an Uber AV struck and killed Elaine Herzberg.[222] The location again was Tempe, Arizona. The crash happened at about 9:58 PM.[223] The AV was driving northbound in the right lane of Mill Avenue.[224] At that location, northbound Mill Avenue has two left turn lanes, two through lanes, and a bike lane on the right shoulder.[225] There's a wide median between the northbound and southbound lanes.[226] Herzberg was walking a bicycle east from the median across the lanes of northbound traffic.[227] The AV collided with her after she had already crossed three lanes.[228] The posted speed limit on that part of Mill Avenue was 45 mph.[229]

According to the National Transportation Safety Board ("NTSB")'s report on the crash, the AV's radar and lidar detected Herzberg 5.6 seconds before the collision.[230] Around the moment of detection, the AV was traveling at 45 mph.[231] Uber's AV software "initially classified

[222] Ryan Randazzo, *Who Was Really at Fault in Fatal Uber Crash? Here's the Whole Story*, ARIZ. REPUBLIC (Mar. 17, 2019, 5:00 AM MT), https://www.azcentral.com/story/news/local/tempe/2019/03/17/one-year-after-self-driving-uber-rafaela-vasquez-behind-wheel-crash-death-elaine-herzberg-tempe/1296676002/ [https://perma.cc/GYN7-D56G].

[223] *See* NAT'L TRANSP. SAFETY BD., HIGHWAY ACCIDENT REPORT: COLLISION BETWEEN VEHICLE CONTROLLED BY DEVELOPMENTAL AUTOMATED DRIVING SYSTEM AND PEDESTRIAN 1 (2019), https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1903.pdf [https://perma.cc/GQS7-HFDM].

[224] *Id.*

[225] *See id.* at 2 (diagram of roadway).

[226] *See id.*

[227] *See id.*

[228] *See id.* (line indicating Herzberg's path).

[229] *Id.* at 3.

[230] *See id.* at 1.

[231] *Id.*

the pedestrian as a vehicle, and subsequently also as an unknown object and a bicyclist."[232] The report states:

> Although the [AV software] continued tracking the pedestrian until the crash, it did not correctly predict her path or reduce the SUV's speed in response to the detected pedestrian. By the time the system determined that a collision was imminent and the situation exceeded the response specifications of the [autonomous] braking system to avoid the collision — 1.2 seconds before impact — the design of the system relied on the vehicle operator to take control of the vehicle.[233]

The AV kept moving forward in its lane and collided with Herzberg. At the moment of impact, the AV's speed was 39 mph.[234] The crash diagram from the NTSB's report is reproduced as Figure 3 below.[235]

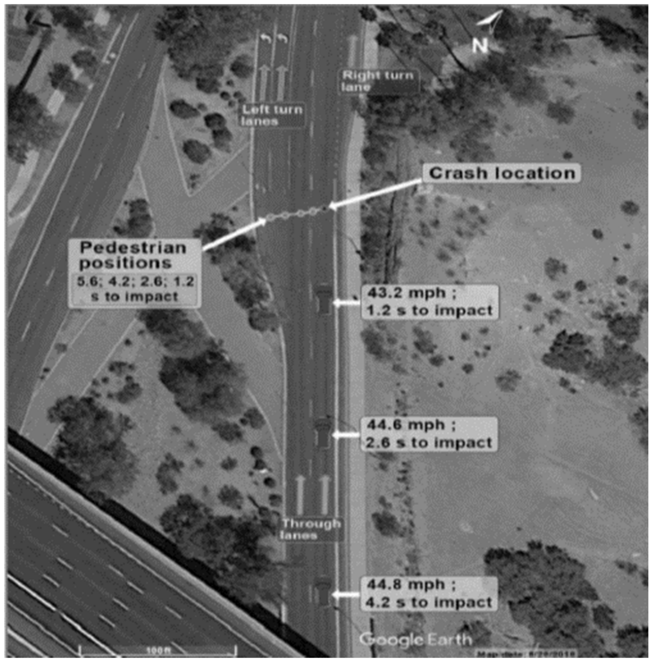
[232] *Id.*

[233] *Id.* (footnote omitted).

[234] *Id.* at 2.

[235] *Id.*

Figure 3: March 18, 2018 Crash from NTSB Report



Uber's backup driver, Rafaela Vasquez, was seated behind the steering wheel at the time of the crash.[236] Data collected from the AV showed that, between six seconds and one second before impact, Vasquez was looking down at the vehicle's center console.[237] The police obtained records from Hulu that indicated Vasquez had been streaming "The Voice" in the minutes leading up to the crash.[238] She took control of the steering wheel less than a second before the collision.[239]

Eight days later, Arizona's Governor suspended Uber's permission to test AVs in Arizona, though Uber had already taken its vehicles off the road.[240] Nine days after the crash, it was reported that Uber had settled with Herzberg's daughter and husband.[241] The two family members later

[236] Randazzo, *supra* note 222.

[237] *See* NAT'L TRANSP. SAFETY BD., *supra* note 223, at 18.

[238] Randazzo, *supra* note 222.

[239] NAT'L TRANSP. SAFETY BD., *supra* note 223, at 18.

[240] Daisuke Wakabayashi, *Uber Ordered to Take Its Self-Driving Cars Off Arizona Roads*, N.Y. TIMES (Mar. 26, 2018), https://www.nytimes.com/2018/03/26/technology/arizona-uber-cars.html [https://perma.cc/PS4K-KZLM].

[241] *See* Ryan Randazzo, *Uber Reaches Settlement with Family of Woman Killed by Self-Driving Car*, ARIZ. REPUBLIC (Mar. 29, 2018, 8:01 AM), https://www.azcentral.com/

sued the State of Arizona and the City of Tempe, claiming that the governments were negligent in overseeing Uber and in designing the brick walkway in the median.[242] Prosecutors declined to bring criminal charges against Uber.[243] Vasquez was charged with negligent homicide.[244]

The NTSB determined that the probable cause of the crash "was the failure of the vehicle operator to monitor the driving environment and the operation of the automated driving system because she was visually distracted throughout the trip by her personal cell phone."[245] It found that Uber's "inadequate safety risk assessment procedures," "ineffective oversight of vehicle operators," and "lack of adequate mechanisms for addressing operators' automation complacency" contributed to the crash.[246] It also faulted Herzberg's decision to cross the street outside a crosswalk and "the Arizona Department of Transportation's insufficient oversight of automated vehicle testing."[247]

In some respects, the crash resembles the type of crashes we should expect from AVs. The Uber AV wasn't speeding, and it had the right-of-way. The NTSB report doesn't focus blame on the AV technology, but it's clear that better software could have prevented the crash. The AV's sensors detected Herzberg with more than enough time to brake and

story/news/local/tempe/2018/03/29/uber-settlement-self-driving-car-death-arizona/469278002/ [https://perma.cc/36RZ-RFPY].

242 Ryan Randazzo, *Family of Woman Killed in Crash with Self-Driving Uber Sues Arizona, Tempe*, ARIZ. REPUBLIC (Mar. 19, 2019, 3:44 PM), https://www.azcentral.com/story/news/local/tempe/2019/03/19/arizona-city-tempe-sued-family-uber-self-driving-car-crash-victim-elaine-herzberg/3207598002/ [https://perma.cc/UF7Z-PCQK].

243 The County Attorney's Office in Maricopa County, which includes Tempe, handed the criminal investigation over to Yavapai County, on the ground that Maricopa's collaboration with Uber on a campaign against drunk driving created a potential conflict of interest. Uriel J. Garcia, *Maricopa County Attorney's Office Cites Conflict in Tempe Uber Death Case*, ARIZ. REPUBLIC (May 31, 2018, 7:20 PM), https://www.azcentral.com/story/news/local/tempe/2018/05/31/maricopa-county-attorney-cites-conflict-tempe-uber-death-case/662072002/ [https://perma.cc/WR4Y-WQTB]. The Yavapai County Attorney's Office declined to prosecute Uber criminally. Mihir Zaveri, *Prosecutors Don't Plan to Charge Uber in Self-Driving Car's Fatal Accident*, N.Y. TIMES (Mar. 5, 2019), https://www.nytimes.com/2019/03/05/technology/uber-self-driving-car-arizona.html [https://perma.cc/9XE8-STRE].

244 Ryan Randazzo, *Operator of Self-Driving Uber Charged with Negligent Homicide in 2018 Fatal Crash*, ARIZ. REPUBLIC (Sept. 15, 2020, 3:42 PM), https://www.azcentral.com/story/money/business/consumers/2020/09/15/rafaela-vasquez-charged-negligent-homicide-2018-uber-crash-arizona/5810172002/ [https://perma.cc/679C-FXZ8].

245 NAT'L TRANSP. SAFETY BD., *supra* note 223, at v.

246 *Id.* at v-vi.

247 *Id.* at vi. According to a postmortem toxicology report, Herzberg had "about 10 times the therapeutic dose of methamphetamines in her system." *Id.* at 62.

avoid the collision. In fact, a human driver may have been able to brake in that time frame, though it's not clear if a driver would have seen her as early.[248] But the AV's software failed to predict Herzberg's behavior, so the AV didn't brake until it was too late.

In other ways, though, the 2018 crash was anomalous. Uber's behavior leading up to the 2018 crash was negligent in several ways that aren't likely to be repeated in many future AV crashes. Uber would have been vicariously liable for Vasquez's inattention, dramatically illustrated by her streaming "The Voice" and looking down at the console for five of the six seconds before the crash. The media reported that, not long before the crash, Uber had changed its policy of having a second person in the passenger seat during testing, even though some employees "worried that going solo would make it harder to remain alert during hours of monotonous driving."[249] Uber's backup driver training record revealed other concerning incidents, including drivers "falling asleep at the wheel" and "air drumming" as the AV passed through an intersection.[250]

Uber's litigation position was even worse than the facts alone would indicate. Elaine Herzberg was the first person killed by a fully autonomous vehicle being tested on public roads. Uber was also dealing with (arguably) unrelated corporate misconduct scandals.[251] The crash was recorded in a widely shared and disturbing video.[252] For these reasons, Uber was likely under tremendous pressure to settle, and the decision to settle reveals little about what would have happened at trial. When Uber resumed public testing, it restored its old policy of having

[248] *See* Brad Templeton, *NTSB Report Implies Serious Fault for Uber in Fatality*, BRAD IDEAS (May 24, 2018, 11:19 AM), https://ideas.4brad.com/ntsb-report-implies-serious-fault-uber-fatality [https://perma.cc/RLS9-4D82] ("It turns out that at 38 mph in 1.3 seconds you go 22m. 22m is precisely the stopping distance for a hard brake at 38 mph.").

[249] Daisuke Wakabayashi, *Uber's Self-Driving Cars Were Struggling Before Arizona Crash*, N.Y. TIMES (Mar. 23, 2018), https://www.nytimes.com/2018/03/23/technology/uber-self-driving-cars-arizona.html [https://perma.cc/T6F2-3CL4].

[250] *Id.*

[251] For a summary dated shortly before the crash, see David F. Larcker & Brian Tayan, *Governance Gone Wild: Misbehavior at Uber Technologies*, HARV. L. SCH. F. ON CORP. GOVERNANCE (Jan. 20, 2018), https://corpgov.law.harvard.edu/2018/01/20/governance-gone-wild-misbehavior-at-uber-technologies/ [https://perma.cc/ZB8W-CJYQ].

[252] ABC Action News, *Uber Self-Driving Car Dash Camera Video Released in Deadly Crash*, YOUTUBE (Mar. 21, 2018), https://www.youtube.com/watch?v=Cuo8eq9C3Ec [https://perma.cc/C57U-5QBK].

a second employee in the passenger seat.[253] Uber's executives eventually gave up on developing AV technology and sold the company's AV program to Aurora.[254] But it's easy to imagine a different crash — with similar behavior by the software, but without clear evidence of Vasquez's and Uber's recklessness — in which a wayward pedestrian's or cyclist's negligence would shield an AV company from liability.

III. CONTACT RESPONSIBILITY

AV companies will only invest in developing AV technology's full crash prevention potential if they internalize the costs of all preventable crashes. As AV technology advances, though, it will become increasingly difficult for courts to determine when a crash involving an AV could have been prevented with a cost-justified investment in safer AV technology. Therefore, I argue that AV companies should be responsible for *all* crashes in which their AVs come into contact with other vehicles, persons, or property. I call this new system "contact responsibility."

Here's how it would work. Contact responsibility would build on NHTSA's recent order mandating that AV companies report crashes involving their AVs to federal regulators.[255] Congress would mandate AV companies would be responsible for damages arising out of any contact described in the reports. If any person was injured as a result of the contact, the company would pay the person's reasonable medical bills; lost wages, up to a generous cap; and pain and suffering damages, according to a fixed schedule.[256] If any property was damaged, the company would pay for reasonable repairs or replacement. Injured claimants would receive timely and adequate compensation, and AV

[253] *See* Eric Meyhofer, *Learning from the Past to Move Forward*, MEDIUM: UBERATG (Dec. 20, 2018), https://medium.com/@UberATG/learning-from-the-past-to-move-forward-f4af566f2c3 [https://perma.cc/6UPZ-WDZW].

[254] *See* Metz & Conger, *supra* note 101.

[255] *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., *supra* note 141, at 10-15. The order defines a "crash" as "any physical impact between a vehicle and another road user (vehicle, pedestrian, cyclist, etc.) or property that results or allegedly results in any property damage, injury, or fatality." *Id.* at 6. The definition clarifies that "a subject vehicle is involved in a crash if it physically impacts another road user or if it contributes or is alleged to contribute (by steering, braking, acceleration, or other operational performance) to another vehicle's physical impact with another road user or property involved in that crash." *Id.* Therefore, some contactless crashes may be reportable under the order but not subject to the contact responsibility system.

[256] Here I follow Abraham and Rabin's proposal. *See* Abraham & Rabin, *supra* note 41, at 161-62.

companies and their insurers would be able to predict their exposure with greater confidence.

Under contact responsibility, disputes about individual cases should be rare. There should be no doubt about whether a contact occurred because an AV's sensors create an electronic record of even slight changes in its position caused by contact with external objects. AV companies would only avoid payment for damages resulting from a contact if they could prove by a preponderance of the evidence that the party seeking payment intentionally caused the crash.[257] In crashes *between* AVs — which should be extremely rare — both AV companies would pay an amount equal to the other party's damages to the government, so they would both internalize the full costs of the crash.[258] Contact responsibility would be an exclusive remedy for all injuries resulting from a crash involving an AV.[259] Congress would preempt all state law tort claims arising out of crashes that were subject to the contract responsibility system.[260]

A. Accident Liability Revisited

The case for contact responsibility builds on the "accident liability" literature, which aims to determine the socially optimal tort liability rules for motor vehicle crashes.[261] The models developed in this literature assume that drivers are rational utility-maximizers, who only take into account the costs that their actions impose on others to the extent that liability causes them to internalize those costs. The models consider how different liability rules affect a driver's level of care (how carefully she drives) and activity level (how many miles she drives). The motivation for considering the driver's activity level is the assumption that even careful driving will result in some residual crashes.[262] Under

[257] Recall that Waymo claims that a driver intentionally cut in front of one of its AVs and braked abruptly. *See* SCHWALL ET AL., *supra* note 13, at 9.

[258] This is Steven Shavell's "strict liability to the state" proposal. *See* Shavell, *supra* note 33, at 2-3.

[259] If contact responsibility were not an exclusive remedy, plaintiffs might, for example, bring tort claims against companies that manufactured an AVs sensors or other component parts. *See* Abraham & Rabin, *supra* note 41, at 158.

[260] Preemption would address AV companies' concerns about having to comply with a patchwork of state regulations. Geistfeld, *supra* note 42, at 1684.

[261] *See generally* CALABRESI, *supra* note 38 (discussing the goals of accident liability); LANDES & POSNER, *supra* note 38 (exploring basic principles of accident law); SHAVELL, *supra* note 38 (focusing on the "economic perspective" of accident liability).

[262] This is a sensible assumption. Recall that the NHTSA attributes 6% of fatal crashes to factors other than driver error. *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., CRITICAL

a negligence rule, drivers are held liable for crashes that they can prevent by driving carefully. Under strict liability, drivers are held liable for *all* crashes involving their vehicles.

The "unilateral accident" model analyzes a crash in which only one driver can choose to take care, like a crash between a car and a pedestrian.[263] The model shows that either a negligence rule or strict liability will cause the driver to choose the optimal level of care.[264] Under a negligence rule, the driver is held liable for crashes she can prevent by driving carefully, so she drives carefully to avoid liability for those crashes. Under strict liability, the driver is held liable for all crashes, and she still drives carefully, so she can at least avoid liability for those crashes she can prevent by driving carefully.

The unilateral accident model also shows that only strict liability will cause the driver to choose the socially optimal activity level.[265] Under a negligence rule, the driver drives too many miles because she doesn't internalize the full cost of any resulting unpreventable crashes — the crashes she can't prevent by driving more carefully. Under strict liability, she internalizes the cost of all crashes in which her vehicle is involved, even unpreventable crashes. Consequently, she drives fewer miles. She only decides to drive when the utility she will gain from driving exceeds the expected social cost of unpreventable crashes that result from her driving. Strict liability also has another advantage over the negligence rule: lower administrative costs.[266] In a strict liability regime, there's no litigation over whether a driver took reasonable care.

The "bilateral accident" model analyzes a crash in which two drivers independently decide on their level of care and activity level. The model shows that any of (1) a negligence rule without a comparative negligence defense, (2) a negligence rule with a comparative negligence defense, and (3) strict liability with a comparative negligence defense

REASONS FOR CRASHES, *supra* note 6, at 2. NHTSA attributes 2% to vehicle issues, 2% to environmental conditions, and 2% to unknown causes. *Id.* at 2-3.

263 Shavell suggests that crashes between cars and cyclists could be understood as unilateral accidents "where it is believed that bicyclists' actions are of minor importance in reducing risks." SHAVELL, *supra* note 38, at 6-7.

264 *See id.* at 8-9; *see also* LANDES & POSNER, *supra* note 38, at 63.

265 *See* SHAVELL, *supra* note 38, at 23-25; *see also* LANDES & POSNER, *supra* note 38, at 67.

266 *See* LANDES & POSNER, *supra* note 38, at 65; *see also* SHAVELL, *supra* note 38, at 9 ("Under strict liability, a court need only determine the size of the loss that occurred, whereas under the negligence rule a court must in addition determine the level of care actually taken (a driver's speed) and calculate the socially optimal level of due care (the appropriately safe speed).").

would induce *both* drivers to take the optimal level of care.[267] The reasoning here is similar to the unilateral accident model. Under any of these combinations of rules, each driver will be liable for *at least* the crashes that she could have prevented by driving carefully, so each driver drives carefully to avoid liability for those crashes.

The bilateral accident model also shows, however, that no combination of rules would cause both drivers to choose the optimal level of care *and* the optimal activity level.[268] As in the unilateral model, a negligence rule causes both drivers to drive too many miles, because they avoid liability for unpreventable crashes. Strict liability would cause drivers to drive the optimal number of miles, but if *both drivers* were held strictly liable for a crash, their incentives would be diluted.[269] For example, if both drivers sustained roughly equal damages in a crash, the payment that each driver would receive from the other driver would offset the payment they made to the other driver. Therefore, any accident liability regime is doomed to be suboptimal for bilateral accidents. The existing law for motor vehicle crashes in most states — a negligence rule with a comparative negligence defense — is optimal as to care, but suboptimal as to activity level.

Steve Shavell, one of the main contributors to the accident liability literature, has recently argued that, *in crashes between AVs*, a liability system that optimizes both levels of care and activity levels is possible.[270] He calls his proposal "strict liability to the state." In his proposal, when an AV crashes with another AV, both AV companies would pay the government an amount equal to all parties' damages from the crash.[271] Shavell reasons that, because both AV companies would internalize the full costs of *all* crashes, they would both choose the optimal level of care.[272] That is, they would make all cost-justified investments in developing safer AV technology. He also argues that both AV companies would choose the optimal activity level, because they would internalize the cost of all crashes that couldn't be prevented through cost-justified investments in developing safer technology.[273] The AV companies' incentives wouldn't be diluted by receiving

[267] *See* SHAVELL, *supra* note 38, at 12-16; *see also* LANDES & POSNER, *supra* note 38, at 80-82.

[268] *See* SHAVELL, *supra* note 38, at 27-30.

[269] Shavell, *supra* note 33, at 26-27.

[270] *See id.* at 2.

[271] *Id.* at 2-3.

[272] *See id.* at 11.

[273] *See id.*

payments from each other, because they would both send their payments to the state.

Shavell contends that strict liability to the state would, in theory, set the optimal incentives for all kinds of motor vehicle crashes, not just crashes between AVs.[274] But he argues that strict liability to the state would be impractical for crashes between CVs, because it would create an incentive for drivers involved in a crash to collude and not report the crash to the authorities.[275] Crashes between AVs are different, he contends, because AV sensors create an electronic record of crashes that would deter underreporting.[276] Shavell doesn't take a position on AV-CV crashes, but he expresses concern that applying strict liability rule to AVs but not CVs will distort incentives.[277]

The accident liability models are powerful tools for analyzing crashes between CVs. Shavell's strict liability to the state provides a compelling solution for crashes between AVs — crashes that should be extremely rare. But for AV-CV crashes, the accident liability models need to be amended to account for two important asymmetries between AVs and CVs. First, AV technology can prevent crashes much more efficiently than drivers can. Second, AV companies are much more responsive to liability incentives than drivers are. The liability regime that applies to AV-CV crashes should reflect these two asymmetries.

As we have seen, AVs have the potential to prevent crashes caused by other road users' errors. They already can monitor their surroundings better and react more quickly. They could be designed to make better predictions about other road users' behavior and better decisions about how to respond to their behavior. Investments in developing safer AV technology will be highly cost-effective because AV software will be deployed at scale. Once an AV company's engineers develop software that can safely manage a given traffic scenario, all robotaxis in the company's fleet will handle similar scenarios safely for the rest of history. The safer technology that an AV company develops will eventually spill over to other companies' fleets, as engineers change jobs or share ideas with colleagues.

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[274] *See id.* at 29 (explaining that the argument for strict liability to the state "does not depend on the assumption that vehicles are autonomous — the rule of strict liability to the state should induce proper incentives to take care and to choose levels of activity such as mileage in *any* accident context" (emphasis in original)).

[275] *See id.*

[276] *Id.*

[277] *See id.* (arguing that in liability regimes in which CVs and AVs were subject to different rules, "some distortion of incentives from ideal ones would occur").

AVs may be involved in some crashes that are so rare and complex that the social benefits of investing in technology that could prevent them wouldn't be worth the cost. AV engineers' efforts to develop safer technology may ultimately run up against the unpredictability of human behavior and the laws of physics. But it's unlikely that juries or judges applying a negligence rule or products liability's risk-utility test would be able to reliably identify which crashes could have been prevented efficiently with yet-to-be developed technology. Only a liability rule that holds AV companies responsible for all crashes involving their AVs will push them to develop AVs' full crash prevention potential.[278]

AV companies will be highly responsive to liability incentives. An AV has no instinct to swerve out of the way of oncoming vehicle. It will only swerve if managers at the company that developed its software thought the business would be liable for the crash. By contrast, liability incentives don't provide much marginal deterrence for unsafe human driving. The kinds of errors that drivers make — driving impaired and violating the traffic laws — lead to more immediate and more serious criminal and civil penalties than tort liability. Most warm-blooded drivers wouldn't fear risking injury or death less if they knew it wouldn't come coupled with liability.

Shavell himself has acknowledged that "it might be that liability for automobile accidents does not much affect the incidence of these accidents, for drivers' precautions may be determined largely by their fear of injury to themselves in accidents and by criminal liability for traffic offenses and drunk driving."[279] The bilateral accident model must assume that drivers are responsive to liability incentives, because without that assumption, the model wouldn't generate any predictions. It's a harmless assumption when there's no reason to expect that one driver in a crash is *relatively* less responsive to liability incentives than another driver. But in a world in which human drivers share the road with AVs, liability rules must account for the reality that drivers are much less responsive to liability incentives than AV companies are.

Contact responsibility would effectively treat a bilateral accident between an AV and a CV as a unilateral accident for the AV. Drivers would face no liability for crashes with AVs, but they would still be

[278] Shavell has previously noted that the application of a negligence rule to a firm's product development decisions might be suboptimal. *See* SHAVELL, *supra* note 38, at 57 ("[A] firm that believes that courts would never learn that it had a particular opportunity to reduce a risk (for example, that a pharmaceutical company had a chance to develop a substitute drug without an adverse side effect) may decide not to pursue the opportunity.").

[279] STEVEN SHAVELL, FOUNDATIONS OF ECONOMIC ANALYSIS OF LAW 284 (2004).

subject to liability for crashes with other vehicles, cyclists, and pedestrians. Their incentives to drive safely wouldn't be significantly undermined. AV companies would face a rule that was at least as strong as strict liability, the rule that the unilateral accident model predicts would be optimal.[280] Administrative costs would be low because there would be no crash-specific adjudication. AV companies would choose the optimal activity level by deploying AVs only when the social benefits exceeded the social costs.[281] Most importantly, AV companies would also choose the optimal level of care by developing all cost-justified improvements in AV safety.

B. *Development Incentives*

Consider the interaction between liability rules and investment decisions from the perspective of an AV company. Suppose the company has developed state-of-the-art software that it calls FollowRules. AVs running FollowRules consistently obey speed limits, respect the right-of-way, and maintain a safe following distance. Now suppose that engineers approach the company's CEO asking for a budget to develop novel code called AvoidContact. The engineers can't describe how AvoidContact would work in detail. They envision that AVs running AvoidContact would behave like AVs running FollowRules under normal conditions but would behave differently in scenarios in which simple rule-following would result in a contact with a driver, cyclist, or pedestrian.

AVs running AvoidContact would be superhuman defensive drivers. They would constantly monitor their surroundings for drivers exhibiting impairment and change lanes or even change routes to avoid them. They would anticipate when drivers might blow through stop signs, run red lights, or take dangerous turns. They would predict when cyclists might drift into their lane or pedestrians might cross the street mid-block. When a driver made an unanticipated error, they would notice it immediately and swerve to avoid a collision or reduce its severity.

If developing AvoidContact were inexpensive, the CEO would greenlight the project. But suppose that AvoidContact was expected to

[280] Contact responsibility more closely resembles absolute liability than strict liability, because it does not require a showing of defect, proximate cause, or even factual cause. *See* Geistfeld, *supra* note 42, at 1666 (defining absolute liability and explaining why courts have generally not imposed it in products liability cases).

[281] For a response to the objection that AV companies will choose a suboptimal low activity level, see *infra* Part IV.B.

cost an additional several hundred million dollars to develop. Then the CEO might place a call to the company's lawyer to estimate the company's liability exposure under both options. A careful lawyer would inform the CEO that an AV that consistently followed the traffic law wouldn't always avoid liability for crashes.[282] Compliance with a relevant regulatory standard is evidence of non-negligence, but it doesn't preclude liability.[283]

The lawyer would explain, however, that drivers are rarely held liable for crashes that don't involve rule violations. As Gary Schwartz has put it, "findings of negligence in highway accident cases do not depend on the kind of open-ended and *ad hoc* balancing that characterizes the law of negligence generally."[284] Instead, "the process of assessing a negligence claim generally involves merely determining which motorist violated which provision in the code itself."[285] The lawyer would stress that lawsuits against AV companies wouldn't resemble normal negligence claims against human drivers. Injured plaintiffs would likely be bringing products liability claims.[286]

But the bottom line, the lawyer would say, is that AvoidContact would likely only marginally reduce the company's expected liability exposure. Most crashes between an AV running FollowRules and a human road user would involve some human negligence. The company would avoid some or all liability as long as the company could raise a comparative negligence defense.[287] Under existing law, the marginal liability savings of AvoidContact might not justify the marginal development cost. A cost-conscious CEO might not approve the project.

[282] Waymo appears to have received this advice. *See* SCHWALL ET AL., *supra* note 13, at 9 n.10 ("Right-of-way is useful as a means of categorizing some events, but it can be insufficient to determine collision responsibilities since it does not reflect all road rule violations (e.g. speeding), nor does it provide information regarding collision avoidability.").

[283] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 4 cmt. e (AM. L. INST. 1998) ("[M]ost product safety statutes or regulations establish a floor of safety below which product sellers fall only at their peril, but they leave open the question of whether a higher standard of product safety should be applied.").

[284] Gary T. Schwartz, *Auto No-Fault and First-Party Insurance: Advantages and Problems*, 73 S. CAL. L. REV. 611, 631-32 (2000).

[285] *Id.* at 632; *see also* RESTATEMENT (THIRD) OF TORTS: LIAB. FOR PHYSICAL & EMOTIONAL HARM § 14 cmt. d (AM. L. INST. 2010) ("[I]n most highway-accident cases, findings of negligence depend on ascertaining which party has violated the relevant provisions of the state's motor-vehicle code.").

[286] *See infra* Part III.C and accompanying notes.

[287] *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 17(a) (acknowledging that a defendant can raise a plaintiff's comparative negligence as a defense in a products liability case).

Under contact responsibility, though, the company would internalize the costs of all crashes in which its AVs were involved, regardless of human road user negligence. The lawyer would give a different answer to the CEO, and the CEO might agree to fund the development of AvoidContact.

To be sure, the choices AV companies face will likely not be this clear cut. Executives might be asked to decide on funding more discrete projects, like a longer-range perception system or more robust behavior prediction software. But the general pattern of incentives is clear. AV companies have strong liability incentives to develop AVs that don't cause crashes and, as long as a comparative negligence defense is available, much weaker liability incentives to develop AVs that can avoid crashes caused by other road users.

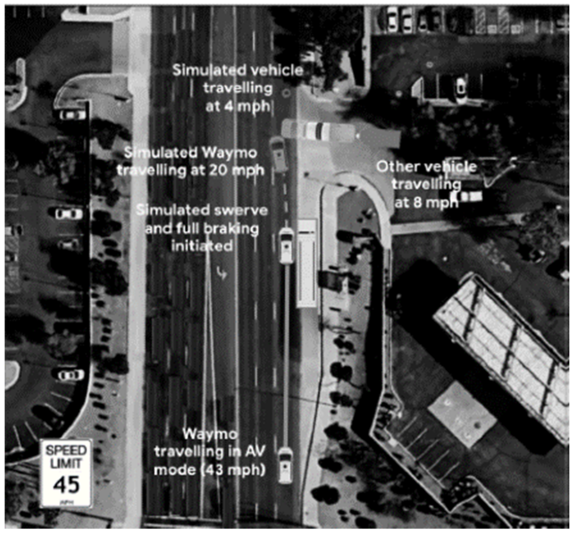
Consider again the head-on collision from the Introduction. Many drivers would have swerved to avoid that crash. It's possible that Waymo's backup driver did swerve. Why didn't Waymo program its AVs to swerve in that situation? Swerving is a risky maneuver. Drivers can't always predict when a nearby vehicle will swerve or how other vehicles might react to the vehicle swerving. Developing AVs that can swerve safely is also a challenging engineering problem.[288] Safe swerving software would require sophisticated behavior prediction and complex decision-making. The software would have to be finely calibrated, because overreactive swerving would give passengers an uncomfortable ride. Yet even though swerving is difficult, it could be *relatively* easier for AVs than for human drivers. An AVs' ability to monitor its surroundings and react quickly — combined with better behavior prediction and decision-making software — could lead to better swerving.

The Waymo report gives a glimpse of this possible future. Figure 4 below depicts one of the angled collisions in the report.[289] A Waymo AV was traveling straight when another vehicle turned onto its roadway from the right:

[288] *See* Brad Templeton, *Waymo Has a Crash in Chandler, but Is Not at Fault*, BRAD IDEAS (May 4, 2018, 9:14 PM), https://ideas.4brad.com/waymo-has-crash-chandler-not-fault [https://perma.cc/7LBM-C45Z] (arguing that developing AV software that swerves to avoid being hit is a hard problem and "not very high" on AV companies' "priority lists").

[289] SCHWALL ET AL., *supra* note 13, at 10.

Figure 4: Angled Collision with Swerve from Waymo Report



In the moments before the collision, a long truck positioned between the AV's and the turning CV obstructed the line-of-sight. Waymo's backup driver took over manual control.[290] Waymo reports that, in its simulation, the AV initiated braking and "an evasive swerve."[291] The swerve would have either been too late or too hesitant to avoid the collision, but the combination of braking and swerving may have reduced the speed of impact.

Companies like Waymo have little incentive to further develop swerving, because it's more useful in avoiding the errors of other drivers, cyclists, or pedestrians than in complying with the traffic laws. In fact, it's possible that swerving might *increase* an AV company's liability exposure in fault determinations. In one recent study, participants were asked to choose how an AV should react to a potential collision ahead.[292] The AV could stay in its lane, which would create an 80% chance of hitting a pedestrian, or it could swerve out of the way, which would create a 50% chance of hitting a bystander on the sidewalk.[293] Only 66% of the participants opted for swerving.[294] But that

[290] *See id.*

[291] *Id.*

[292] Björn Meder, Nadine Fleischhut, Nina-Carolin Krumnau & Michael R. Waldmann, *How Should Autonomous Cars Drive? A Preference for Defaults in Moral Judgments Under Risk and Uncertainty*, 39 RISK ANALYSIS 295, 299-300 (2019).

[293] *Id.* at 299.

[294] *Id.* at 300.

number increased to 75% if the AV in the example was replaced with a human driver.[295] In other words, jurors might not forgive risky lifesaving behavior when the driver is a software program.

Under contact responsibility, AV companies will invest in developing swerving, or drunk driver avoidance, or any other advanced behavior to the extent that it will avoid crashes. AV companies today collect more data on crashes and how they can be prevented than any government agency, researcher, or traditional automaker ever has. Each AV in a company's fleet has sensors that passively record the real-world behavior of nearby vehicles, cyclists, and pedestrians. That naturalistic data can be used to simulate how other road users would react in risky scenarios. AV engineers could develop novel approaches to handling those scenarios and test them against simulations. AVs could become superhuman defensive drivers, giving other road users a margin of error. But AV companies will need the liability incentive to unlock investment.

C. Superiority to Conventional Products Liability

Contact responsibility would create better incentives than products liability doctrine does. Under current law, a plaintiff injured in a crash with an AV could bring three kinds of products liability claims against an AV company: (1) a failure to warn claim; (2) a manufacturing defect claim; or (3) a design defect claim. Failure to warn claims should be rare in AV crash cases. Robotaxis should be safer than CVs within the relevant ODD by the time of deployment, and AV companies can easily warn passengers of the residual risk.[296] Manufacturing defect claims should also be rare. They should be limited to quality control failures in the production of sensors and other vehicle hardware.[297] AV companies should be able to detect anomalies quickly because they will

[295] *Id.*

[296] *See* Abraham & Rabin, *supra* note 41, at 143 ("[M]anufacturers would presumably be responsible for providing consumers aggregate information regarding the accident risks associated with different vehicle models. But this information is most satisfactorily provided through the pricing system, with identification of the risk premium included in the cost of the vehicle."); Geistfeld, *supra* note 42, at 1656 "[A] manufacturer can satisfy its obligation to warn about the inherent risk of crash through disclosure of the premium for insuring the autonomous vehicle."). The same can be said about the cost of a ride in a robotaxi.

[297] *See* Geistfeld, *supra* note 42, at 1633 (predicting that, in AV cases, "liability for manufacturing defects will be largely limited to quality-control problems with the hardware . . . components of the system that do not perform according to design").

receive rapid feedback about their vehicles' and sensors' on-road performance.

The most important AV crash claims will be design defect claims.[298] In most states, the standard for proving a design defect claim is the risk-utility test.[299] Under that test, a product's design is defective "when the foreseeable risks of harm posed by the product could have been reduced or avoided by the adoption of a reasonable alternative design" and "the omission of the alternative design renders the product not reasonably safe."[300] The "reasonable" in "reasonable alternative design" injects a cost-benefit analysis, which makes the risk-utility test more like a fault standard than true strict liability.[301] Defendants aren't expected to adopt a design that will prevent all injuries, just the design that optimizes safety in light of the cost.[302]

In an AV crash case, a plaintiff would rarely be able to show that a reasonable alternative design could have prevented the crash that caused her injury because AV companies will usually be running the safest code available. In many design defect cases, companies are found liable because their managers rejected a safer alternative design as too costly. For example, in the products liability litigation over the Chevrolet Cobalt's faulty ignition switch, it was revealed that "GM engineers considered the problem and even developed potential fixes, but GM decided the 'tooling cost and piece price [were] too high' and

[298] *See* Abraham & Rabin, *supra* note 41, at 143-44 (anticipating design defect claims in AV crash cases); Geistfeld, *supra* note 42, at 1636 (predicting that AV products liability cases will turn on "(1) whether the crash of an autonomous vehicle is a malfunction, or (2) whether a vehicle that did not malfunction nevertheless has an unreasonably dangerous or defective design"); Vladeck, *supra* note 40, at 132 ("[T]here is no doubt that there will be design defect cases brought against the manufacturers and designers of self-driving cars.").

[299] Geistfeld notes that some states still rely on the risk-utility test's rival, the "consumer expectations" test. *See* Geistfeld, *supra* note 42, at 1635. He explains that "the apparent disparities among the rules governing defective product design largely disappear once the consumer expectations test has been adequately defined." *Id.* at 1636.

[300] RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2(b) (AM. L. INST. 1998).

[301] *See* Vladeck, *supra* note 40, at 135 (explaining that "[t]he word 'reasonable' is intended to import a quantitative cost-benefit analysis into the test").

[302] *See, e.g.*, David G. Owen, *Defectiveness Restated: Exploding the "Strict" Products Liability Myth*, 1996 U. ILL. L. REV. 743, 754 ("[S]ince the degree of risk or safety in every product design is counterbalanced by considerations such as cost, utility, and aesthetics, the basis of responsibility for design choices logically should be based on the principle of *optimality* . . . ." (emphasis in original)).

'none of the solutions represent[ed] an acceptable business case,' so the repair ideas were scrapped."[303]

In an influential early article on AV crash liability, David Vladeck suggested that AV design defect cases might resemble these CV design defect cases, but with more complex technology.[304] A plaintiff attempting to show that a reasonable alternative design could have prevented a crash, Vladeck wrote, would need both an expert engineer to argue that the design was technically feasible and "another expert (likely an economist) to establish that the savings achieved by the reduction [in crashes] would outweigh the attendant costs of modifying the vehicle."[305]

It's possible that there could be a trial like the one Vladeck envisions in AV crash cases that involve design choices about sensors or vehicle hardware. For example, in 2016, Joshua Brown was killed when his partially autonomous Tesla crashed into a truck, which was making a left turn against traffic.[306] Brown had engaged the L2 Autopilot system and wasn't paying attention to the truck ahead.[307] The NTSB later determined that "the Tesla's automated vehicle control system was not designed to, and did not, identify the truck crossing the car's path or recognize the impending crash."[308] Tesla's statement on the crash suggested why: Autopilot didn't "[notice] the white side of the tractor trailer against a brightly lit sky."[309]

The Tesla Model S that Brown was driving relied on cameras and radar for sensors.[310] Commentators pointed out that if Tesla had added lidar — a sensor used by almost all companies testing L4 AVs — the vehicle would have detected the truck.[311] Elon Musk has argued that

303 Nora Freeman Engstrom, *When Cars Crash: The Automobile's Tort Law Legacy*, 53 WAKE FOREST L. REV. 293, 330 (2018).

304 *See* Vladeck, *supra* note 40, at 138-40.

305 *Id.* at 138.

306 *See* NAT'L TRANSP. SAFETY BD., HIGHWAY ACCIDENT REPORT: COLLISION BETWEEN A CAR OPERATING WITH AUTOMATED VEHICLE CONTROL SYSTEMS AND A TRACTOR-SEMITRAILER TRUCK NEAR WILLISTON, FLORIDA vi (2016), https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1702.pdf [https://perma.cc/X98B-7HQ7].

307 *See id.* at 41. The report cautions, however, that "investigators could not determine from the available evidence the reason for his inattention." *Id.*

308 *Id.* at 30.

309 *A Tragic Loss*, TESLA (June 30, 2016), https://www.tesla.com/blog/tragic-loss [https://perma.cc/AC6E-5AQR].

310 *See* NAT'L TRANSP. SAFETY BD., *supra* note 306, at 30.

311 *See, e.g.*, Brad Templeton, *Man Dies While Driven by Tesla Autopilot*, BRAD IDEAS (June 30, 2016, 4:00 PM), https://ideas.4brad.com/man-dies-while-driven-tesla-autopilot [https://perma.cc/2TS5-P9GU] (arguing that lidar could have prevented the Brown crash).

lidar is unnecessary for partially or even fully autonomous vehicles.[312] Regardless of whether Musk is right, Tesla's primary reason for not using lidar now is likely its high cost. Companies testing L4 AVs are using lidar on the assumption that its price will decline before they are ready to deploy at scale. Tesla doesn't have that luxury because it's selling series production vehicles today.[313]

Software has a different cost structure than hardware.[314] AV companies should never reject a safer software design once it has been developed. The cost of implementing an over-the-air software update will be almost zero.[315] The cost is incurred upfront, when the AV company invests in its engineers' labor to develop the software. Even the most enterprising plaintiffs' lawyer is unlikely to develop a software fix that a team of AV engineers, armed with data from testing and simulations, has failed to find. A plaintiff might want to argue that greater investment might have led to a yet-to-be developed fix. But, as Andrzej Rapaczynski has observed, "no court will ever claim to know that some 'reasonable' additional research investment in the past would have produced a still unknown safety improvement that would have prevented the accident in question."[316]

One might think that the plaintiff could simply have an engineer testify that it would have been possible to add a few lines of code that would have prevented the specific crash that caused the plaintiff's injury.[317] But the risk-utility test would require the plaintiff to show that there was code that would have prevented the crash that injured the plaintiff *without* making the AV less safe in equally common traffic scenarios. The commentary to the Restatement explains that "[i]t is not sufficient that the alternative design would have reduced or prevented

[312] *See id.*

[313] *See id.* ("Current LIDARs are too expensive for production automobiles . . . .").

[314] This analysis suggests that plaintiffs injured in crashes involving AVs might attempt to bring software defect claims disguised as hardware defect claims.

[315] *Cf.* Smith, *supra* note 39, at 47 ("The cost of a reasonable alternative design that involves changing only a few lines of code may be close to zero.").

[316] Andrzej Rapaczynski, *Driverless Cars and the Much Delayed Tort Law Revolution* 7 (Colum. L. & Econ., Working Paper No. 540, 2016), https://scholarship.law.columbia.edu/cgi/viewcontent.cgi?article=2963&context=faculty_scholarship [https://perma.cc/TJP3-QDF4].

[317] *Cf.* Gary E. Marchant & Rachel A. Lindor, *The Coming Collision Between Autonomous Vehicles and the Liability System*, 52 SANTA CLARA L. REV. 1321, 1334 (2012) (expressing concerns that plaintiffs will have experts testify "that an adjustment would have provided a safer alternative system that would have avoided the accident in question" and the AV company "will almost always lose the cost-benefit argument, conducted in hindsight in the litigation context, when it focuses at the micro-scale between slightly different versions of the autonomous system").

the harm suffered by the plaintiff if it would also have introduced into the product other dangers of equal or greater magnitude."[318] In other words, the defendant AV company could argue that the plaintiff's proposed code would fail its regression testing.[319]

A plaintiff might prevail in an AV software design defect lawsuit against an AV company that lagged others in the industry. Proving that a defendant's technology is inferior to the industry custom isn't a necessary element of products liability claim. It's black letter law that a jury can still find a defendant liable even if no competitor has adopted the reasonable alternative design that the plaintiff's attorney identifies.[320] In the words of Judge Learned Hand, "a whole calling may have unduly lagged in the adoption of new and available devices."[321] But in practice, defendants often avoid liability by arguing that their design was state-of-the-art.[322] These issues will be especially complex in AV crash cases, because the state-of-the-art may change every time the leading AV company updates its code.[323]

At least for the foreseeable future, different businesses will be operating AVs with different software.[324] Waymo's AV software, for example, may be able to safely handle some potential crash scenarios that Cruise's AV software can't. A plaintiff injured in a crash with a Waymo AV could try to argue that if Cruise had used Waymo's state-of-the-art design, its AV would have avoided that crash. In practice, though, these claims are unlikely to be successful. Waymo would seek

318 RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. f (AM. L. INST. 1998).

319 *Cf.* Choi, *supra* note 129, at 84-85 (explaining that patches to one software bug can generate "new, unverifiable interactions").

320 *See* RESTATEMENT (THIRD) OF TORTS: PRODS. LIAB. § 2 cmt. d ("If the plaintiff introduces expert testimony to establish that a reasonable alternative design could practically have been adopted, a trier of fact may conclude that the product was defective notwithstanding that such a design was not adopted by any manufacturer, or even considered for commercial use, at the time of sale.").

321 T.J. Hooper, 60 F.2d 737, 740 (2d Cir. 1932).

322 *See* Rapaczynski, *supra* note 316, at 18 (explaining that, after the 1990's, "design defect jurisprudence has . . . returned to its starting point of full-fledged negligence-based liability, with . . . manufacturers being told that they would be fully protected from design-defect liability for any accidents that may be caused by their 'state-of-the-art' machines.").

323 *See* Abraham & Rabin, *supra* note 41, at 142 (explaining that state of art issues will be especially complex in AV crash cases because AV technology will be in "a state of continual improvement").

324 Abraham and Rabin predict that AV software from competing companies will converge over time and that, "[a]s largely uniform software becomes pervasive, the concept of a reasonable alternative design . . . is likely to become increasingly indeterminate." *Id.* at 144.

to prevent its intellectual property from being disclosed. It might be able to assert trade secret protection.[325] More importantly, as Mark Geistfeld has argued, if these claims started to succeed, they would essentially "[r]equir[e] new entrants to equal or exceed the safety performance of autonomous vehicles already on the road," which could "undermine competition in the market by entrenching the first movers."[326]

By contrast, contact responsibility would create investment incentives that are more compatible with healthy competition on safety. New entrants wouldn't be judged by the particulars of the leading AV company's technology. They would face liability for all crashes in which their AVs come into contact with other vehicles, persons, or property. It's possible that an AV company would deploy technology that was safer than a competitor in certain scenarios but less safe in others. Under contact responsibility, companies would have the incentive to reduce the total cost of crashes, rather than to prioritize reducing crashes that competitors have already solved. Fully independent safety development might reduce net crashes faster than catch-up development would.

It's possible that AV companies will be held liable in cases in which a faithful application of existing doctrine wouldn't lead to liability simply because jurors or judges are biased against AVs. One recent study gave judges a series of hypothetical crash cases and found that they were more likely to find an AV at fault than a human driver and more willing to award higher damages to a plaintiff injured by an AV than one injured by a human driver.[327] Biased jurors or judges may increase expected liability costs for AV companies, but the added costs won't reliably track the riskiness of a company's AV technology. A stricter liability rule, rather than an unpredictably stricter application of existing rules, will create better incentives for investing in safer technology.

D. Superiority to Reform Proposals

Concern that products liability doctrine will generate suboptimal incentives in AV crash cases has led scholars to propose reforms. These proposals can be divided into three general approaches: (1) a negligence

[325] *See id.* (arguing that, in design defect litigation, AV software algorithms might "be subject to trade secret protection").

[326] Geistfeld, *supra* note 42, at 1680.

[327] JEFFREY J. RACHLINSKI & ANDREW J. WISTRICH, JUDGING AUTONOMOUS VEHICLES, CORNELL L. SCH. LEGAL STUD. RSCH. PAPER NO. 21-12, at 14-21 (2021), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3806580 [https://perma.cc/BU9C-4CNN].

rule with a heightened standard of care;[328] (2) a strict liability rule or a no fault system;[329] and (3) a regulatory premarket testing regime.[330] Each of these approaches would improve on the status quo, but none would lead AV companies to take all cost-justified precautions.

1. Heightened Standard of Care

Courts could avoid the difficulties of applying the reasonable alternative design standard by treating the AV company defendant as if it were a driver sued under a simple negligence claim. Then they could apply a heightened standard of care to account for AV technology's superior crash prevention potential.[331] That kind of approach wouldn't be unprecedented. California, for example, has long held common carriers to an "utmost care" standard.[332] Bryant Walker Smith has considered whether courts might gradually adopt a heightened standard of care for AV companies.[333] He gives the example of a crash in which an AV is hit by a car that runs a stop sign.[334] He suggests that the injured passengers might "argue that the automated driving system could and should have recognized that [the CV] was not slowing down, predicted that [it] would run the stop sign, and taken immediate evasive actions."[335] He concludes that "[a] jury that wouldn't expect this kind of expert defensive driving from a human driver may nonetheless expect it from an automated driving system."[336]

The challenge of applying a heightened standard of care is defining its content. If AVs are held to what the best AV technology available at the time of the crash could have done, the test becomes simply an alternative formulation of the reasonable alternative design standard. If the heightened standard of care demands more of AV companies than

328 *See* Smith, *supra* note 39, at 49-50. Note that Smith only suggests that juries might take this approach. He does not take a position on its desirability.

329 *See* Abraham & Rabin, *supra* note 41, at 132; Vladeck, *supra* note 40, at 146.

330 *See* Geistfeld, *supra* note 42, at 1651-54.

331 Vladeck notes that a Louisiana appellate court once declined to hold a driver liable for crashing into a pedestrian with the reasoning that "[a] human being, no matter how efficient, is not a mechanical robot and does not possess the ability of a radar machine to discover danger before it becomes manifest." Vladeck, *supra* note 40, at 131 (quoting Arnold v. Reuther, 92 So. 2d 593, 596 (La. Ct. App. 1957)).

332 *See* CAL. CIV. CODE § 2100 (2021) ("A carrier of persons for reward must use the utmost care and diligence for their safe carriage, must provide everything necessary for that purpose, and must exercise to that end a reasonable degree of skill.").

333 Smith, *supra* note 39, at 48-50.

334 *Id.* at 48-49.

335 *Id.*

336 *Id.* at 49.

the technology currently allows, juries would be tasked with resolving speculative arguments about what improvements are feasible. It's possible to imagine lay juries holding AV companies crashes liable for crashes that could have been avoided by slightly faster reactions or slightly earlier detections. But it's harder to imagine juries faulting the AV company for not developing emergent behavior. The most demanding version of a heightened standard of care — holding AV companies liable for any crash that could have been prevented without violating the laws of physics — closely resembles contact responsibility. Whatever marginal improvement in incentives that a physics-based standard of care achieves over contact responsibility likely wouldn't be worth the costs of litigation.

2. Strict Liability / No Fault

Another set of scholars has advocated for strict liability rule or a no fault alternative for AV crashes. Vladeck proposes a judicially-enforced strict liability rule.[337] Kenneth Abraham and Bob Rabin propose replacing liability with "Manufacturer Enterprise Liability," a no fault system.[338] The virtue of these proposals is that plaintiffs would avoid the difficulty of proving that a reasonable alternative design was available or that the defendant failed to exercise reasonable care.[339] A strict liability or no fault system would create some incentive for AV companies to further develop AV technology's crash prevention potential.[340] The challenge for strict liability and no fault alternatives is how to address cases in which another road user's negligence is the primary cause of the crash. That's *the* critical issue because, as the AV crash data indicates, most crashes involving AVs will involve some human negligence. If AV companies can raise some kind of comparative negligence defense, then the value of strict liability or no fault will be diminished. AV companies will often evade responsibility, even when they could have prevented the crash in a cost-justified way.

337 *See* Vladeck, *supra* note 40, at 146.

338 *See* Abraham & Rabin, *supra* note 41, at 132.

339 *See id.* at 141-42 (explaining how the challenges that plaintiffs would face in proving design defect claims against an AV company motivate their enterprise liability alternative); Vladeck, *supra* note 40 at 147 ("[A] strict liability regime will spare all concerned the enormous transaction costs that would be expended if parties had to litigate liability issues involving driver-less cars where fault cannot be established.").

340 *See* Abraham & Rabin, *supra* note 41, at 153 ("[B]earing financial responsibility for [AV] losses will give the manufacturer an incentive to research ways of avoiding accidents that are currently unavoidable.").

Abraham and Rabin acknowledge this issue and advocate for a narrower form of comparative negligence.[341] They propose that "injury caused by the egregious negligence of a CV driver, coupled with minimal causal involvement by the [AV]" wouldn't be eligible for compensation under their system.[342] They give as examples "a rear-end collision while the [AV] is nearly stopped" and "reckless, intoxicated driving by the CV driver."[343] But these examples illustrate the case for contact responsibility.

Liability for crashes in which an AV is rear-ended isn't a trivial issue. The crash data show that crashes in which a CV rear-ends an AV are common.[344] In many of these crashes, the AV is stationary or nearly stationary. It's understandable that drivers aren't generally held liable for being rear-ended. For human drivers, there's a tradeoff between paying attention to the front and sides of a vehicle and checking the rear-view mirror. The driver of a vehicle approaching from behind is likely to notice the risk of collision first. It's also generally easier for that driver to avoid a crash by braking abruptly than it is for the driver of the vehicle in front to avoid it by accelerating. This is especially clear if the vehicle in front is stationary.

But the assumptions that justify not holding a stationary CV's driver responsible for being rear-ended won't hold for AVs, if their full potential is realized. AV software continuously monitors all 360 degrees of its surroundings.[345] AV sensors should be able to detect objects approaching from the rear — and determine their speed and acceleration — faster than a human driver would. They should also be able to more quickly assess whether it's safe to accelerate or swerve out of the way. The idea that a vehicle, waiting at a stoplight, might accelerate into the intersection to avoid a rear-end crash may sound fanciful or risky. It usually would be for a *human* driver, who couldn't calculate whether a collision would occur in the intersection. But the natural tendency to anthropomorphize AVs can be misleading. Emergent behavior might save lives and fenders. AV companies might not develop that behavior without a financial incentive.

341 *See id.* at 167. Vladeck does not address the issue of driver negligence. His chief example involves a negligent pedestrian. *See* Vladeck, *supra* note 40, at 130-31. His analysis implies that he would not permit the AV company to raise a comparative negligence defense in that case. *See id.* at 145-46.

342 Abraham & Rabin, *supra* note 41, at 167.

343 *Id.*

344 *See supra* Parts II.A–II.B.

345 *See* WAYMO, *supra* note 76, at 14.

Drunk driving presents an even more important issue for AV development. Drunk driving killed 10,142 Americans in 2019.[346] Decades of public policy interventions haven't solved the problem, so it's worth investing in technological interventions to mitigate its consequences. Identifying and avoiding drunk drivers will present technical challenges. Humans have a theory of mind that tells them that, when they see a vehicle swaying in their lane or otherwise driving erratically, the driver might be drunk. They might reduce their speed, increase their following distance, bias their position towards one side of their lane, or change lanes to avoid the risky driver.

With greater investment, though, AV technology could dramatically improve on human drivers' abilities to minimize the harm of drunk drivers. AVs' superior ability to monitor their surroundings could enable them to recognize when a driver is intoxicated earlier. Their ability to react faster could increase the set of possible evasive maneuvers. Their potential to make better decisions — and learn from the exponentially greater experience they will have compared to human drivers — could allow them to select a safer response. An AV company's investment in developing software that can safely handle encounters with drunk drivers could pay dividends any time that any AV in its fleet encountered a drunk driver.

More generally, the drawback of any liability regime that insulates AV companies from liability for crashes in which a driver was negligent or reckless or the AV played a limited causal role is that it will discourage investment in developing technology that could prevent those crashes. Neither the culpability of human error nor the causal involvement of the AV is a reliable proxy for what crashes are efficiently preventable. A drunk driver who drives into oncoming traffic is egregiously culpable, yet a collision may be easy to avoid by perception software with a longer range. Likewise, a stationary AV may be wholly passive in a crash, yet the AV could have avoided the crash simply be anticipating it and safely moving out of the way. An AV's contact with another vehicle, person, or property is a more reliable proxy for what crashes AV technology could have prevented.

3. Premarket Testing

Mark Geistfeld proposes that NHTSA implement a premarket testing system that would displace state tort liability.[347] Under his plan, NHTSA

[346] *See* NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., MOTOR VEHICLE CRASHES IN 2019, *supra* note 1, at 9.

[347] *See* Geistfeld, *supra* note 42, at 1678-80.

would require that AV companies demonstrate, based on data from premarket testing, that their AVs are at least twice as safe as CVs.[348] Compliance with the premarket testing regulation would be a complete defense to tort claims.[349] Geistfeld argues that, relative to the tort system, NHTSA has "a comparative institutional advantage for determining the appropriate testing criteria for evaluating the safety performance of an autonomous vehicle."[350] He is undoubtedly right that NHTSA's technical staff is better equipped to assess AV safety than lay juries are.

But a fixed safety threshold creates a deadly dilemma. Suppose that NHTSA could reliably establish when a company's AVs were twice as safe as CVs within their ODD. Before the company's AVs passed the "twice as safe" threshold, there would be a period in which its AVs were significantly safer than CVs but couldn't be legally deployed, which would mean more lives lost in CV crashes. After the AVs passed the threshold, though, the company would have no further legal incentive to keep developing cost-justified safety improvements. This dilemma isn't an artifact of Geistfeld's choice of "twice as safe." It's a more general defect of fixed safety thresholds. Setting the threshold higher would further delay deployment and the associated safety benefits. Setting the threshold lower would reduce AV companies' incentives to invest in further safety improvements once the threshold is passed.[351] The advantage of contact responsibility is that AV companies would deploy AVs once they are reasonably safe but would still stand to profit from incremental improvements in AV safety.

E. Political Incentives

Developing safer technology isn't the only way that AV companies could reduce their costs under contact responsibility. They could also use their money and power to lobby for public policies that reduce unsafe human driving or encourage the manufacture of safer vehicles. Traffic safety regulation suffers from a collective action problem. The benefits are widely dispersed, and the costs are often concentrated on entrenched interest groups, like the automakers and the alcohol

348 *See id.* at 1653.

349 *Id.* at 1686.

350 *Id.* at 1679.

351 Geistfeld argues that market incentives would push companies to invest in more safety improvements if consumers were properly informed. *See id.* at 1682. For a response to that argument, see *infra* Part IV.C.

industry. Under contact responsibility, the political economy of safety regulation would change.

AV companies would stand to gain from legislation requiring technological fixes to unsafe driving. For example, Congress could eliminate most drunk driving by mandating that every CV sold in the United States came with an ignition interlock device.[352] Blowing into an ignition interlock device before driving would undoubtedly annoy many drivers. But the annoyance and the cost of the devices wouldn't be worth more than several thousand lives each year. Congress could also mandate that every CV, other than emergency vehicles, come equipped with a governor that limited its speed to 75 mph.[353] The social costs in fatalities, injuries, and property damage from high-speed crashes likely exceed the social benefits of being able to drive faster than 75 mph. In our current liability regime, the cost of drunk driving and speeding are spread out over auto insurers, health insurers, disability insurers, and victims, which reduces the incentive for any one party to bear the cost of lobbying for stricter regulation.[354] Contact responsibility would concentrate the costs of drunk driving and speeding on the balance sheets of some of the most well-capitalized corporations.

Another way to reduce the costs of crashes is to develop vehicles that require seat belt use. NHTSA estimates that 90.7% of adults sitting in the front seats of passenger vehicles in 2019 wore seat belts.[355] Yet 47% of those killed in crashes in that years' FARS data weren't wearing seat belts.[356] AV companies could design AVs, and automakers could design CVs, so that the trips couldn't begin until the driver and all passengers identified by the vehicle's sensors have buckled their seat belts. AV companies have some incentive to enforce seat belt use under existing liability rules, but the incentives are diluted because some states allow

[352] *See* Patrick M. Carter, Carol A. C. Flannagan, Raymond Bingham, Rebecca M. Cunningham & Jonathan D. Rupp, *Modeling the Injury Prevention Impact of Mandatory Alcohol Ignition Interlock Installation in All New US Vehicles*, 105 AM. J. PUB. HEALTH 1028, 1028 (2015) (estimating that mandatory ignition interlocks would prevent 85% of drunk driving fatalities).

[353] *See* Bryant Walker Smith, *Regulation and the Risk of Inaction*, *in* AUTONOMOUS DRIVING, *supra* note 109, at 584.

[354] *See* Kyle D. Logue, *The Deterrence Case for Comprehensive Automaker Enterprise Liability*, 2019 J.L. & MOBILITY 1, 18 (explaining that, because state minimum auto insurance coverage mandates are too low, "many of the costs of auto accidents are currently being externalized to non-auto first-party health and disability insurers").

[355] NAT'L HIGHWAY TRAFFIC SAFETY ADMIN., MOTOR VEHICLE CRASHES IN 2019, *supra* note 1, at 8.

[356] *See id.*

defendants to introduce evidence that a plaintiff didn't wear a seat belt as a comparative negligence defense or to mitigate damages.[357] Under contact responsibility, AV companies would have an incentive to enforce seat belt use in their AVs and push legislators to require that new CVs came with seat belt enforcement sensors.

Contact responsibility would also lead AV companies to stop the arms race in vehicle weight. Research has shown that "[w]hen drivers shift from cars to light trucks or SUVs, each crash involving fatalities of light-truck or SUV occupants that is prevented comes at a cost of at least 4.3 additional crashes that involve deaths of car occupants" or other road users.[358] AV companies subject to contact responsibility would be less likely to deploy SUVs, because they would internalize damages to all persons injured in any crash. Traditional automakers developing AVs might become less enthusiastic about selling conventional SUVs to consumers. AV companies might lobby for regulations that would cause SUV owners to internalize the costs of their dangerous vehicles.

AV companies subject to contact responsibility might also push to expedite the arrival of V2V technology. V2V communication would enable an AV to know the position, direction, and speed of other vehicles before they traveled into sensor range. With that information, an AV's software would have more time to react and plan a safe path. It could chart a detour to avoid a vehicle moving in a manner that suggested its driver was impaired. But, as we have seen, V2V technology faces an economic collective action problem on top of the political collective action problem that all driver safety regulation faces.[359] No individual AV company or automaker will invest in equipping its vehicles with V2V technology unless it expects that most other vehicles will be similarly equipped. Federal legislation could solve the economic collective action problem by creating a uniform, national V2V network and requiring that all AVs and CVs be equipped with transponders that could communicate with other vehicles on the network. Contact responsibility would solve the political collective action problem by giving AV companies an incentive to lobby for the legislation. More generally, contact responsibility would align AV companies private lobbying incentives with public safety.

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357 *See* Gary L. Wickert & Jacob Coz, *Seat Belt Defense in All 50 States*, CLAIMS J. (Sept. 7, 2017), https://www.claimsjournal.com/news/national/2017/09/07/280329.htm [https://perma.cc/VUQ4-Q3NQ] (surveying state laws on the admissibility of seat belt use evidence).

358 Michelle J. White, *The "Arms Race" on American Roads: The Effect of Sport Utility Vehicles and Pickup Trucks on Traffic Safety*, 47 J.L. & ECON. 333, 334 (2004).

359 *See* Templeton, *supra* note 139.

IV. OBJECTIONS AND RESPONSES

There are four plausible objections to contact responsibility: (1) that it will create a moral hazard risk; (2) that it will delay deployment of AV technology; (3) that it's unnecessary because AV companies will have sufficient market incentives to develop safer AVs; and (4) that it will generate the wrong incentives in contactless crashes. Each of these objections diminishes under scrutiny.

A. Moral Hazard and Moral Luck

Contact responsibility would insulate human drivers from liability for negligence that results in a crash with an AV. The accident liability models predict that this would create a moral hazard. Drivers would have suboptimal incentives to drive carefully around AVs. This objection is intuitive, but it rests on the dubious premise that human drivers are highly responsive to liability incentives. In reality, liability incentives provide only modest *marginal* deterrence to unsafe human driving.[360] The strongest deterrents are the driver's own fear of injury or death and desire not to injure or kill others. The deployment of AVs won't change human nature.

Liability is a weak deterrent under existing law.[361] Most drivers are insured, and most plaintiffs recover from the defendant's insurer. Plaintiffs' attorneys rarely pursue "blood money" directly from the driver's pocket.[362] The risk of injury is immediate. The risk of an increase in liability insurance is delayed and may be discounted. As Abraham and Rabin explain, "the threat of liability on the part of a driver creates only very attenuated safety incentives, because the principal economic impact of liability is only an eventual increase in the cost of auto liability insurance."[363]

Under contact responsibility, a driver involved in a crash with an AV might see her insurance premium rise after the crash even though she faced no liability. This is because contact responsibility wouldn't displace driver liability for crashes *between* CVs. Drivers would still need

[360] *See supra* Part III.A.

[361] Empirical research on whether no fault systems increase traffic fatalities is mixed. *See* Nora Freeman Engstrom, *An Alternative Explanation for No Fault's "Demise,"* 61 DEPAUL L. REV. 303, 332-33 (2012) (reviewing the research).

[362] *See* Tom Baker, *Blood Money, New Money, and the Moral Economy of Tort Law in Action*, 35 LAW & SOC'Y REV. 275, 277 (2001) (acknowledging the "strong norm against paying blood money in a negligence case").

[363] Abraham & Rabin, *supra* note 41, at 134.

to carry insurance to cover the risk of liability from those crashes.[364] A driver's involvement in a crash with an AV may indicate that she has a higher risk of being involved in, and liable for, a crash with a CV. Therefore, her insurer might raise her premiums, even though it didn't have to pay for her crash with the AV.

A driver who negligently crashes into AVs would also face penalties other than tort liability. Drivers tend to cause crashes by violating the traffic laws. These violations risk fines or other civil penalties. Certain kinds of reckless driving, such as drunk driving, also violate the criminal law and subject the driver to criminal penalties. In fact, a driver may be *more likely* to be penalized for a traffic law violation that results in a crash with an AV, because the AV will create an electronic record of the crash. Under NHTSA's order, the AV company would be mandated to report the crash. Law enforcement could use those reports to investigate crashes with serious wrongdoing.

One also might object that, even if contact responsibility doesn't create a significant moral hazard risk, it's unfair to AV companies to bear the cost of negligent driving. I struggle to muster outrage. Any unfairness would be purely financial. The cost would be spread across the shareholders of corporations that are worth tens or hundreds of billions of dollars in market capitalization. Driving is heavily subsidized activity.[365] Those subsidies will increasingly accrue to AV companies.

Likewise, one could object that it's unfair that the negligent driver avoids the cost of liability. But that kind of unfairness is pervasive under existing law. Negligent driving is a classic case of moral luck.[366] The blameworthy act is driving negligently, not causing a collision. Most instances of negligent driving don't result in any punishment because the negligent driver is lucky enough not to collide into another vehicle or get caught by the police.[367] Under contact responsibility, the number

[364] The force of this response will diminish as AVs become more widely deployed. Regulators may need to respond by increasing enforcement of the traffic laws. The wide availability of safe AVs may create political will for tighter regulation of unsafe driving.

[365] *See generally* Gregory H. Shill, *Should Law Subsidize Driving?*, 95 N.Y.U. L. REV. 498 (2020) (discussing a "submerged, disconnected system of rules that furnish indirect yet extravagant subsidies to driving").

[366] *See generally* David Lewis, *The Punishment that Leaves Something to Chance*, 18 PHIL. & PUB. AFFS. 53 (1989) (arguing that analogous kinds of moral luck function as a "penal lottery"). *But see* Sanford H. Kadish, *Foreword: The Criminal Law and the Luck of the Draw*, 84 J. CRIM. L. & CRIMINOLOGY 679, 685 (1994) (questioning the harm requirement in criminal law on moral luck grounds and using drunk driving as an example).

[367] For example, Mothers Against Drunk Driving ("MADD") claims that "[e]ach day, people drive drunk more than 300,000 times, but only about 3200 are arrested."

of acts of negligent driving that don't result in an increase in the driver's insurance premium would increase, because negligent drivers wouldn't be liable for striking AVs. But even those drivers lucky enough to strike an AV rather than a CV would still be eligible for punishment in the form of a traffic citation or criminal conviction. The increase in moral luck in the world would be modest.

B. Delaying Deployment

Since the early days of AV testing, scholars have worried AV companies will delay deployment because the expected liability cost would be too uncertain or too high.[368] Contact responsibility would reduce uncertainty about an AV company's expected liability exposure, but it would increase the company's expected liability cost relative to a negligence rule. The increase in expected liability cost could create perverse incentives.

Suppose that a traveler has the choice between taking a trip in a CV taxi or in a robotaxi. Under contact responsibility, the driver of the CV taxi would only be liable for crashes with other CVs caused by her negligence. She wouldn't be liable for crashes with other CVs caused by another driver's negligence, and she wouldn't be liable for any crashes with AVs. By contrast, an AV company would be liable for all crashes involving its robotaxi. Accordingly, the AV company would face a higher expected liability cost *per crash* than CV taxi drivers would. If AV companies pass the increase in liability cost onto consumers, a traveler might choose the less expensive ride in the CV taxi over the robotaxi on the margin. This would generate a perverse result: the traveler would take a less safe mode of travel.[369]

The accident liability models predict this result.[370] A driver subject to a strict liability rule chooses a lower activity level by driving fewer

Statistics, MADD, https://www.madd.org/statistics/ (last visited July 11, 2021) [https://perma.cc/954D-SHR5].

368 *See, e.g.*, Marchant & Lindor, *supra* note 317, at 1334 (expressing concern that expected liability costs could delay deployment).

369 A similar perverse incentive exists when regulators mandate that manufacturers adopt new safety technologies in CVs, because these regulations often apply only to newly manufactured vehicles. *See* JERRY L. MASHAW & DAVID L. HARFST, THE STRUGGLE FOR AUTO SAFETY 94 (1990) ("[I]mposing new and more costly technologies always extend[s] the useful life of old ones by providing economic incentives for their continued use . . . there [is] always a safety loss in the transition period as consumers continue[] to use worn-out equipment[.]").

370 *See* Shavell, *supra* note 33, at 29 ("[S]uppose that if an [AV] and a [CV] are involved in an accident, liability of the [CV] is governed by fault, whereas the [AV] owner would be held strictly liable and pay damages to the state. Then the incentives of

miles.[371] Here, AVs drive fewer miles because the increase in the price of the rides due to increase in expected liability cost reduces consumer demand on the margin. By contrast, a driver subject to a negligence rule for CV crashes and no liability for AV crashes doesn't have an incentive to drive fewer miles.[372] Here, CV taxis undercut robotaxis on price and provide more rides. The net effect would be a delay in the deployment of AVs.

This objection is plausible, but the analysis is more complicated than it initially appears. Even though AV companies subject to contact responsibility would incur a higher expected liability cost *per crash* than CV taxi companies, they may incur a lower expected liability cost *per mile* than a CV taxi company would. The analysis needs to account for the likelihood that (1) AVs will cause far fewer crashes than human drivers cause and (2) AVs will avoid more potential crashes caused by other drivers than drivers avoid.

Consider a world in which AVs and CVs share the road. For simplicity's sake, assume that in each crash, one vehicle strikes another, and the striking vehicle is always at fault. Suppose that, for a given number of miles, a CV taxi strikes nine CVs and one AV, but the safer robotaxi strikes only one CV and never strikes an AV. Now suppose that, over the same number of miles, the CV taxi will be struck by a CV nine times and an AV once. The robotaxi, which is better able to avoid crashes, will be struck by a CV only seven times and will never be struck by an AV.[373] Under contact responsibility, even though the CV taxi was involved in 20 crashes, the CV taxi driver would be liable only for nine crashes — the nine times it struck another CV. The robotaxi was involved in eight crashes and the AV company would be liable for all eight — the crash in which the robotaxi struck a CV plus the seven crashes in which it was struck by a CV.

The hypothetical illustrates that, if AVs cause far fewer crashes than human drivers cause *and* AVs avoid slightly more crashes caused by others than humans drivers avoid, then even under contact responsibility, expected liability could be lower for a robotaxi than for a CV taxi operating the same number of miles. To be sure, the AV

the [CV] owner to take care would be appropriate, but he would be led to drive too many miles; and the incentives of the [AV] owner would be proper.").

371 *See* LANDES & POSNER, *supra* note 38, at 66-67; SHAVELL, *supra* note 38, at 23.

372 *See* LANDES & POSNER, *supra* note 38, at 66-67; SHAVELL, *supra* note 38, at 23-24.

373 AVs will also mitigate the severity of crashes, not just their frequency. For example, one could suppose that the AV is struck by a CV eight times, but because the AV is able to mitigate the severity of those crashes, the total liability cost of those eight crashes is equivalent to the total liability cost of seven crashes.

company's expected liability would be *even lower* under existing law. The point is just that contact responsibility wouldn't necessarily generate a higher liability cost per mile for AVs than for CVs.[374]

Contact responsibility might also change *how* AVs are deployed rather than when they're deployed. An AV company could account for the risks of crashes caused by other road users' errors in choosing its AVs' ODD. For example, if an AV company's technology is adept at avoiding crashes on roads with a speed limit of 45 mph or less, the AV company can simply restrict its AVs' ODD to low-speed roads. Again, there is a potential perverse incentive. For a passenger taking a trip that requires driving on high-speed roads, the AV company's decision not to deploy its robotaxis on those roads may result in the passenger traveling in a less safe CV taxi. But there might be a countervailing effect. Some trips can be completed within a tolerable amount of time either by high-speed roads or low-speed roads. Some passengers might choose to take a robotaxi on the low-speed roads rather than a CV taxi on the high-speed roads.

The net effect of contact responsibility could be a slower deployment of AVs on risky roads and a shift in some trips currently taken on risky roads to safer roads. It could also start a race-to-the-top on safety. Under contact responsibility, AV companies could credibly tell state and local governments that they would be more likely to deploy a robotaxi service in cities with safer roads, spurring investment in better infrastructure or tighter regulation. This is why it's critical to consider the indirect political effects of liability rules.

Another reason to doubt the force of the delayed deployment objection is that the economics of robotaxis give AV companies an incentive to deploy AVs as soon as feasible. Robotaxi services have network effects.[375] Each additional passenger using an AV company's network increases the likelihood that an AV will be nearby when it's requested. Each additional passenger on the network reduces the miles AVs in a fleet will travel without a fare-paying passenger. These network effects advantage the first mover. Subsequent competitors will have to spend dearly to attract passengers to a fledgling network.

[374] AV rides may also be less expensive on a per mile basis than CV rides because of utilization efficiencies. *See supra* Part I.B.

[375] For an analysis of which aspects of robotaxi services might have network effects, see Benedict Evans, *Winner-Takes-All Effects in Autonomous Cars*, BENEDICT EVANS (Aug. 22, 2017), https://www.ben-evans.com/benedictevans/2017/8/20/winner-takes-all [https://perma.cc/Q6CJ-P85R]. For the impact of network effects on competition, see Brad Templeton, *Competition in the Robotaxi World*, BRAD TEMPLETON, https://www.templetons.com/brad/robocars/compete.html (last visited July 25, 2021) [https://perma.cc/VSV5-QJ5T].

If contact responsibility were implemented, and evidence emerged that AV companies were delaying deployment because of expected liability costs, the right response would be to subsidize AV rides, not to change the liability rule. The appeal of contact responsibility is that it gives the decision-makers with the most efficient means to prevent crashes — AV companies — targeted incentives to invest in crash prevention technology. Those incentive effects would be preserved even if AV rides were subsidized. AV companies would simply make even more profit from preventing crashes.

An even better solution is Kyle Logue's proposal to replace driver liability for all motor vehicle crashes — including crashes between CVs — with automaker enterprise liability.[376] Logue's enterprise liability proposal could be combined with Shavell's strict liability to the state. In every crash, the developer of both vehicles — the automaker if the vehicle was a CV and the AV company if the vehicle was an AVs — could be strictly liable to the state. If automakers internalized all the costs of crashes arising out of the operation of their CVs, they would have strong incentives to build safer vehicles and lobby for tighter safety regulation, just as AV companies would under contact responsibility.[377] Automakers would also seek to accelerate the deployment of AVs, so they could avoid liability for driver errors.[378] The main obstacle to this approach is politics. Legislatures might not be interested in revisiting our entrenched system of driver liability. Contact responsibility may be more politically viable because of the widespread uncertainty about how the tort system will handle AV crashes.

C. *Market Incentives for Safety*

Some scholars have argued that market incentives will push AV companies to invest in developing safer AV technology.[379] They are undoubtedly right that robotaxi passengers will prefer a lower risk of injury. But market incentives will only push AV companies to make some, but not all, of the investments in cost-justified safety improvements that contact responsibility would. Market incentives for safety could only match contact responsibility's incentives for safety if

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[376] *See* Logue, *supra* note 354, at 20-29.

[377] *See id.* at 24-25.

[378] *See id.* at 25-26.

[379] *See, e.g.*, Geistfeld, *supra* note 42, at 1682 (arguing that, if disclosure of an AV's risk-adjusted insurance premium were mandated, "consumers could easily compare the relative safety performance of different [AVs], thereby incentivizing manufacturers to improve upon the safety performance of their vehicles in order to lower the associated insurance costs").

three conditions were met. First, passengers could choose between robotaxi services with AVs developed by competing AV companies for the same trip. Second, the passengers were sufficiently informed about the relative safety performance of the AV companies' technology to factor it into their choice of travel mode. Third, the passengers chose to evaluate the AVs' safety not based on their own personal risk, but on the overall risk to society.

By the time of deployment, robotaxis should be safer than CV taxis in their ODD. The only meaningful competition on safety would come from other robotaxi services. It's possible that there will be competition among AV companies in some metropolitan areas. But what information should passengers be provided about those companies' relative safety performance? Geistfeld has argued that AV companies should be mandated to disclose their vehicles' insurance premiums.[380] A safety metric based on insurance premiums is in some respects an elegant solution. It would incorporate information about both the frequency and the severity of crashes. It would be credible because it would come from the AV company's insurer, a third party with financial incentives to correctly assess the risk.[381] Comparisons between two AV companies operating the same city wouldn't be a pure comparison between the companies' technologies. They would also be influenced by differences in the relative safety of their ODDs. But the comparison would create a salutary incentive for AV companies either way: build safer technology or deploy it on safer roads.

The weakness of an insurance-based safety metric is that it wouldn't fully reflect the total costs of crashes. The metric wouldn't reflect injuries or property damage to third parties from crashes in which the AV company wasn't found liable. It would also undercount injuries to passengers to the extent they were able to recover from third parties. In theory, regulators could estimate the incremental increase in insurance cost that the AV company would have sustained if it had been liable for all crashes and then mandate that AV companies share that figure with passengers. But that figure would only be relevant to the most altruistic consumers. Most passengers would want to know their personal risk of injury, not the social costs of crashes involving the company's AVs. In fact, AV companies might be able to decrease the injury risk to their passengers while *increasing* the total social costs of crashes by deploying robotaxi SUVs. By contrast, contact responsibility would cause AV

[380] *See id.* at 1682.

[381] If AV companies choose to self-insure, they would need to disclose their expected liability costs for the relevant period.

companies to internalize all the costs of crashes involving its AVs, not just the cost to its passengers.

D. Contactless Crashes

Tort law limits recovery to breaches of the duty of care that are the factual cause and the proximate cause of a plaintiff's injury. Factual cause asks whether the injury would have happened but for the actions of the defendant.[382] Proximate cause, which the latest Restatement calls "scope of liability," asks whether the injury was reasonably foreseeable.[383] Contact responsibility would dispense with both the factual cause and proximate cause requirements. Dispensing with factual cause will remove uncertainty about whether AV companies will be held responsible for crashes involving stationary AVs. Dispensing with proximate cause would ensure that AV companies couldn't reintroduce fault-like defenses under the guise of causation.[384] Juror intuition about whether a crash is "reasonably foreseeable" wouldn't be a more reliable guide to whether a crash could have been prevented with a cost-justified investment in developing safer technology than juror intuition about negligence is.

A contact rule is a rough-and-ready proxy for which crashes AV companies can prevent by developing safer technology.[385] It might appear to generate apparently undesirable results in crashes that don't involve contact between an AV and another vehicle, person, or property. But those results wouldn't undermine incentives as much as it appears. Two examples illustrate this point. First, suppose that an AV stops abruptly, which causes a CV behind the AV to stop abruptly in turn to avoid rear-ending it. Now suppose that the CV's abrupt stop

[382] *See* RESTATEMENT (THIRD) OF TORTS: LIAB. FOR PHYSICAL & EMOTIONAL HARM § 26 (AM. L. INST. 2010) ("Tortious conduct must be a factual cause of harm for liability to be imposed. Conduct is a factual cause of harm when the harm would not have occurred absent the conduct.").

[383] *See id.* § 29 cmt. j ("[W]hen scope of liability arises in a negligence case, the risks that make an actor negligent are limited to foreseeable ones, and the factfinder must determine whether the type of harm that occurred is among those reasonably foreseeable potential harms that made the actor's conduct negligent."). "Scope of liability" is the term the Restatement (Third) uses for "proximate cause."

[384] New Zealand's Accident Compensation Corporation, which replaces tort liability for almost all personal injuries in that country, has struggled to draw lines on causation. *See* Peter H. Schuck, *Tort Reform, Kiwi-Style*, 27 YALE L. & POL'Y REV. 187, 190-97 (2008).

[385] The contact test might generate undesirable results in rare cases in which the contact was vertical. *See* Abraham & Rabin, *supra* note 41, at 160 (noting that "a vandal could drop a heavy object from a highway overpass onto a vehicle").

enables it to avoid rear-ending the AV, but also causes it to be rear-ended by a second CV. In that case, the AV wouldn't have come into contact with either of the CVs but would have been the factual and proximate cause of the crash.

Second, consider a real-world contactless crash caused by an AV. In 2011, Google engineer Anthony Levandowski had secretly modified the company's AV software to relax restrictions on its AVs' ODD.[386] He took a colleague out for an autonomous ride in a Prius that Google had converted into an AV.[387] An account in *The New Yorker* claims that

> [t]he car went onto a freeway, where it travelled past an on-ramp. . . . [T]he Prius accidentally boxed in another vehicle, a Camry. A human driver could easily have handled the situation by slowing down and letting the Camry merge into traffic, but Google's software was not prepared for this scenario. The cars continued speeding down the freeway side by side. The Camry's driver jerked his car onto the right shoulder. Then, apparently trying to avoid a guardrail, he veered to the left; the Camry pinwheeled across the freeway and into the median.[388]

In other words, the Google AV behaved in a dangerously unpredictable manner, and the Camry driver attempted a dangerous maneuver in response and crashed. But there was no contact between the vehicles.

It might appear that the contact rule generates the wrong results in the second-order rear-ending case and the Levandowski case. But consider the cases from the perspective of a software engineer. Contact responsibility gives AV companies an incentive to develop AVs that can avoid being rear-ended. An AV that stopped so abruptly that a CV behind had to stop abruptly in turn would often be rear-ended. In many cases, the CV wouldn't stop quickly enough to avoid contact with the AV. Similarly, the Levandowski case could have ended with the Camry cutting off the Google AV and colliding with it. If it had, it would have been a crash that Google would have had an incentive to prevent under contact responsibility. It's easy to imagine cases in which an AV causes a crash without coming into contact with other vehicles. But they're

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[386] *See* Charles Duhigg, *Did Uber Steal Google's Intellectual Property?*, NEW YORKER (Oct. 15, 2018), https://www.newyorker.com/magazine/2018/10/22/did-uber-steal-googles-intellectual-property [https://perma.cc/V2YK-UHRM]. Levandowski later left Google, founded a startup called Otto, sold it quickly to Uber, and then was fired during litigation between Uber and Waymo in which it was revealed that Levandowski had stolen Google's IP. *See id.*

[387] *See id.*

[388] *Id.*

almost always scenarios that an AV company should develop software to avoid if it wants to prevent contacts.[389]

Conclusion

In the coming years, decisions made on the road by hundreds of millions of human drivers will be replaced with decisions made in a small number of corporate software labs. Society has built a set of institutions and practices — driver's ed, driver's licenses, traffic tickets, designated drivers, and public awareness campaigns — designed to help human drivers make better decisions. As Jerry Mashaw and David Harfst once wrote, "[a]ttempts at driver behavior modification have dominated the legal approach to vehicle safety."[390] Tort liability for traffic crashes is part of that behavior modification infrastructure, but its role is modest.

When AVs are deployed, most of the policy levers that society uses to prevent crashes will become obsolete. Instead, what will matter are the incentives acting on the engineers in those corporate software labs and the incentives acting on the managers who set the engineers' budgets. Liability will take on a more important role in preventing crashes, because the best way to change the managers' incentives is to make the cost of crashes show up on their balance sheets.

The deployment of AVs will cause crashes to decline regardless of the liability rule. When that happens, it might seem that the liability system is working as designed. But if we retain today's liability rules, there will still be people killed and injured in preventable crashes. We should stop viewing crashes as regrettable but inevitable accidents. We should treat crashes as public health failures, and we should put AV engineers to work on eliminating them.

389 Because a contactless crash would not be subject to the contact responsibility system, a plaintiff injured in a contactless crash involving an AV could bring a products liability suit against the AV company.

390 Mashaw & Harfst, *supra* note 369, at 32.