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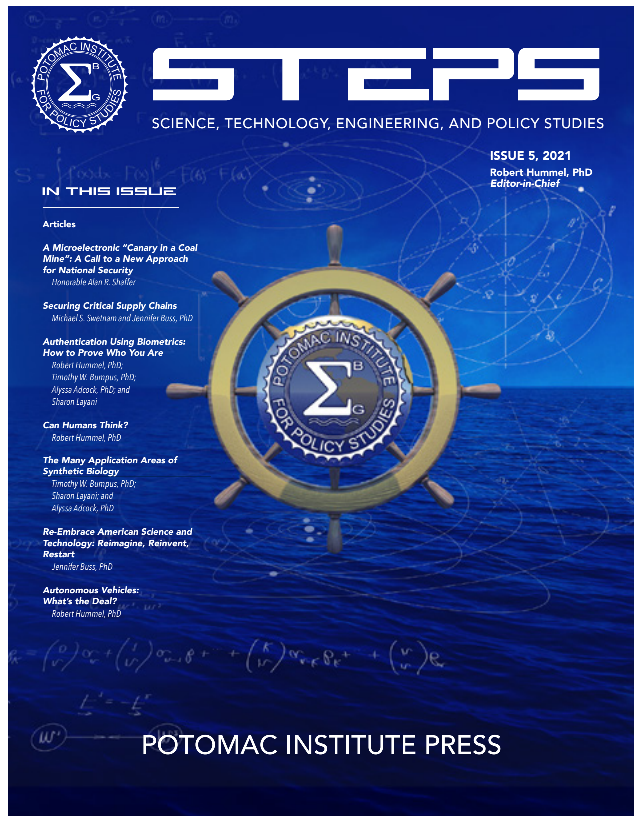

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Autonomous Vehicles: What's the Deal?

Robert Hummel, PhD

Autonomous vehicle technology promises to make driverless vehicles a reality. Yet the introduction of commercial driverless vehicles has been delayed, and there are warning signals that perhaps the technology will not be ready any time soon. We list some of the warnings, successes to date, and challenges to their introduction and integration into the transportation enterprise. We note some particular special cases where introduction might be possible in the short term. One difficulty is that the development of autonomous vehicle technology is proceeding under the assumption that the infrastructure (the roads, and other vehicles) will provide minimal assistance. We note that government could accelerate the development by providing standards, sensors, and communications as part of the infrastructure as improvements are made to roads and bridges.

Disillusionment?

Very few years ago, autonomous vehicles were going to change the world. Now, it seems as though the revolution has been postponed. Indeed, in the past year, there have been significant signs that disillusionment has set in. And yet, progress continues to be made and many demonstrations and experiments show promising results. Research and development are absorbing resources and talent worldwide. Does government have a role? Where do we go from here?

Before we describe the accomplishments to date, consider the warning signals:

- Uber, which had invested billions into developing driverless vehicles for their ridesharing services (which would then become robo-taxi services), spun off its autonomous vehicle effort in late 2020 to form a new company called Aurora.[1] Uber invested $400M in Aurora.

- Lyft followed suit, selling its autonomous vehicle subdivision to a subsidiary of Toyota, in early 2021.[2] It seems that both Uber and Lyft had been competing in development of robo-taxi capabilities but became disillusioned by the delays and cost of development.

- Yandex, a Russian/Dutch concern that was (among other things) pursuing self-driving vehicles for robo-taxi services, spun off the division to an independent entity called Yanex Self Driving Group, in late 2020.[3] Independence facilitates raising venture capital.

- In 2018, prior to Uber's divestiture, an autonomous Uber test vehicle with a safety driver struck and killed a woman walking her bike across a busy highway in the dark of night.

- Waymo, a division of Alphabet, announced the departure of the CEO and many of its top executives in early 2021,[4] thereby suggesting Google's multi-year foray into the development of autonomous vehicles is also not proceeding at the expected pace.

- A preliminary investigation of an accident where a Tesla vehicle ran into a tree killing two occupants indicated that there was no one in the driver seat.[5] Tesla vehicles include an "Autopilot" mode that serves as a driver assistance system. Tesla CEO, Elon Musk,[6] denied that Autopilot was enabled at the time of the crash.

- In 2019, Phys.org provided five reasons why experts say that self-driving vehicles carrying passengers are at least ten years, or maybe multiple decades, away.[7]

- A *New York Times* article in May 2021 quotes industry executives to suggest that the "transformation" will occur over the next "30 years."[8]

No one is giving up, and none of these signals indicate that self-driving vehicles are impossible. On the contrary, many companies continue impressive research and development, and commercial success seems imminent. However, initial progress has been slower than once anticipated.

Positive Autonomous Vehicle Developments

Plenty of experimental systems operate on real roadways, carrying human occupants. In some cases, the vehicle operates without a safety driver. All the major automobile companies either have R&D efforts in subdivisions or partnerships in technology companies, or both, to develop increasingly more autonomous control systems. Moreover, some cities employ "robo-taxi" services as pilot programs.

Several technology companies have impressive demonstrations with online videos showing driverless vehicle operation. Much of the impetus is to provide and expand robo-taxi services, where the control system allows the vehicle to serve as a driverless taxi service, taking paying customers from one location to another. Much like Uber and Lyft, the service is summoned using an app.

One of the main pilot programs is taking place in Phoenix, Arizona. Google started an autonomous vehicle subsidiary in 2009, which is now part of the Alphabet portfolio in a company called Waymo.[9] Waymo One, out of Phoenix, is an autonomous vehicle ridesharing service that operates without people in the driver's seat.[10] Waymo Driver is their autonomous driver technology, which they claim is the world's most experienced driver according to odometer readings.

Other tests and pilot projects are taking place in Gangzhou, China. This large metropolitan city (the third largest city in China, 75 miles from Hong Kong) hosts a (free) robo-taxi service by WeRide,[11] with over a hundred thousand rides through 2020.[12] In addition to Gangzhou, WeRide is authorized to test driverless vehicles in San Jose and claims over 2.5 million miles of testing and operation. Another competitor in Gangzhou, DiDi Autonomous Driving,[13] is a break-out from DiDi Chuxing automaker and has raised a billion dollars equivalent in venture capital. They have an online demo of an autonomous vehicle operating for five hours without intervention from a human driver (i.e., without a disengagement).[14]

Another impressive demonstration is presented by Mobileye, a company owned by Intel, with demonstrations of autonomous driving using visual sensing and crowd-sourced mapping technology in Jerusalem, Israel, driving for twenty minutes in a complex urban environment without disengagements.[15] The vehicle merges into traffic, navigates complex turns, and senses and avoids pedestrians.

One of the main autonomous vehicles companies, Cruise,[16] is a subsidiary of GM and is backed by GM and Honda, with further investments from Microsoft, Walmart, and venture capital. Cruise has a resulting valuation of at least $30 billion.[17,18] They have displayed a driverless concept car called Origin, which has no steering wheel or gas pedal. Intended ultimately for the ridesharing market, it is likely to initially see use in special transport situations, like transporting people from parking lots to tourist venues. (A French company, EasyMile, has fielded such driverless shuttles.[19]) Cruise has been testing autonomous vehicles based on the Chevy Bolt in San Francisco and claims to have logged the most miles compared to all competitors.[20] These tests are said to be driverless with minimal intervention by a safety driver (said to be Society of Automotive Engineers [SAE] Level 4 conditions).[21] In March 2021, Cruise acquired Voyage—a company that has tested some of its autonomous vehicle technology under certain speed restrictions within retirement communities.[22] Cruise has plans to start a robo-taxi service in Dubai in 2023.[23]

There are dozens of other technology companies developing autonomous vehicle components or supporting technologies. Inexpensive sensors and communications devices are especially important. Much development is required to train (or teach) systems about special cases in navigation and traffic negotiation.

All of this implies that the autonomous vehicle revolution is about to happen, with commercial availability for driverless vehicles and robo-taxi services imminent. However, the tests to date all have certain restrictions and constraints, with the hope that these restrictions can be overcome through further development. Moreover, most of the development assumes that the road and associated infrastructure is unavailable to assist autonomous vehicles, except that GPS and geolocation services are a given. Because the challenges are great, assistance from infrastructure could be important to safety and further success.

Challenges

Car and Driver says that R&D for self-driving cars has cost $16B as of early 2020, and there is not much short-term reward.[24] A significant fraction of the US total R&D budget is dedicated to the development of various forms of autonomous vehicles, largely funded by venture capital. The opportunity costs are significant, but the potential payoff is large. So far, the payoff is minimal in terms of return on investment.

Still, the demos and testing of the companies engaged in developing autonomous vehicles continue to show steady progress and impressive results. We noted commercial robo-taxi services in Phoenix and Gangzhou, and we expect to see them elsewhere, soon. Yet the warning signs and experts suggested that long-term benefits might be decades in the future. So, what is the disconnect? Will we see driverless vehicles in everyday traffic soon? Will robo-taxis become the more common form of commuting, and when?

The difficulty is that there are important challenges to the widespread adoption of truly autonomous, driverless vehicles.

Most of the time when driving, a person pays relatively little attention, adjusting the steering or acceleration in response to simple visual inputs. Machine learning can accomplish the same by interpolating from training data to provide safe autonomous navigation of a vehicle, for those cases where there is plenty of data. The methods can include a mix of deep neural networks, together with rules based on specific inputs like lane markers and stop signs. And thus, driverless vehicles have shown a level of success, generally with a safety driver present, in limited domains.

But problems arise when you consider the volume of activity that is encompassed by vehicular transport in the United States. Americans drove around 3.2 trillion miles in 2019 (fewer miles were driven during the 2020 pandemic).[25] In 2020, all autonomous vehicles world-wide drove less than 2 million miles, which was more than in 2019.[26] The leaders (by far) in miles driven were Waymo and Cruise. While 2 million miles is sufficient to start to give an indication of the frequency in which an operator needs to take over (disengagements), it can't possibly be representative of all the various conditions and situations that are encountered in 3.2 trillion miles. Waymo says that they have driven a total of 20 million miles since 2009[27] (a twelve-year period), with 6.1 million of those miles in the Phoenix, Arizona metropolitan area.

While millions of miles have been accumulated for training, trillions of miles will be necessary. That is six orders of magnitude apart. Thus, the challenge is to deal with many kinds of weather conditions, environments, and navigation situations to include parking lots, tunnels, underground facilities, round-abouts, etc. Simulations can fill in needed experience to a degree, but massive collection from non-autonomous vehicles may be essential. Furthermore, statistical approaches based purely on training are likely to be inadequate: rules and methods of inference will likely need to supplement training. And then there are the extremely unusual situations.

At times, driving requires anticipation and/or analysis of the intentions of other drivers. Sometimes driving requires extrapolation from prior experience concerning road conditions or the local environment, with analysis based on very few, if any, prior experiences. Pre-encoded rules do not necessarily cover all possible cases. Today, machine learning techniques in artificial intelligence are not capable of such deeper reasoning and instead rely on many examples for interpolation from training data.[28] Accordingly, until artificial intelligence approaches can perform extrapolative analysis based on few or no prior experience to cause a vehicle to successfully navigate unusual or challenging situations, a fully autonomous vehicle will not be possible. On the other hand, vehicles should be able to navigate safely under many conditions when these rare situations are not present.

There is also the issue of autonomous vehicles operating in conjunction with human drivers. Humans infer the intentions of other drivers all the time to ensure their own safety. They might have difficulty inferring the intentions of autonomous vehicles, and autonomous vehicles almost certainly are not good at inferring humans' intentions as it bases its decisions on average cases.

It is widely thought that once autonomous vehicles are safer than human drivers, autonomous vehicles will find a widespread commercial market. The economic benefits are large, providing the driver can be taken out of the loop. But safety is a separate issue. The marketplace not only needs to *know* that autonomous vehicles are safe, but they also need to be *convinced*.

Beyond statistical significance in proving safety, convincing consumers might require that autonomous vehicles be vastly safer than human drivers. The average person overestimates their own abilities, but also assumes a greater risk of loss when emplacing trust in someone else, or something else.

One of the greatest challenges, however, will be liability. Currently, drivers pay insurance companies to pay for losses, because drivers incur the liability for most accidents. With autonomous vehicles, the software developers must incur at least some of the liability, which will significantly raise the cost of software delivery and thus the cost of the vehicles. While overall costs might simply be shifted, or even decreased, the perceived entry cost of possessing an autonomous vehicle, or using a robo-taxi, might inhibit adoption.

Prognosis

First, note that advanced driver assistance systems (ADASs) have already made driving far safer and have begun to dominate the market for new cars. While far from driverless technology, these systems use sensors and processing to assist drivers in keeping vehicles and their occupants safe. But ADASs do not get rid of the driver, and thus the payoff is in terms of safety. We expect increasing sophistication of available commercial ADASs.

Greater levels of autonomy are possible, but there remain issues around highly unusual situations and conditions which currently require the cognitive skills of a thinking human driver. The goal, for the time being, will therefore be to develop vehicles in which a human can take charge when required, but most of the time offer minimal input. Safety will be enhanced, and drivers will have more freedom if they can be divested from the mundane driving tasks. However, for now, having a driver (whether in the vehicle or remote) that can take over at a moment's notice will remain essential.

Personal and commercial vehicles can minimize the amount of time in which a driver needs to take control by making use of a smart road and communications that integrates local data from multiple vehicles, environment conditions, and road sensors. Integration of the information from the multiple vehicles in a local vicinity can enhance both safety and efficient flow. A logical component of a hybrid approach to autonomous or semi-autonomous vehicles includes smart road infrastructure.

Based on the successful demonstrations and ongoing experimental services, there are likely certain applications that might provide commercial payoffs for mostly autonomous vehicles.

Robo-taxi services in limited areas: Most taxi and ride-sharing services operate in limited urban areas, taking passengers from one easily accessible location to another. By learning the precise layout of roads in a region of a few square miles, or even a few hundred square miles, and the rules of the road for that limited area, a large proportion of rides might be accommodated in a driverless fashion. This remains the hope, and while the challenges include operating in a hybrid environment with non-autonomous vehicles and pedestrians, robo-taxi services in specific regions are likely viable, especially if smart infrastructure can assist the vehicles. There will likely be certain limitations, like fixed pick-up locations, as in current pilot projects, but the economic drivers are compelling.

Interstate portal to portal cargo delivery: Trucking can be transformed by using driverless vehicle technology to move trucks from one portal along a major long-haul artery (like an interstate highway) to another point "down the road," so that a driver can deliver the truck from a complex urban location to the portal, and a different driver distributes the cargo by picking up the truck at the second portal.[29]

Full autonomous mode: ADAS systems might become so sufficiently trustworthy that a driver can allow the vehicle to go into a super-cruise control mode, for example on an interstate that does not require the driver to pay attention until alerted and given sufficient warning that human control will be required.

Delivery of packages: Driverless package delivery services might be viable for certain sets of distribution points and in certain areas. Expanded use of bike lanes and dedicated lanes might help smooth delivery of goods.

How Government Can Help

Government's primary role is to enhance safety of vehicular traffic. Safety is greatly improved by incorporating ADASs into most new vehicles and also by improvements to the infrastructure. Safety is also enhanced if that infrastructure can promote sharing of data among vehicles and with the road, i.e., smart roads. While we wait for breakthroughs that allow for greater full autonomy that can take the human out of the loop entirely, it behooves all stakeholders to pursue dual paths that utilize advanced driver assistance as well as novel and advanced smart road technologies, including high bandwidth communications and fast processor speeds to assist in navigating and controlling traffic.

Fully autonomous vehicles, as indicated by SAE autonomy levels 4 and 5, could accrue major economic benefits and so are desirable to help grow the economy and improve standards of living. However, assuming that their introduction is imminent is not an excuse to neglect infrastructure improvements that enhance safety, irrespective of the level at which the vehicles perform. In fact, we cannot be sure that full autonomy is imminent or at what cost (monetarily or in terms of safety) it might be acquired. In any case, smart road technology can enhance both safety and driverless vehicle introduction, working in conjunction with autonomous vehicle technology hosted entirely on the vehicle.

The task of installing appropriate infrastructure for smart roads is daunting and yet can happen incrementally, as the infrastructure for roads and bridges are renewed. There are multiple models for how industry can team with government to establish the technological infrastructure to help guide vehicles safely and efficiently; indeed, this already exists with respect to traffic lights and existing highway sensor systems.

On an interim basis, it is possible that the interstate highways can be upgraded, such that drivers could allow vehicles to be completely autonomous from one depot or entry ramp to a destination depot or exit ramp, and that the driver pays attention in local traffic between the origin and destination and the major depot points. For long haul cargo traffic, for example, the driver could depart at the depot location and be joined by a different driver at a depot near the destination point. Of course, such transit is already commonplace using rail lines.

Accordingly, government can assist in setting standards, facilitating communications, and ensuring that road infrastructure allows modern and upgradable data collection points and data sharing capabilities. Working with industry, government can help define the application programming interfaces (APIs) and data formats that would enable roads to communicate and coordinate with multiple vehicles. China's Belt and Road Initiative (BRI) ostensibly includes smart technology that will permit China to collect massive amounts of data[30] but may also by default set standards by virtue of being the first to market. While there is much interest in smart road technology, there is insufficient action in the United States and a lack of governmental coordination that can rationalize the marketplace and guide auto manufacturers in a coherent fashion.

Government might also be able to assist in the development of autonomous vehicle technology, for example for robo-taxi services in specific cities, regions, or for certain application domains, by furthering the sharing of data and setting standards. However, it is probably not viable for government to collect data to be used to train algorithms, despite the need for massive amount of training data, due to privacy concerns. Instead, government might facilitate the formation of data collection entities that work cooperatively with smart road developers and automakers.

We may experience further advances in autonomous conveyance of cargo and passengers, or perhaps we will stall short of full autonomy and always require a human driver to be ready to take control if called upon. Either way, technological advances towards both autonomous vehicle control and smart road infrastructure can make transportation safer, more efficient, and less costly, benefiting all of society.

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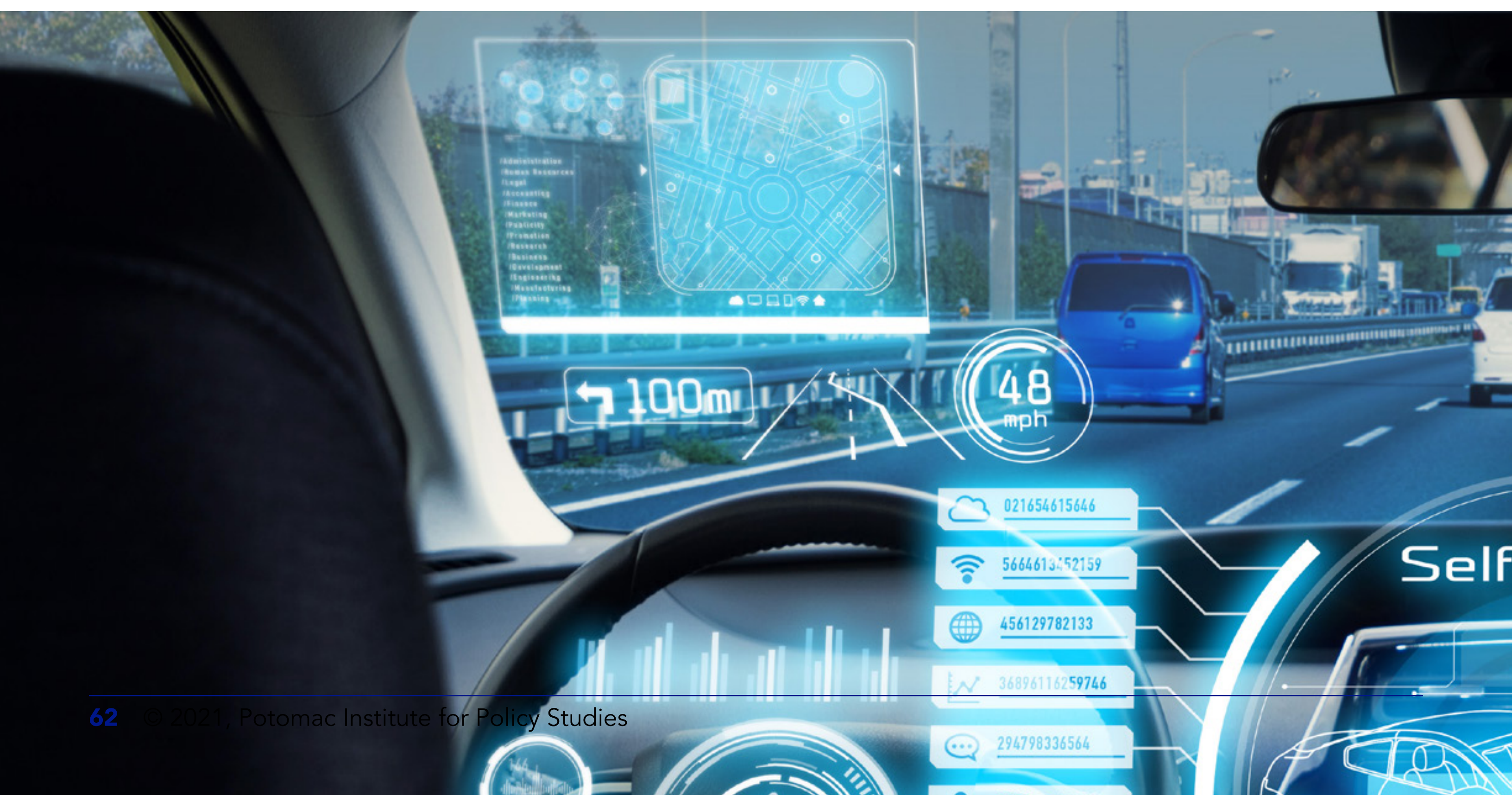

Endnotes

1. "Aurora Acquires Uber's Automated Driving Unit–And Uber's Cash," *Forbes* December 7, 2020, https://www.forbes.com/sites/samabuelsamid/2020/12/07/aurora-acquires-ubers-automated-driving-unitand-ubers-cash/?sh=4b93a95963eb.
2. Yandex Self-Driving Group, "Toyota is Buying Lyft's Autonomous Car Division For $550 Million," *The Verge* Sept. 3, 2020, https://www.theverge.com/2021/4/26/22404406/toyota-lyft-autonomous-vehicle-acquisition-amount-deal.
3. Yandex Self-Driving Group, "Yandex Self Driving Group Takes a New Leap With $150M In Investment," *Medium* Sept. 3, 2020, https://medium.com/yandex-self-driving-car/yandex-self-driving-group-takes-a-new-leap-with-150m-in-investment-8e9b86803d6a.
4. Billy Duberstein, "Is Waymo a Bust?" The Motley Fool, May 26, 2021, https://www.fool.com/investing/2021/05/26/is-waymo-a-bust/.
5. "Tesla CEO Elon Musk Responds To Texas Crash In Investigation Into Two Deaths," NBC News, https://www.nbcnews.com/news/us-news/tesla-ceo-elon-musk-responds-texas-crash-amid-probe-two-n1264623.
6. Mr. Musk's official title is Technoking of Tesla. A position from which he acts as the chief executive.
7. Five reasons experts think autonomous cars are many years away (phys.org) https://phys.org/news/2019-04-autonomous-cars-anytime.html.
8. "The Costly Pursuit of Self-Driving Cars Continues On. And On. And On.," *The New York Times* https://www.nytimes.com/2021/05/24/technology/self-driving-cars-wait.html.
9. "Waymo," https://waymo.com/.
10. "FAQ," https://waymo.com/faq/.
11. "WeRide," WeRide. https://www.weride.ai/en/dmv-unmanned-test-license-en/.
12. "WeRide Robotaxis Gain Loyal Passengers But Fixed Pick-Up, Drop-Off Spots Irk Some, Survey Shows," *South China Morning Post* https://www.scmp.com/tech/start-ups/article/3111277/weride-robotaxis-gain-loyal-passengers-fixed-pick-drop-spots-irk.
13. "Autonomous Driving-DiDi technology," DiDi official website (didiglobal.com). https://www.didiglobal.com/science/intelligent-driving.
14. "Didi Autonomous Driving to Pocket USD 300 million Investment, Raising Potential Market Value Higher Than Pony.ai," Synced, https://syncedreview.com/2021/06/01/didi-autonomous-driving-to-pocket-usd-300-million-investment-raising-potential-market-value-higher-than-pony-ai/.
15. "Autonomous Driving & ADAS (Advanced Driver Assistance Systems)," Mobileye https://www.mobileye.com/.
16. "Cruise," https://www.getcruise.com/.
17. "Walmart Investing in GM's Cruise Self-Driving Car Company," CNBC, https://www.cnbc.com/2021/04/15/walmart-investing-in-gms-cruise-self-driving-car-company.html.
18. https://millennialmoney.com/argo-ai-stock-ipo/.
19. "Fully Driverless First/Last Mile Shuttle Service on Medical Campus," EasyMile, https://easymile.com.
20. Riley Beggin and Kalea Hall, "Cruise Posted Most California AV Testing Miles in 2020," *Transport Topics* February 10, 2021, https://www.ttnews.com/articles/cruise-posted-most-california-av-testing-miles-2020.
21. Andrew J. Hawkins, "Cruise is Now Testing Fully Driverless Cars In San Francisco," *The Verge* December 9, 2020, https://www.theverge.com/2020/12/9/22165597/cruise-driverless-test-san-francisco-self-driving-level-4.
22. KirstenKorosec, "Cruise Acquires Self-Driving Startup Voyage," *TechCrunch* March 15, 2021, https://techcrunch.com/2021/03/15/cruise-acquires-self-driving-start-up-voyage/.
23. https://millennialmoney.com/argo-ai-stock-ipo/.
24. "Companies Have Spent $16 Billion on Self-Driving-Car Research," Car and Driver https://www.caranddriver.com/news/a30857661/autonomous-car-self-driving-research-expensive/.
25. Alternative Fuels Data Center: Maps and Data - Annual Vehicle Miles Traveled in the United States (energy.gov) https://afdc.energy.gov/data/10315.
26. "Chart: The Self-Driving Car Companies Going The Distance" Statista, https://www.statista.com/chart/17144/test-miles-and-reportable-miles-per-disengagement/.
27. "Safety Report and Whitepapers, " Waymo, https://waymo.com/safety/.
28. See Erik J. Larson, *The Myth of AI, Why Computers Can't Think The Way We Do* (Cambridge: Bellnap Press) 2021.
29. "Moving us Towards a Self Driving Future," Aurora, https://aurora.tech/.
30. "Weaponizing the Belt and Road Initiative," Asia Society Policy Institute, September 8, 2020, https://asiasociety.org/policy-institute/weaponizing-belt-and-road-initiative.