The Antiplanner
Dedicated to the sunset of government planning

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Dude, Where's My Driverless Car?

A minor footnote in the history of the COVID-19 pandemic is that this may be the first major crisis in history that was assisted by driverless vehicles. A Chinese company named Neolix is using its driverless delivery vans to transport medical supplies and sterilize streets in Wuhan.

Since 2010, I've been promoting the idea that the advent of driverless cars means we shouldn't be wasting money building archaic rail transit projects. Now, a decade later, seems an appropriate time to see how far the industry has come and how far it has to go to make widespread use of driverless cars a reality. Some say that the task of creating a fully driverless car is more difficult than anticipated and we won't have them for many more years.

This seems premature since Waymo didn't promise driverless cars until 2019, a promise it arguably kept; General Motors in 2020, a promise it may be able to keep if the coronavirus doesn't interfere; and Ford in 2021. When Ford in 2016 promised to be "mass producing vehicles with full autonomy" by 2021, some claimed that it was being deceptive because, they said, it would take many more years before driverless cars could "go anywhere."

However, Ford's announcement said the cars would have no steering wheel, gas pedal, or brake pedal, but it didn't say they could go everywhere. Instead, it specifically said it would make them (and perhaps operate them itself) for ride-hailing services.

As I noted in 2015, this was because the first self-driving cars will heavily rely on precise (to within 10 centimeters) digital maps, usually made with expensive LIDAR systems. The cars will be able to go anywhere that has been mapped and (unless driven by humans) nowhere that hasn't been mapped, a concept known as *geofenced*. Since, presumably, people will be reluctant to buy cars that can't leave your urban area and may not even be able to enter your driveway, Ford and GM both expect to make fleets of such cars for ride hailing rather than for sale.

A car that only works in geofenced areas is known as a *level 4* driverless car. A car that can go anywhere is a *level 5* driverless car. When people say that we won't have true driverless cars for many years, they mean they don't think we will have level 5 cars, but Waymo, GM, and Ford have only been promising level 4 cars. While this distinction was clear to me, Ford's CEO recently apologized to investors who might have been misled into thinking that it was promising level 5 cars by 2021 when it was only promising level 4.

Levels of Vehicle Automation

There are several different classifications of vehicle automation, but the one most often used was written by the Society of Automotive Engineers (SAE). This is a six-level system ranging from 0 to 5. Level 0 has no automation other than, perhaps, vehicle stability control.

Level 1 is described as having either steering controls or brake/acceleration controls, while level 2 is supposed to have both. This distinction is really unnecessary. In order to have computerized steering controls, a car needs a steering-by-wire system; mechanical steering can't be controlled by a computer. In order to have computerized brake/acceleration controls, a car needs braking and acceleration by wire; mechanical brakes can't be controlled by a computer. If a car has steering by wire, it almost certainly has braking/acceleration by wire, so there probably aren't very many level 1 cars out there, or if there are then converting them to level 2 is simply a software upgrade.

A more important distinction is between two kinds of steering controls. *Lane keeping* attempts to detect the stripes or other indicators of the edges of the lane the vehicle is in. If the vehicle strays to one edge or the other, the lane-keeping system to nudge it back. If the driver keeps his or her hands off the wheel for long enough, the vehicle will drunkenly lurch back and forth as it detects the stripe on one side and then the other. However, most lane-keeping systems automatically stop working if they detect that the driver has kept his or her hands off the wheel for a prolonged time.

The other kind of steering is *lane centering*. As with lane keeping, this requires the vehicle to detect stripes or other indicators of both sides of the lane. The vehicle will then drive in the center of the lane as it detects it. This

works fine under normal circumstances, but when one lane diverges into two, for a few moments the vehicle may try to center itself into the widening lane, then lurch one way or the other when it detects the line between the two lanes. Of course, neither lane keeping nor lane centering can work if the stripes are so worn out or covered with snow that they are invisible.

There are also two different kinds of brake/acceleration controls. The first is *emergency braking*. In this case, the vehicle uses radar, optical cameras, or other means to detect objects ahead of it. If the object is large enough and not moving or moving slowly, the system will slow or brake the car, attempting to avoid a collision. Various tests of vehicles with emergency braking systems have found that some (such as Subaru) can avoid a collision even if they are driving 45 miles an hour faster than the vehicle or object in front of them, while others (such as some BMW models) don't do well at even 12 miles per hour.

The second system is *adaptive cruise control*. Drivers using adaptive cruise control set a speed and the systems monitors vehicles in front. If a vehicle in front is going slower than the set speed, the vehicle with adaptive cruise control maintains a safe driving distance behind that vehicle. Some adaptive cruise control systems only work down to 20 miles per hour; others stop working below 5 mph; the good ones work at any speed down to a complete stop. Adaptive cruise control can rely on the same hardware as emergency braking, so one is really just a software upgrade from the other.

For what it's worth, in my opinion level 1 should be lane keeping and emergency braking while level 2 should be lane centering and adaptive cruise control. Unfortunately, most vehicles with adaptive cruise control only come with lane keeping, probably because the manufacturers don't trust drivers to pay attention to the road if their vehicles have true lane centering. Tesla is one that does include lane centering, and it has contributed to some grisly accidents killing the drivers who apparently weren't paying attention.

Which brings us to level 3, the most controversial level in the scale. Where level 2 is sometimes called "hands off," level 3 has been called "eyes off." In level 3, the vehicle can drive itself under many circumstances, but it contains controls to allow a human to take over when the vehicle gets out of its comfort zone. The Tesla accidents happened because the drivers thought they were driving a level 3 system when in fact it was merely an advanced level 2 system.

The big question with level 3 systems is how quickly the vehicle can hand off driving responsibilities to a human if the driving conditions go beyond the vehicle's capabilities. If the human is attentively watching the ride, the transition can be pretty fast, but if the human is reading or watching a video, the vehicle might get into a serious hazard before a handover can take place. For this reason, many manufacturers say they are skipping level 3 and going straight to levels 4 or 5. Cadillac, however, offers a level 3 technology on its cars it calls SuperCruise. It is geofenced and requires cell phone reception but it can operate on more than 200,000 miles of limited-access highways.

(Note: Some observers apply the term *self-driving* to level 3 and 4 systems and reserve *driverless* for level 5 systems. This hasn't become general practice and this paper uses self-driving and driverless interchangeably.)

Mapping for Autonomy

As noted above, a level 4 or "mind off" vehicle can drive itself, without human assistance, but only in some places—probably because it is geofenced. A level 5 vehicle has no limits as to where it can go. While that seems to be a big difference, what if we have level 4 cars and *everywhere is mapped*? Then they would be indistinguishable from level 5 cars.

Ford owns its own mapping company. Uber bought mapping technology from Microsoft. General Motors is also making its own maps. The biggest mapping company, however, is Here, which was founded by Nokia but is now owned by BMW, Mercedes, Volkswagen, and several other partners.

This General Motors' Cruise vehicle is making LIDAR maps of San Francisco. Click here to watch a YouTube video in your browser about how Here is making such maps. Photo by Dllu.

Here has mapped well over 27 million miles of roads worldwide for vehicle navigation systems. Such maps aren't good enough for autonomous vehicles, but Here had a million kilometers (600,000 miles) mapped to autonomous vehicle standards by the end of 2018. Here's autonomous maps are in the cloud (meaning vehicles using them can only work in areas with cell services) and self-updating: whenever a vehicle using the maps encounters a change, it notifies the cloud which notifies other vehicles using Here. Ford's system works the same way.

The United States alone has 2.7 million miles of paved roads and another 1.3 million miles of unpaved roads, so the mapping companies have a ways to go. Moreover, just mapping the roads isn't enough: to be fully functional, parking lots, driveways, and other service areas will also need to be mapped. Yet adding these areas to the maps may end up being a trivial exercise.

Just as autonomous vehicle maps are self-updating, anyone should be able to supplement the maps by adding private roads, driveways, and parking lots to the digital

cloud. The average person may not be able to afford the hardware needed to make precise maps, in which case Here and other mapping companies could offer local companies franchises to do the work.

These companies could add your driveway and garage to the digital maps for a hundred bucks, allowing your self-driving car to take you all the way home. For a few thousand dollars they might map a shopping center parking lot or office parking garage. Car washes and auto repair shops could also have their workbays included in the map database for easy servicing. State highway agencies may find it useful to make their own LIDAR maps which they can share with the public. Even if they don't, trucking companies or auto clubs may even hire mapping companies to do major intercity highways that Here or its competitors haven't yet mapped. In this way, the maps needed for level 4 autonomous vehicle operation could be rapidly expanded.

Once the nation is fully mapped, level 4 vehicles would actually have advantages over level 5 vehicles. A true level 5 vehicle would depend on highway stripes being visible at all times. Level 4 vehicles will know where the stripes are even if they are worn out or covered with snow or ice. Level 5 vehicles would rely on highway speed limit signs and other safety signs. Level 4 vehicles will have these included in their maps.

The Race to Market

In the meantime, scores of companies are racing to develop autonomous vehicle hardware and software. At latest count, the state of California has granted 65 different companies permits to test driverless technologies. Even more companies haven't applied for California permits because they are doing their testing elsewhere.

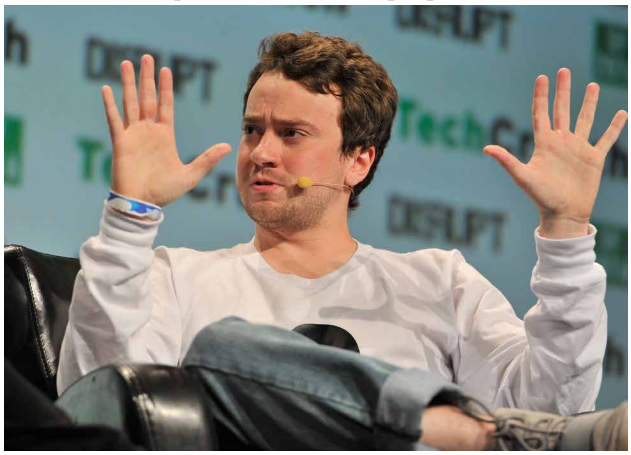
California permittees include companies from China, Germany, Japan, South Korea, and, of course, the United States. Companies in France and Sweden are also known to be working on driverless cars but haven't obtained permits from California. The companies fall into at least four general categories:

- Automobile manufacturers such as General Motors, Ford, Volkswagen, and Mercedes;
- High-tech companies such as Waymo, Apple, and Intel;
- Automobile parts suppliers such as Bosch and Continental;
- Transportation network companies such as Uber and Lyft.

Many of these companies have billions of dollars at their disposal and are lavishly spending it on driverless vehicle research because they know the market for such transportation will be worth trillions of dollars a year. Given this, it seems likely that the barriers to affordable driverless cars will be breached sooner rather than later.

Some companies started putting driverless vehicles in operation in cities around the world as early as 2016. These include small shuttle buses that can operate in traffic but on fixed routes. This is much simpler to design than a system that can go to any address requested and deal with complex intersections that it has never seen before.

Then there is George Hotz. In 2007, at the age of 17, he was the first hacker to unlock the iPhone, which at the time could only be used on AT&T networks. In 2015, he announced he was designing autonomous vehicle technology that would be based on an artificial intelligence system rather than the rule-based systems used by other high-tech companies. In other words, instead of writing software for every possible highway and street situation, Hotz's software would simply learn from how people actually drive.



George Hotz describing his self-driving car plans to a San Francisco conference. Click here to view a YouTube video in your browser of Hotz demonstrating his Comma device to a reporter. Photo by Steve Jennings.

Hotz's company, Comma.ai, currently sells a device that can potentially turn any drive-by-wire vehicle into a level-2 vehicle with adaptive cruise control and lane centering. Comma doesn't have a California license; to avoid federal and state regulation and red tape, it is selling the hardware and giving away the software, known as Openpilot. The hardware consists of an inexpensive smart phone, mounting brackets, and cables to connect it to the vehicle.

The device's back-facing camera watches the road and what it sees appears on the screen. The front-facing camera watches the driver to make sure he or she stays attentive. If the device finds itself in a situation it can't handle, it alerts the driver. The driver can take control of the vehicle at any time, and every time this happens the device records it and the information is transmitted to Comma's main computer. This allows the computer to learn from new situations, and what it learns is uploaded to all of the vehicles running the software.

Currently, the device works with many different vehicles, and if your car isn't on the list, Openpilot is open-source software so you can add it (provided it has steering-, braking-, and acceleration-by-wire). For example, it works with the Subaru Crosstrek with Eyesight (Subaru's built-in camera) but not the Outback with Eyesight. (The main barrier, I suspect, is not the software but connecting to the

vehicle's computer.) Of course, if you have Eyesight, you already have adaptive cruise control and lane keeping, so all you get with Hotz's device is lane centering, which is probably why no one has added the Outback to Comma's list.

While falling short of level 4 or even level 3, Comma.ai is learning from every use. The company says it has sold more than 2,500 devices that have driven 14 million miles, which is more than almost any other company except Tesla's autopilot and Waymo's level 4 system, which is up to 20 million miles. Hotz calls level 4 self-driving cars a "scam," but it's not hard to imagine that Hotz plans to eventually improve Openpilot sufficiently that he can tie it into navigation systems and all of the sensors on the car and have a true level 5 vehicle.

The Tipping Point

So who will win the driverless competition? It would be hard to bet against Waymo, which not only has operating driverless cars in Chandler, Arizona, it has recently persuaded investors to give it $2.25 billion to start a driverless heavy trucking service. General Motors' Cruise and Audi are not far behind, while Apple and Ford may be lagging.

An even bigger question is: when will you be able to give up driving? The answer may be sooner than you think. Waymo is operating a driverless ride-hailing business in the suburbs of Phoenix (though it is shut down for the duration). Cruise has promised to operate one in San Francisco this year. Though it may also be delayed by the city's shelter-in-place order, the current pandemic could actually accelerate the introduction of autonomous vehicles for use as delivery trucks.

Once two companies have actual vehicles in operation, rather than just testing stages, there will be a race to map and provide driverless ride-hailing coverage to all the major urban areas in the nation. Companies such as Ford and Uber will spend billions to catch up with Waymo. Companies such as Chrysler-Fiat and Toyota that are too far behind Waymo to catch up will buy the software from Waymo and apply it to their own vehicles.

Just as Uber and Lyft took the world by storm between 2014 and 2018, driverless ride hailing will reach a tipping point after which it becomes a dominant form of common carrier travel in urban areas. I estimate this will probably happen by about 2025. At around the same time, enough of the nation will be mapped to autonomous vehicle standards that auto manufacturers will start selling driverless vehicles instead of just using them in ride-hailing operations. In addition, companies like Comma will gladly upgrade people's drive-by-wire cars to level 4 or 5 operation, allowing millions of people to benefit from driverless transportation without having to buy a new car.

Although some have predicted that by 2030 almost all travel will be in shared vehicles, a survey by Here indicates that about half of households will want to own their own vehicles. This confirms my own previous estimates. People who drive more than the median number of miles per year—which by definition means half—will save money by owning rather than sharing because they'll only have to pay the marginal cost for each additional mile they drive while people using shared vehicles will pay the average cost for every mile. People who live in rural areas, which includes 20 percent of the nation's population, will also want to own their own vehicles.

I now think that half the population may be far too low as the current pandemic will teach many that shared vehicles can be hazardous to their health. Thus, auto ownership will remain high while ride-hailing will be used mainly by visitors to urban areas and those people living in dense inner cities such as New York and San Francisco who don't want to compete for parking space.

In short, my prediction is that driverless travel will dominate public conveyances—taxis, ride hailing, transit—by 2025 and dominate most travel by 2030. Will you be traveling by Waymo, Cruise, Audi, Ford, Tesla, or Comma? That's harder to predict, but it will be fun to watch them battle it out.

Randal O'Toole, the Antiplanner, is a land-use and transportation policy analyst and author of Gridlock: Why We're Stuck in Traffic and What to Do About It. *Masthead photo of a driverless shuttle bus in Estonia is by Pjotr Mahhonin.*