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Automated Vehicle Systems Outlook

2021 Update

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AUTHOR Richard R. Mudge, Ph.D.
Compass Transportation and Technology Inc.

Alain Kornhauser, Ph.D.
Princeton University

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Executive Summary

Despite the advent of COVID-19, autonomous vehicle (AV) market leaders continued to invest in technology and to establish partnerships with vehicle original equipment manufacturers (OEMs). A few AV household names were acquired by other firms and one automated trucking firm went out of business. Amazon purchased Zoox; Uber never recovered from a fatal crash in 2018 and the firm's technology group was taken over by Aurora, which is run by former Google and Tesla executives; Aurora also partnered with Toyota and Paccar, a large truck manufacturer. Apple continues to be rumored to be about to enter the AV business. TuSimple, whose focus has shifted from cars to trucks, became a publicly traded firm. Velodyne, a leading manufacturer of light detection and ranging (lidar) sensors, also recently went public. Other AV firms have plans to become public companies.

Headline news for observers in the insurance industry and for actuaries was General Motors' announcement in March that their OnStar division would now include a car insurance business. This coincides with GM's plan to deploy automated technology beyond a few Cadillac models. This action follows an earlier effort by Tesla to open an auto insurance line in California, partly due to Elon Musk's belief that traditional auto insurance firms did not understand the safety value of Tesla technology. GM's action could be a model for other OEMs or a call for insurance firms to partner with firms active in the AV business. GM could also use this opening to encourage deployment of AV technology given the likely impact on safety,

Is this a recognition that as more of the liability exposure associated with road transportation shifts back to product liability, automated systems in the car itself will do more driving and more accident avoidance than the driver? A hundred year ago, mechanical failures caused many crashes. Since Ralph Nader's 1965 book, *Unsafe at Any Speed: The Designed-In Dangers of the American Automobile*, regulations and the industry have substantially eliminated product liability to such an extent that driver (mis)behavior is entangled in more than 90 percent of crashes and thus is the fundamental burden of personal auto insurance. As automated driving systems take over the driving function, one can see a shift in the balance of liability to the product side, back to the manufacturer. Moreover, to gain customer acceptance, manufacturers may find they need to guarantee their performance by absorbing their liability implications, thus relieving the purchaser of personal liability.

COVID-19 brought about declines in use of transportation other than freight and cars. The sharp declines in use of mass transit, commercial flights and Amtrak show an interest in avoiding group travel. This could continue and make development of aTaxis (automated shared ride vehicles) less likely.

A new president and a new Congress open the door for new regulations and federal legislation. Until now, no important federal AV legislation has been passed. These trends are likely to change, but it is too early to speculate about how radical a change might occur. The first signal of change may be that organized labor will be stepping in.

On an optimistic note, car and truck AV firms look to 2022 to begin deployments. Waymo (part of Google) has already been operating fully autonomous (no safety driver) vehicles in a suburb of Phoenix—and charging customers to use them. Waymo hints at adding other metro areas, perhaps even later this year.

Cruise and Ford have similar ambitions, with likely deployments in 2022. Some intercity truck AV firms also mention 2022 as a year to begin fully driverless operation—likely on roads between Texas and Arizona.

Section 1: Introduction

Substantial progress has been made in the availability of cars with automated driving technologies. The lack of clarity in terminology, however, is nothing short of appalling. A prime example is the misleading way Elon Musk describes the Tesla's automated features.[1]

Consumer Reports, the American Automobile Association (AAA), the Insurance Institute for Highway Safety (IIHS) and Rand Corporation as well as regulatory agencies around the world share frustration regarding the lack of a clear taxonomy for automated technologies. Much of this confusion was introduced by the Society of Automotive Engineers (SAE), which proposed six different levels.[2] Unfortunately, the definitions of these levels contain so much fine print that they made sense only to engineers and not to consumers. Whether using marketing terms or the SAE levels, consumers envision technical capabilities without realizing they were not intended to be available when or where the customer wants to use them.

Since "expected safety benefit" is the fundamental attribute that actuaries seek to estimate, it is vital to know how the consumer plans to use (or often misuse) the automated feature in question. This calls for the collection of data on use and claims over time. Given the pace of change in deployment of new technology, this means we are looking backward for a value needed in the future.

1.1 CAR SAFETY FEATURES

How we characterize car safety has evolved over time. Certainly, no manufacturer or seller of any consumer product wishes their product to be unsafe. Car manufacturers are no different. Because their products do result in losses, the personal auto industry has evolved along with the need for auditors to best estimate the expected liabilities to properly price coverage. In response, the auto industry has been sure that the responsibility for maintenance, operations and any related liabilities belonged to the car owner and not the manufacturer. In contrast, the manufacturer usually retains liability regarding autonomous vehicles (AVs).

Issues with these products are termed "accidents" and not "crashes." The National Highway Traffic Safety Administration (NHTSA) associates "human involvement" with 94 percent of accidents[3]. A more poignant characterization is 94 percent of car crashes involve driver misbehavior. They slam into the car ahead when they didn't notice it slowing down. They go around a curve too fast. They skid into a tree when they lock the brakes. They change lanes when they don't see a car in their blind spot. They back up over a child when they were texting and didn't look at their backup camera or their mirrors.

Over the years, car manufacturers have developed automated systems that seize the driving functions from the driver in a desperate attempt to mitigate and possibly avoid crashes in these misbehaving situations. Anti-lock brakes intervene to modify the driver's misuse of the brake. Electronic stability control intervenes to modify the driver's use of the brakes and throttle in going around a curve. Automated emergency braking (AEB) intervenes to apply the brakes at "the last instant" to avert or mitigate a rear-end crash. Blind-spot warning systems try to inform the driver that they should not be changing lanes.

The key challenge of these systems is to be vigilant at all times and all places and intervene only in situations in which a crash is imminent. They remain dormant until needed and let the driver be the driver. Technically, this means their false-positive rate must be very close to zero; otherwise, the driver will either find a way to turn the systems off or return the product to the showroom claiming they bought "a lemon." Also, the false-negative rate must be very small or else crashes won't be averted or sufficiently mitigated.

Most new cars feature the systems we call **safely driven cars** (or trucks or buses). Over the years, these systems and others that monitor the driver to try to ensure the driver is alert and that inform/educate drivers of their “challenged” driving behavior (so-called telematics devices) have substantially improved. Automated emergency braking provides a good example of this improvement, although substantial room remains for improvement, including in the ability to identify stopped objects in the lane ahead, to intervene earlier but with reduced false-positives and to be enabled in back-up situations.

Other automated driving features focus more on adding comfort and convenience to the task of driving than safety. Automakers have, of course, always wanted driving to be fun and not work. Automatic starters, automatic transmissions and power steering all make it easier to drive. The same is true with this generation of what we call **self-driving features**. These features are over-and-above the always-on, everywhere safely driven features and are user-selectable. The driver decides when to turn them on and when to turn them off. They are intended to do the work done by the driver’s feet, the driver’s hands and the driver’s eyes and each needs to do the work of the driver’s brain, which is substantially more challenging than just determining that a crash is imminent.

This additional burden is such that the false-positive/-negative rate associated with these systems is acceptable only under certain driver-behavioral conditions and in only some places and under certain environmental conditions, termed operational design domain (ODD). Use of these systems in other than these conditions could substantially compromise safety, nullifying the improvements derived from more comfortable and convenient driving.

Consider cruise control. This is a very simple system that takes control of the throttle from the driver’s foot (and brain) to keep the car going a constant, driver-selected speed. The driver is free to use this comfort and convenience function at anytime, anywhere. However, it is now the responsibility of the driver to turn off this system; otherwise, the vehicle could run through a red light and smash into the car ahead. Thus, the driver must remain aware and alert to the road conditions ahead—called “eyes on.” The driver must also continue to steer (lateral control), “hands on,” and, of course, remain in the driver’s seat.

We consider these driver-behavioral conditions to be critically important. They should be enforced by the availability of the self-driving feature itself. If the feature requires the driver to remain alert and have their eyes on the road ahead, then the feature should not only have all the sensors necessary to determine that the false alarm rate for the system is acceptable, but also should be monitoring the driver to ensure the driver is engaged properly. If the driver is not properly engaged, the system should have the vehicle pull over and stop safely or just stop safely, disengage, and put the full driving responsibility back on the driver.

This terminology construct is important because as safety technology begins to become regulated, we may have the opportunity to attach explicit and enforceable limits on the availability of technology to ensure the traveling public does not misuse the technology. The beginnings of such regulation has started in Europe with respect to automated lane-keeping systems (ALKS) under the auspices of the United Nations.[4] The approach in Europe is to have “type approval” from regulating authorities prior to a feature’s/product’s release into the marketplace rather than “self- approval” by the manufacturer as exists in North America. In Europe, the regulations regarding ALKS require the system not only perform as designed but also that the driver is doing what is required: staying attentive and remaining in the driver’s seat. Placing the burden, responsibility and liability on the manufacturer that these comfort and convenience automated driving features are available for use only in their ODD, which includes proper driver behavior, is seen as a way to avert their possible degradation of safety.

Again, technology itself is expected to deliver real safety, comfort and convenience when properly used. Since misuse can negate all safety benefits, it is imperative to strictly enforce against any misuse. This action may also encourage insurance regulators to allow insurance products that are constrained explicitly to proper use and that proper use becomes a product liability burden of the manufacturer.

1.2 CLASSIFICATION OF AUTOMATED DRIVING TECHNOLOGIES APPROPRIATE FOR THE INSURANCE INDUSTRY

Vehicle automation involves technology intended to mitigate or reduce crashes and/or add to the comfort and convenience of mobility. When the technology improves sufficiently such that the oversight responsibility of the human driver can be completely removed in some places under some environmental conditions, then fleet managers will be provided the opportunity to deliver mobility to the public at large as well as improve the movement of goods throughout that ODD.

In summary, vehicles will have automated features that make them:

- **Safely driven cars** (and light duty trucks), which are always on everywhere and automatically intervene to avert or mitigate crashes. Some features are currently mandated, such as automatic brakes. Most new cars have several other systems of varying degrees of efficacy. These systems are appreciated by consumers and manufacturers are beginning to compete on the efficacy of the systems such that the marketplace makes the better of these systems "must haves" and thus negate the need for them to be regulated. In fact, as happened with anti-lock brakes, product liability risk can be expected to lead to well-functioning safely driven systems as consumer acceptance is achieved.
- **Self-driving cars**, which focus on driver-selected comfort and convenience systems that only perform acceptably in some places and under some environmental conditions and, most importantly, places stringent requirements that the driver remain engaged in the driving tasks. This driver-behavioral requirement must be enforced by the systems themselves, otherwise safety may be degraded.
- **Driverless cars**, which place no behavioral requirements on a human driver in some places under some environmental conditions. When operating in those areas at those times, no driver is needed. An operator of such vehicles can focus on providing mobility for passengers and goods without the need for a licensed and alert driver throughout that ODD.

Each of these vehicle types has important safety thresholds. However, these technologies can generate substantial risks and liabilities if misused.

Simply put, the expected performance of these technologies can vary widely based on when and where they are used. Operational design domain defines where and when each technology is designed to work. Indeed, it should be stated explicitly that each technology should not be used outside its ODD. Given the extent to which the initial releases of some of these technologies have been misused, it is imperative for the ODD to take center stage in describing how, where and when each technology should be used.

Without clear enforcement of the self-driving car's comfort and convenience technologies, the misuse of the vehicle will be impossible to forecast, rendering substantial uncertainty regarding liabilities and risks. With driverless cars, this risk is likely to be large since misuse can yield very large damages, perhaps making private ownership of such cars unattractive.

There are two recommendations for AVs that aim to reduce or eliminate misuse of technology:

- **Recommendation 1.** Any description of an automation functionality (the "what") should begin with the operational design domain (the "where" and "when"). For example:
  - Automated emergency braking has the following ODD (when and where): in most weather and road conditions when the time-to-collision with an object is less than 1.6 seconds, assuming the entity ahead continues to travel at the same speed as the AEB vehicle.

  - Automated operations should operate in road lanes with few potholes, good lane markings, no upcoming traffic control signs and with a licensed, non-drowsy driver in the driver's seat.
- **Recommendation 2.** Each vehicle equipped with an automated functionality and an ODD that includes driver conditions must have a system that monitors the driver's behavior. The system should closely monitor the driver to ensure the driver is alert, looking at the road ahead and positioned in the driver's seat.
  - This functionality must have a safe disengagement mode should the driver's behavior begin to violate the ODD. If the driver violates the ODD, functionality should not be returned to the driver until a severe penalty has been imposed.

1.2.1 SAFE-DRIVING TECHNOLOGIES

The ODD for these technologies (most new cars today) tend to be "everywhere" and "all the time." These crash mitigation systems are important yet divorced from the driving function. Examples include airbags, seat belts and energy-absorbing structural design. Examples that override driver action include anti-lock brakes and electronic stability control. Acceptance by consumers of these systems has led to their broad use and limited misbehavior.

Lane departure warning systems are often disengaged by the driver since their ODD extends their influence to include minor lane departures that do not appear unsafe. This can generate an unacceptably high false alarm rate. Blind-spot warning systems have had much better consumer acceptance. The ODD includes an obviously unsafe condition. Back-up cameras are relatively ineffective unless they also include automated emergency braking. Automated emergency braking systems are the most important technology since their fundamental purpose is to avoid collisions. Unfortunately, their ODDs are not well understood and vary by manufacturer. Their effectiveness varies by speed. The "where" is not everywhere and may not work if the obstruction is stationary.

1.2.2 SELF-DRIVING TECHNOLOGIES

Engagement of these automated systems tend to be left to driver discretion. Thus, it is important for the driver to know the ODD for each subsystem and that they should not be disengaged. It is absolutely critical that the driver know who is responsible for what at all times. That responsibility may change either because of driver preference or because the vehicle is no longer operating in the correct ODD.

In sum, self-driving technologies work only some of the time and in some places. (Don't worry, as soon as they work all the time and in all places, it will be a very big deal and you'll know it.) At this point, none of them perform any better than an average driver who is not misbehaving. Consequently, these systems amount to comfort and convenience features that, at best, should not degrade safety. On the other hand, to maintain safety, the systems must work properly when engaged by the driver and the driver must not engage them when and where the systems will not work properly. Examples of self-driving technologies include:

Cruise control. This requires a human in the vehicle. It does not require foot use but it does require the driver to be seated in the driver's seat, use their hands to steer, to be aware and alert and keep their eyes open; it is available only in certain speed and lane grade ranges, doesn't respond to traffic signals, and doesn't work if there is a stationary object in the lane ahead.

Automated lane keeping systems. This requires a human pilot. The driver uses their feet, hands, and eyes, and it only works if proper lane markings exist.

Automated parking. This requires a human pilot, to be alert and use their eyes; it does not require foot or hand use. The starting point is speed zero and requires an area recognized by the systems as a parking opportunity

Summon. This technology does not require an in-vehicle human pilot, but it does require a pilot to use their eyes, and it only functions within the driver's own property.

Level 3. This requires an in-vehicle human pilot, although the pilot would not necessarily need to use their feet, hands and eyes, but only on some certified-in-real-time road segments

To date these systems have been sold on a "buyer beware" basis in that all liability implications fall on the driver and their insurer. Consequently, misuse of these systems was the driver and insurer's "problem." Unfortunately, misuse of these systems and the resulting degradation of safety can be expected to cause regulators to insist that future versions of these self-driving technologies include monitoring systems that preclude them from becoming available, let alone used, outside the real-time, operational design domain for which their functionality has been certified by the OEM to maintain safety. That "floor" for safety can be expected to be that experienced by an average non-misbehaving driver in similar driving situations.

If a crash happens during the use of one of these systems, it generally can be characterized as

1. a "rare" event in which the driver did not misbehave, and the insurer is dragged in and may well be liable (the fundamental purpose of insurance);
2. involving a system failure, and the OEM is dragged in and may well be liable from a product liability standpoint; or
3. resulting from driver misuse of the system, which the system could not overcome, and the OEM may well be liable from a product liability standpoint.

1.2.3 DRIVERLESS

A truly driverless vehicle can be operated without a human pilot's intervention; it would not require foot, hands, or eye use and could even be operated from the back seat. The ODD for a driverless vehicle is vital since its capabilities may degrade dramatically outside this area. Google has a long history of developing autonomous vehicle technology. Google's subsidiary, Waymo, has made travel by driverless vehicles available in parts of Phoenix, Arizona. Waymo's driverless vehicles in Arizona provide an example of an ODD—fine in Chandler and Tempe, but not in other Phoenix suburbs. [5]A driverless car that can truly go anywhere (SAE calls this Level 5) may take some time to develop and may not be that practical since travelers almost always know where they plan to go and when.

Just because the vehicle is labeled driverless, it can still be misused since it is always possible to stray beyond the ODD. Liability issues are likely to begin with the manufacturer. In the case of a service provided by a commercial firm, as with an automated shared ride vehicle (aTaxi), liability may be assigned to the commercial firm. Such liability issues may make a driverless vehicle less attractive to an individual to own because the dollar value from a crash could be quite large.

Section 2: COVID-19

During the pandemic caused by COVID-19, U.S. automobile traffic dropped by 40 percent at the peak—and close to 10 percent at the end of 2020. The good news is that crashes are down more than 30 percent. In sharp contrast, fatalities have increased to an annual rate of 42,000 and the fatality rate per mile driven has jumped by 24 percent.[6] In sum, with a sharp drop in congestion, speeds have increased.

COVID-19 has changed how, where and when people travel. There are two implications for the future of autonomous vehicles:

- New travel patterns may affect the pace of AV deployment and where and when such vehicles might be used.
- COVID-19 has forced people to rely on technology in new ways. Zoom is just one example. This convenience may make people and businesses more open to technology in their vehicles.

What has changed? The demand for all modes of travel have declined, with the most dramatic changes for public transit (down 72 percent for rail and 37 percent for bus) and air travel (domestic travel down 60 percent). Automobile and truck travel have decreased much less. For example, auto travel is now down only about 10 percent. Truck traffic (as well as intermodal freight) have increased by about 5 percent above normal since July 2020.[7]

The relative strength of auto travel implies that automobiles will continue to be a popular mode of transportation, indicating a likely future interest in automated cars. Truck demand also continues to be strong, with similar positive implications for automated trucks. Auto and truck OEMs recognize these opportunities and continue to work to improve vehicle automation.

The nature of this demand will likely change dramatically. Perhaps the most discussed change has been the dramatic shift toward telecommuting. Before COVID-19, telecommuting was already the fastest growing form of commuter "travel," accounting for almost 6 percent of commuting.[8] COVID-19 merely sped up an existing, modest trend. Telecommuting has several major implications:

- A sharp decrease in commuting to work; this means less congestion, partly offset by a dramatic drop in the use of transit (rail in particular)
- An increase in mid-day, local travel
- An increase in intercity travel (200 to 400 miles) as people avoid air travel
- A decrease in the attractiveness of urban centers, as closing restaurants, theater and sporting events has brought about a shift in populations to suburban parts of major urban areas

Despite a 10 percent drop in automobile travel, highway fatalities have increased. For one, less traffic means less congestion and thus higher speed. There also may have been a shift in the car-driving public, with more young people driving rather than hanging out in bars and clubs. This should revert back to more normal fatality rates in time as traffic congestion returns and as alternative forms of entertainment open up.

In most metro areas, normal work congestion has dropped further. INRIX found that nationwide, traffic delays dropped to 26 hours a year, down from 99 in 2019. The Washington, D.C., metro region showed the largest change, with congestion dropping 77 percent, reflecting the high fraction of regional commuters who worked from home. [9]

There has been an increase in walking and bicycle use as well as nontraditional transportation mode use, such as electric scooters. These are inherently more dangerous. But each is less expensive than cars and more convenient than most mass transit. They also are single-person modes, reducing demand for group travel, such as with Uber and Lyft rideshares. This has negative implications for the future deployment of aTaxis.

Shared vehicles have long been seen as the most likely use of autonomous vehicles by the general public. An aTaxi would operate as today's Uber and Lyft do but with a greater emphasis on shared rides. One active debate concerns whether people would share rides with strangers in driverless vehicles. This seems less likely while fear regarding COVID-19 discourages people from traveling with strangers.

How soon will people relax enough to share rides? The leading autonomous vehicle firms (Waymo, Cruise and Argo AI, among others) show no signs of shifting their business model away from one built around shared vehicles. They continue to believe that the dramatic drop in travel costs due to driverless vehicles will stimulate a significant and very profitable income. Rather than shared rides, perhaps they will focus on family rides. This may still provide adequate financial returns, although social benefits will decline.

At the same time, truck transport has remained a strong source of freight movements. This has positive implications for use of autonomous trucks. Truck drivers continue to be in short supply—another economic rationale for automated trucks.

As for telecommuting, a major economic and urban force, most observers do not see a return to previous work patterns. A recent U.S. Department of Transportation (DOT) report has a scenario that shows overall working from home dropping to 16 percent by the end of 2022 versus 26 percent in 2020 (and 5 percent before the pandemic).[10]

One of the lasting effects of what will be at least a quarantine of more than a year is the broad acceptance of technology to do many of the things we once did for ourselves. This includes our general acceptance of e-commerce and technology to order our groceries and takeout and have them delivered to us.

In the near term, the pandemic has reduced the amount people travel, given that more people have worked from home and fewer endured shopping trips. This only reduces the number of miles travelled. It does not reduce the consumer appetite for vehicles; indeed, auto travel has declined the least of all modes. What may be more important is that continued use of vehicles and the expectation of technology and automation may change the consumer appetite for technology in cars. Consumers may show increased interest in technology that enhances comfort, convenience and safety.

Such a change in consumer willingness and desire for automated technology will not be lost on the OEMs and they will respond with products that play on that consumer appeal. The extent to which these products change loss expectations is, of course, of fundamental interest to actuaries. This report describes where we expect the major changes to occur as we emerge from the pandemic:

- Vehicle miles traveled (VMT) per vehicle will likely show little change, but the trip length distribution can be expected to change. Fewer short trips (shopping and commuting) are likely in combination with more frequent longer trips (to replace short flying trips). These trends need to be monitored by actuaries and, luckily, public (U.S. DOT Bureau of Transportation Statistics) and private (e.g., INRIX) data sources have improved greatly in recent years.
- Vehicles per household can be expected to increase somewhat in part since more people live in suburbs. This implies that fewer used cars will be “crushed” and new cars sales are likely to remain stable. Used cars will last longer, perhaps creating a perception that new technology is lagging.
    - Insurers have an opportunity to encourage after-market technology enhancement for “clunkers.”
    - These enhancements could become an attractive initiative for personal auto insurers, although this requires changes in state regulations to allow such “promotional items” by insurance companies. This seems like an “easy sell” but nothing is easy that requires regulatory change.
- Truck mileage will continue to increase, both for local delivery and for intercity movements. This is a market where automated technology will reduce costs substantially, stimulating new markets.

Section 3: News Update

General Motor's announcement in March about the decision to offer their own auto insurance product generates a major structural change within the industry. The new president and Congress open the door to new federal regulations and legislation. COVID-19 has changed the structure of the transportation industry. In the near term, this has profound implications for how AVs will likely be deployed and the underlying business model for the AV firms. Thoughts on the future of autonomous vehicles follow.

- **OEM insurance.** There has long been a logical link between insurance and the ability to encourage deployment of automated technology that reduces the likelihood of crashes and fatalities. Insurance companies are limited in this regard in part due to their lack of near real-time data regarding the effectiveness of new technologies. Auto OEMs do not have this problem. A large firm such as GM should have the ability to promote the most effective devices and ensure their dealers educate customers regarding their use. Tesla has had their own auto insurance arm in California for almost a year.[11] This was motivated by the belief that existing auto insurance firms overcharged Tesla customers since they did not recognize the safety benefits of a Tesla. No information has been reported regarding the success of this project. With two auto firms now in the insurance business, other auto OEMs may consider similar products. Auto insurance firms also may explore new products.

  Appendix A has a link to a podcast featuring a conversation between Princeton professor Alain Kornhauser and Andrew Rose, the new head of GM's OnStar Insurance company. They discuss the implications of this new enterprise for the deployment of autonomous vehicles. There is also a link to the Incentivizing Through Insurance session held at the fourth annual Princeton SmartDrivingCar Summit.

- **New administration and new Congress.** Congress has been unable to pass comprehensive legislation regarding autonomous vehicles. This leaves oversight and regulation to a mix of state regulations and rules. Despite approval by relevant committees, the most recent attempt to pass national legislation was unable to reconcile debate regarding truck regulation and labor protection. The previous legislation did have important provisions that would allow firms to deploy a certain number of AVs without prior approval from NHTSA. This provision would support testing of new technologies and thus could speed deployment.

  To date, federal regulations have been low key, based in part on the philosophy that it was too early in technology development for aggressive regulations and worry about picking winners and losers. Even though deployment has been slow, there is a good chance that the Biden administration will take a more aggressive approach toward safety risks. This may reflect an interest in avoiding potential contradictions among individual state regulations.

  Both federal regulations and legislation may take time. This creates uncertainty before the final actions become clear. It also creates an opportunity for firms and interested parties to lobby both the administration and Congress. First indications suggest that labor unions intend to play a larger role.[12] The Biden administration has proposed a large ($2.3 trillion) program that includes funding for infrastructure. Automated technology is not mentioned, although the proposed program for a national network of electric charging stations could be beneficial since electric power is the preferred source of power for most autonomous vehicles.

- **COVID-19.** Section 2 provided background on the effect of COVID-19 on transportation and the economy in 2020 and speculated some about the future. One near-term effect is that people are trying to avoid close personal contact. This results in sharp drops in use of mass transit and airplane and rail travel, and may prevent people from sharing rides in aTaxis, as previously mentioned. Concern over shared rides may mean manufacturers of driverless vehicles will need to focus on individuals and family groups. On the other hand, longer distance rides as a substitute for air travel may make a driverless car more relaxing for a family group. Other than intercity trucking, car travel has experienced the smallest negative effect of any transport mode. This implies stronger market interest in both cars and trucks—the two leading markets for AVs.

- **Deployment begins.** While past forecasts for the arrival of autonomous vehicles have all been very optimistic, there are some signs of progress. Waymo has operated driverless vehicles (no safety driver) in suburbs of Phoenix with paying customers.[13] Lyft provides a driverless car as an option for their local customers. Waymo, Cruise, Ford and Zoox (now part of Amazon) all hint at deployments in other urban areas in 2022 or perhaps late 2021. San Francisco is often mentioned, but no announcements have been made. Ford is testing in Miami, Pittsburgh, Austin, Texas, and Washington, D.C.

  Nuro is one of several local delivery firms that have begun to deploy in certain urban areas (Houston, Texas, and San Mateo, California). Unlike sidewalk delivery vehicles, Nuro travels on urban streets, with no driver. Customers take packages from the vehicle. NHTSA also approved Nuro to operate without a steering wheel. [14]As summarized below, several intercity trucks appear ready to deploy.

  While travelers are not yet able to call an autonomous vehicle in any major urban area, deployment appears to be likely in a few metro areas in the near future. No surprise, but driverless firms have taken a conservative approach regarding deployment. Accidents, fatal or otherwise, are likely to bring an end to a firm's business model. Uber provides a prime example since they were forced to sell their AV program to Aurora.[15]

- **IIHS and the Highway Loss Data Institute (HLDI) data.** These groups collect data on safety performance of vehicles and of individual technologies. These results show significant safety impacts of a full range of technologies deployed in "safe" category vehicles and the potential for these types of vehicle to reduce crashes and thus save lives and reduce injuries. Since safe vehicles are being deployed much more rapidly than driverless cars, they may end up having a more significant impact on highway safety than AVs themselves. One problem is that many drivers are annoyed by false positives and turn off safety features.

- **Vehicle connectivity with 5G.** In 1999, the Federal Communications Commission (FCC) dedicated a portion of bandwidth near the 5.9 GHz portion for use by the transportation industry. This reflected the U.S. DOT set of dedicated short-range cellular (DSRC) applications that supported communication among automated vehicles. A number of states have deployed DSRC technology along highways and some automobile firms expressed support for including DSRC radios in new cars. This process was slow and other broadband users lobbied the FCC to rededicate a portion of this bandwidth for Wi-Fi and related commercial applications. The 5G technology was proposed as an alternative way to provide communication among vehicles and with infrastructure-based information systems. After aggressive lobbying from both sides, in November 2020 the FCC provided more than half of the previous bandwidth for nontransportation-related uses, with the balance available for an updated version of DSRC, termed cellular vehicle-to-everything (C-V2X).[16] The de facto result of this ruling was to make 5G cellular communication technology the primary option for vehicle communication. The deployment of 5G has begun, but results are scattered, so it will be some time before a national 5G network is in place.

This FCC ruling has two major effects: 1) state DOTs and other public transportation agencies will have a less important role in the deployment of autonomous vehicles than in previous transportation programs, and 2) AV developers will rely on C-V2X and 5G communications for rapid communication among vehicles and with infrastructure managers. The FCC may visit this ruling again once new commission members have been appointed by the Biden administration. Meanwhile, auto OEMs are not deploying DSRC radios.

- **AV safety.** Tesla says their data show their cars are safer than the automobile fleet in general. They claim one accident for every 4.4 million miles versus NHTSA data that show one for every 479,000 miles for the fleet as a whole. [17]The data sound very impressive, but no details are provided regarding when and where the data have been collected and how this compares with data form NHTSA. The data have been criticized by many observers including NHTSA. It is likely that Tesla's Autopilot data are used on highways (a much safer category of road) rather than a mix of all roads. This makes it difficult to separate the role of the Autopilot technology from non-Tesla vehicles. This debate over the data makes the case yet again for more data on a consistent basis. IIHS continues to provide the most consistent source of timely industry data.

- **Intercity trucking.** One long-term focus of research and development within the autonomous industry has been intercity trucking. One motivation is the direct economic return either from not needing the driver or changing the driver's functions. Trucking firms are a commercial enterprise so they can convert these savings to their bottom line.

  Firms such as TuSimple propose to operate autonomous trucks on interstate roads between warehouses located near interchanges.[18] They say 2024 is a likely deployment date—a change from recent discussion targeting 2022. The goods would then be transported from the warehouse to their local destination. Other firms, such as Locomation, propose to operate fleets of vehicles in a leader-follower operation. [19]This involves a driver in the front vehicle, with fuel savings for the fleet as a whole. This approach makes it possible to change the nature of the truck driver's job, reducing stress.

  The potential economic gains are substantial. Most firms that began by focusing on cars have added a truck version. Examples include Waymo and Aurora (in partnership with Paccar). Tesla plans an electric over-the-road truck as well.[20]

- **Mixed-traffic freight delivery.** Nuro is allowed to drive in California and Texas (Houston) with no safety driver and no steering wheel. This is a specialized vehicle that provides local freight delivery, but it does travel on city streets in mixed traffic. [21]California now allows five companies to test vehicle operations with no drivers but only on specific roadway segments. This is an important step forward in vehicle testing.

- **Major technology firms and auto OEMs.** Amazon bought Zoox, a firm that designed their own autonomous vehicle but which needed additional financial support.[22] Despite rumors that Amazon planned to convert the Zoox technology to freight delivery, they claim to still be focused on aTaxis—the same business model as other AV firms. Uber's AV arm was best known for the fatal accident caused by a test vehicle in Tempe, Arizona. They recently combined their autonomous vehicle group with Aurora, a firm run by former senior staff from Google and Tesla.[23] Uber maintains a small ownership but has given up on the automated business.

- **States.** States remain active in the autonomous vehicle market, even though DSRC has been replaced by 5G. Michigan has begun to deploy a corridor between Detroit and Ann Arbor that will encourage rapid deployment of autonomous vehicles of several types—cars, trucks, buses etc. This is viewed as generating economic activity[24]. Other groups, including one in the Pacific Northwest, have similar plans.

- **Transit autonomous vehicles.** New Flyer and Robotic Research have completed a full-size electric transit bus. The Connecticut DOT received a grant from the Federal Transit Administration (FTA) to deploy several autonomous transit buses on a bus rapid transit system in Hartford. Other deployments are likely. These buses are almost certain to be electric powered, so they fit with current interest in reducing pollution. [25]

Section 4: Trigger Points

This section describes a series of "trigger points" or factors that could hinder or accelerate the market for autonomous vehicles and thus shape the nature of how and when technology is deployed. Tracking these elements can provide guidance regarding the pace of deployment for each of the three parts of the general framework described above: safely driven, self-driving and driverless.

These trigger points are organized in three groups:

- Policy: Institutional/regulatory change
- Technology
- Market penetration rates

A new president and a new Congress have potential implications for a change in federal regulations and possible federal legislation. To date, few changes have occurred with draft federal legislation failing to pass and federal regulations under both the Obama and Trump administrations, which took a low-key approach. Both the Biden administration and Congress appear likely to make significant changes in regulations and legislation in the next year or two.

Technology continues to show real change with declines in the cost of sensors and improvements in performance. An active debate continues among those who favor the use of light detection and ranging (lidar) and those who prefer cameras and radar. (Tesla stands out in the anti-lidar camp.)

Market penetration continues to show progress, with Waymo operating a small fleet of driverless vehicles with paying customers in a suburb of Phoenix. Several firms appear ready to cover parts of other metro areas in late 2021 or 2022. Intercity trucking firms continue to test their technology and hint at deployments in 2022 on certain western roads. There are a growing number of specialty vehicle deployments. NHTSA approved one local delivery firm (Nuro) to operate without a steering wheel and the number of sidewalk delivery firms continue to grow along with the use of drones and recent tests for larger aircraft. [26]

4.1 POLICY

Policy remains stalled but a new administration and Congress are likely to bring change. Regulations have not progressed so far other than some local governments placing a cap on shared ride firms, or transportation network companies (TNCs). AV deployment depends on support from federal and state regulations. With a new federal Administration, the greatest risk concerns interstate movement by automated trucks. Trucks have become the focus for most large AV firms. Labor union concerns over job security may have an influence on any federal legislation. Labor issues were one reason the last effort to pass federal legislation stalled in Congress. This could happen again. Ironically, the lack of federal direction may be a positive thing for truck AV firms. But NHTSA does not need an act of Congress to change regulations. This uncertainty, however, has not slowed the pace of investment in AVs.

1. Clarification of state versus federal regulatory responsibilities
   - **Results.** Legislation from the last Congress stalled due, in part, to opposition by truck labor unions and concerns for stronger safety regulations. Two recent U.S. DOT reports on autonomous vehicles continue to promote a hands-off policy.[27] State regulations continue past trends—that is, encouraging deployment. (California now allows testing of full driverless vehicles, with five firms approved.) As part of efforts to encourage economic development, some states are trying to speed deployment of autonomous vehicles. Michigan's Route 40 effort between Detroit and Ann Arbor is the most ambitious, with backing from Cavnue, part of Sidewalk Labs, a subsidiary of Alphabet.
   - **Commentary.** Worries exist today concerning the risk that inconsistent regulations among states might add to vehicle costs. Federal legislation to clarify federal and state roles could provide a more consistent playing field. There is a risk, however, of too much detail too early. Thus, the nature of legislation is at least as important as the legislation itself. The new Congress is expected to make another attempt to pass legislation.

2. Regulatory requirement for a given technology
   - **Results.** There has been no change and no incentive for manufacturers to wait for regulatory action. The low-speed shuttle industry has been advocating for clearer guidance from NHTSA. Some vehicles do not require a waiver, but vehicles built in the U.S. do. All need a local waiver from the state department of motor vehicles.
   - **Commentary.** Regulatory actions for specific technologies are rare today. Any specific requirements will likely speed deployment but also could slow innovation and encourage firms to slow deployment in order to wait for action by NHTSA. Relaxing rules for deployment of low-speed shuttles appear to be the most likely change. Medium-speed shuttles (cutaways) are under development and, while not required, may involve regulatory change. NHTSA has allowed at least one type of vehicle to operate without a steering wheel.

3. Requirement to include vehicle technology information in vehicle identification numbers (VIN)
   - **Results.** This is increasingly mentioned at regulatory meetings, but so far, no movement has occurred. It likely requires a strong push by safety advocates, insurers, researchers, law enforcement and repairers. Tesla's in-house insurance (starting with California) will provide Tesla with the equivalent information. GM's new in-house insurance will provide the same advantages for General Motors.
   - **Commentary.** Requiring system information in the VIN would allow accurate tracking of vehicle safety performance in consideration of installed systems, making analytic, regulatory or risk estimation efforts more effective. This would be a positive action both in terms of encouraging deployment and supporting analysis of technology effectiveness. When will Tesla (and now GM) release information regarding the effectiveness of their technology for broader consumption?

4.2 TECHNOLOGY

There is some progress here. New safe vehicles are increasingly equipped with safety features (emergency braking and lane tracking, for example). The number of self-driving vehicles is growing. Tesla leads the field but other firms have begun to deploy vehicles with some self-driving abilities (e.g., GM, Honda,). A correlation suggests that there may have been a positive impact of these recent trends regarding reduced auto fatalities in 2018, but COVID-19 reversed any such positive trends. Sensor costs have dropped significantly (lidar is a good example) and performance has improved (again for lidar but also for optical and radar). More experience is needed regarding reliability of lidars. But some firms say that lidar sensors need to be replaced within two years, generating significant future operating costs. There is continued interest in using optical sensors, perhaps in place of lidar. In time, this would reduce costs further.

4. Automated emergency braking
   - **Results.** Most new car sales in 2020 were equipped with AEB (and other systems such as lane tracking)—a very encouraging trend. But not all drivers use AEB and AEBs can cause problems with fake positives particular regarding stopped vehicles. (This problem has generated several Tesla crashes.) One hopes that with experience (and perhaps pressure from the insurance industry and government regulations), the severity of these issues can be reduced.
   - **Commentary.** AEB is one of the most important automation applications with value for safely driven, self-driving and driverless vehicles. In addition to confusing marketing terminology and promises, the effectiveness of current industry applications varies widely and system performance parameters are not broadly understood. Increased standardization could improve safety and speed safety gains.

5. Cost of lidar systems
   - **Results.** Increased competition among more than 50 firms versus only one a dozen years ago has reduced costs. At least one firm advertises a lidar device for less than $500. More established firms talk about total lidar costs dropping to about $5,000 per car in the next two to three years.[28] Apple even installed a lidar in its latest smart phone.[29]
   - **Commentary.** Lidar units are generally considered central to effective self-driving and driverless systems. A few years ago, these costs totaled tens of thousands of dollars for each unit (down from more than $100,000 half a dozen years ago). With increased demand and competition, prices have dropped in recent years and further reductions are expected within the next few years, accelerating the deployment of self-driving and driverless vehicles, possibly also supporting vehicle retrofits. These changes are occurring despite recent trends toward use of optical sensors.

6. Costs and effectiveness of other sensors
   - **Results.** General improvements continue as demand for optical sensors and radars increases.
   - **Commentary.** Optical sensors have become increasingly important as some firms begin to shift away from lidar as the dominant type of sensor. As with AEB, no industry standards currently exist and private firms do not share raw data.

7. Growth in vehicle cyber insurance
   - **Results.** There has been no significant change.
   - **Commentary.** Cyber insurance is expected to become increasingly important in the autonomous vehicles space as applications become more advanced. Growth in this segment will reflect the rate of adoption and maturation and the degree to which confidence exists in the ability to limit potential cyberattacks.

4.3 MARKET PENETRATION RATES

Deployment has begun but remains limited, so little hard data exists regarding vehicle use. Exceptions include the following: low-speed shuttles continue to grow, but their market share is low and there are few signs of a sustainable business case; the intercity truck market appears ready to begin commercial use with promises of 2022 for certain routes in the West; and interesting examples of local freight delivery exist.

Nuro received approval from NHTSA to operate a local driverless freight delivery vehicle without a steering wheel (deployed in Houston).

However, none of these trends show significant growth. Shared rides in TNCs (Uber, Lyft) have dropped considerably due to COVID-19. A few jurisdictions (individual cities plus California) have begun to add costs to TNCs to reduce demand and support taxis and transit. Some locations (New York City and California) have worked to restrict their flexibility. This is not yet a national trend but it is important to watch since it has implications for efforts to limit the growth of autonomous vehicles.

The lack of wide-spread AV deployment has stimulated negative press reports, reducing previous public enthusiasm for AVs. Other than state regulatory work (California stands out) there has been little effort by federal and state agencies to help speed AV deployment. The federal focus is on deployment of electric vehicles, with almost no mention of AVs. The recent decision by the FCC to shift part of the 5.9GHz band width away from transportation also serves to reduce state ability to stimulate AV deployment. One unanswered question concerns the possible impact of the Michigan effort to build an AV-only lane in Michigan between Detroit and Ann Arbor. While the state of Michigan supports this effort, success depends on the ability of a private firm (Cavnue, part of Alphabet) to show that there is a business case. If successful, other regions are likely to follow. This effort will also make AV and related technology visible to the traveling public

8. **Privately owned light vehicles and commercial light vehicles with safely driven and self-driving tech**
    - **Results.** There has been noticeable growth in safety technologies in new safe vehicles and not just for high-end cars. New cars now include AEB, although tests by *Consumer Reports* show that a large fraction (up to 50 percent) of drivers turn off many safety features,[30] in part, due to annoyance with false positives. More firms are promoting self-driving vehicles. These help to generate comfort with the "feel" of driverless vehicles.
    - **Commentary.** Share of personally owned vehicles with safely driven and self-driving systems should be tracked, with a focus on type of technology. Within this group of vehicle types, share could be tracked by new vehicles manufactured (easiest), VMT (more difficult) and passenger miles traveled (PMT, most difficult). Variation across type of region is important (e.g., Central Business District (CBD), suburban, rural). IIHS offers an opportunity to test vehicles prior to collecting large volumes of data. GM and Tesla's private insurance services will have access to these data but, based on past behavior, they are unlikely to share.

9. **Ride sharing, measured by total number of shared rides and average occupancy**
    - **Results.** Growth continues, with the number of shared rides exceeding the number of national transit bus riders—prior to COVID-19.[31] The rate of growth has slowed. Pressure from Uber and Lyft to become profitable may encourage higher fares, slowing growth further.
    - **Commentary.** The market share from ride sharing is a key indicator of a fundamental change in vehicle use and AV adoption. Widespread ride sharing—reflected in average vehicle occupancy—would favorably affect demands on infrastructure, safety, ownership and insurance. COVID-19 has made ride sharing less attractive.

10. **Driverless vehicle share of VMT or PMT in a given market**
    - **Results.** These numbers remain small—with only a few hundred vehicles in Chandler, Arizona, and a few local freight delivery vehicles operated by Nuro. Major OEMs and technology firms still talk in terms of deploying automated vehicles in the near future. Ford mentions 2022 while Cruise and Waymo hint at new urban areas by later this year or 2022. Where remains a question as well.
    - **Commentary.** Driverless technology will precipitate changes in ownership models, safety and costs. The single most important trigger point will be when driverless earns a meaningful share—

measured either in terms of given market, region or country. These data should be tracked by type of market (CBD, metro area, rural) and by region of country (for example, areas with poor weather versus good weather).

11. Driverless commercial vehicles
    - **Results.** To date, experience has involved tests. This is about to change with several firms planning deployment later this year or in 2022. Few details exist on the geographic extent of these plans but most likely they will cover the same regions used for vehicle testing (routes between Texas and Arizona).
    - **Commentary.** Detail by region is important. Western states are likely to grow faster than more densely populated Eastern states with less attractive weather. Because of its economic value, commercial VMT should be measured in three ways:
        - **Partial automation.** Commercial trucking is already pursuing platooning or operating driverless in restricted domains, such as expressway miles only. This should lead to reduced labor costs and increased safety for the automated portion of the journey, with the risks of the remainder of the journey a function of safe/self technologies.
        - **Full automation.** This can be found in true end-to-end driverless VMT.
        - **Local delivery.** Nuro stands out but sidewalk vehicles have begun to be deployed and speculation exists about plans by Amazon and prospects for drone delivery

Concluding Comments

The autonomous vehicle industry always seems to be in transition. Today, this transition begins from a low-point in terms of enthusiasm in the press and the public. Private firms continue to raise funds ($8.5 billion in the last 12 months alone) and the industry has seen a burst of firms that plan to enter the public stock market. Technology problems remain. After a decade of missed forecasts by almost every firm, the volume of promises has toned down. One hopes that this means future forecasts will be more credible.

The efforts by GM and Tesla to integrate insurance into their products is encouraging, with prospects of linking financial incentives regarding the deployment (and use) of new technology. This covers changes other than full driverless vehicles.

The impact of COVID-19 on travel patterns and the willingness to travel in groups creates uncertainty regarding the popularity of the standard business model – shared rides in aTaxis. The industry is still searching for a business model for passenger service. In contrast, the freight market seems focused on moving goods between warehouses adjacent to the Interstate (TuSimple stands out in promoting this model). Local freight movement is growing with firms like Nuro beginning deployment and Walmart and other large retain firms exploring short and medium distance delivery. There is also encouraging growth in smaller markets such as transit service (see the AV deployment by Connecticut DOT) and interest in truck yard automation.

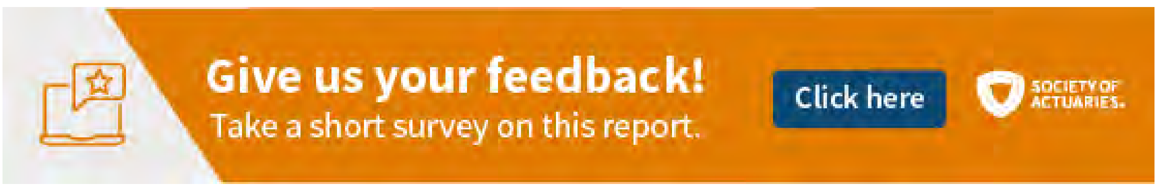
In sum, while investment dollars are still not the problem, technology issues continue to slow deployment in complex geographies (where people live). The lack of a proven business model remains a concern. Industry enthusiasm continues and the next five years (no longer the next two years) look promising.

Appendix A: Podcast with Head of GM OnStar Insurance Program

Princeton University professor Alain Kornhauser conducted a podcast interview with Andrew Rose, the head of General Motors' new OnStar Insurance program. The new product has implications both for the deployment of autonomous vehicles and for the insurance industry.

The link to the podcast interview can be found here: *https://youtu.be/k5PZ2s_yZHI*.

This years' Princeton Smart Driving Car Summit held a session on insurance and autonomous vehicles: **Automated Driving Technologies – Driving Change in Insurance.** Speakers included Alain Kornhauser from Princeton, Jacques Amselm from Allianz Technology; Michael Scrudato from Marsh Afinity (formerly with Munich Re); Kara Kockelman from University of Texas, Austin, and Jerome Lutin, former NJ Transit. The link to a summary of the session is here: *https://viodi.com/2021/03/05/automated-driving-technologies-driving-change-in-insurance/*



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Society of Actuaries
475 N. Martingale Road, Suite 600
Schaumburg, Illinois 60173
www.SOA.org