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An Update on the Outlook for Automated Vehicle Systems

October 2019

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An Update on the Outlook for Automated Vehicle Systems

Section 1: Summary

Reality has caught up with the hype/romance of the popular press concerning the future of automated driving. Disappearing is the vision of connected swarms of driverless personal cars flowing effortlessly down our arterials and freeways. The buying public, however, is beginning to absorb the driver-assisted technologies that not only deliver safety, comfort and convenience, but also serve to embolden the traditional consumer-oriented business model. This, in turn, has helped accelerate private investment and technology partnerships that involve almost every automobile manufacturer.

On the Driverless front, reality has set in that complete removal of human oversight is a non-trivial hurdle. Except for possibly Tesla, all visions of driverless vehicles operating on public roadways involves a business model based on a professional fleet operator managing the vehicles rather than individual vehicles owned by consumers. All demonstrations and tests to date, be they for the movement of people or goods, involve some form of explicit human oversight by a trained on-board attendant or driver, or active remote-control oversight. Worldwide, only Waymo has indicated that they are about to begin testing driverless mobility services in Arizona, without a safety driver. That indication only surfaced in October of 2019.

The first large-scale commercial deployment of driver-assisted technologies is likely to involve intercity trucks. Testing by several companies is expected to transition to operational deployments later this year and in 2020. A limited number of local freight tests exist with each relying of remote human oversight or control. These include pizza delivery on college campuses and tests by larger firms (Amazon has field tests in Puget Sound,[1] for example). Low-speed shuttles continue to attract a variety of small-scale demonstrations, but few sustainable business cases (retirement communities may be an exception). Drones are being tested by several firms for local freight delivery.

Sensor costs continue to decrease, with some dramatic claims regarding Lidar costs.[2] There is general agreement, however, that these sensors need to be replaced frequently, some as soon as within two years. An active debate continues regarding the use of Lidar versus optical sensors. Tesla, for example, does not use Lidar, instead relying on radars and optical sensors.

A major event is Tesla's in-house insurance plan for California.[3] This has important implications. Tesla claims their vehicles are significantly safer so this provides an opportunity to deliver financial returns to vehicle owners, generating positive feedback.

The need for more data on safety performance continues, particularly given the rapid deployment of technology in non-automated vehicles. The industry remains dependent on the Insurance Institute for Highway Safety **(**IIHS) as the best source for information on early driver-

assistance features – what this report terms Safe and Self-vehicles. Consistent terminology is important as well, given the amount of marketing jargon that distorts the actual effectiveness of new technology and confuses consumer and industry understanding of the application, its value, and the effectiveness of new technology.

Most existing regulations are positive (not too cold and not too hot). On the other hand, New York City, Chicago, and California have undertaken efforts to limit the current business model for TNCs (Transportation Network Companies such as Uber, Lyft, etc.). While increasing the cost of ride-hailing, these changes also provide incentives to speed the transition to driverless vehicles. Sharing rides is an important part of the economic and social benefits for driverless vehicles and a vital part of the financial model for firms in the Mobility-as-a-Service (MaaS)/Ride-Hailing business.

The question becomes whether local governments will continue to discourage shared rides on driverless vehicles that appear to divert traffic from transit, or if they will see this as a service that is simply another form of transit that increases the effectiveness of the transportation system.

A review of the trigger points section of the report shows no signs of an imminent breakthrough in technology or deployment; the only exception being the very recent Waymo indication that they may actually begin transitioning their Chandler/Phoenix 'Waymo One' to Driverless operation without an attendant on-board. Sensor costs are improving, with positive implications for future development. Interest is growing in the freight market (including drones) but deployment is limited. More importantly, the enormous hurdle of removing the attendant/driver from the vehicle has yet to be achieved anywhere in the world, and today only Waymo may be in a position to actually achieve this in the near future.

The text box summarizes major trends. The impact of these changes will affect every aspect of the motor vehicle industry, including vehicle insurance (directly through changes in vehicle safety, performance, and ownership, and indirectly through total trips, the mix of trip types, intensity of use, the total number of vehicles required to meet demand, and the relative share of occupied / unoccupied vehicle miles travelled), infrastructure insurance (transit, highways), and even residential insurance.

Major Trends

- Safety will improve quickly, but incrementally. Most new cars include technology that will generate important safety gains and reduce expected financial liabilities since these safety measures are focused on crash avoidance, not just crash mitigation. In time, driverless vehicles will help, but their primary motivation is to provide mobility as broadly as possible.
- State and federal regulatory agencies have been helpful, with policies and regulations allowing innovation, but there are growing signs of local concerns for the shared mobility model.
- Vehicle-to-vehicle and vehicle-to-infrastructure communication continues to migrate away from a public-sector focus, relying instead on commercial solutions such as 5G for the infrastructure side supporting the operational, management, and commercial needs of large fleets of vehicles providing Mobility-as-a-Service to people and goods.
- Data ownership issues continue to grow in importance, with implications for safety investigations, liability determination, and the ability to identify causation.
- Driverless deployments will appear in specific Operational Design Domains (ODD) (good weather, geofenced areas, explicitly certified road segments, time-of-day, etc.), rather than broadly, for the foreseeable future.
- Fleet ownership/management will likely dominate the early stage of driverless vehicle deployment, in part due to high vehicle costs, strict adherence to the Operational Design Domain, and the need for professional maintenance of more complex vehicles. Economic viability depends on ride-sharing whenever feasible. Some states may even prohibit private, consumer-oriented ownership of these vehicles.
- Cybersecurity will continue to be a substantial technical concern.
- As per mile costs decrease, vehicle and passenger miles of travel will increase. Incentives exist for longer commutes, reduced short-haul aviation, and larger commercial markets based on reduced cost to move freight.

Section 2: Introduction

The popular press plays an important role in public perception regarding automated vehicles. In contrast to the excitement generated two to three years ago, we are now in a period of "reverse hype" with most articles focused on the slow pace of development and concerns regarding possible negative impacts on traffic congestion and growth of suburbs. At the same time, an increasing number of new cars come equipped with sensors and systems that mirror those that will be used by driverless vehicles. This means that a growing portion of the traveling public are becoming familiar with the underlying technology that will be part of autonomous vehicles.

To help describe these trends and highlight differences between the cars we see on the street today and driverless vehicles, this report relies on three market-related definitions:

- **Safe** – This category describes most new cars. The driver is solely responsible for vehicle operation, but technology can improve safety by alerting to risks or by implementing safety actions such as automatic braking and blind-spot warning. There is considerable variation in the effectiveness of these technologies among Original Equipment Manufacturers (OEMs) and individual models, creating uncertainty regarding the exact impact on safety.

- **Self-Driving** (or just "Self" since "self-driving" implies more autonomous ability) – These cars can assume responsibility for select driving tasks under specific road or weather conditions. An alert driver ready to take control is required, although over confidence in the technology means some drivers act as if they are in a driverless vehicle. Because their performance depends on driver intervention, safety benefits beyond Safe technologies are not yet well understood and, in some cases, may not be significantly better than the best Safe systems. Self-driving cars require a driver in order to provide any meaningful mobility or value. They deliver additional comfort, convenience, and safety to the auto industry's existing customer base. As such, they are a "consumer play" and require no regulations or public oversight beyond what exists today. Any safety issues can be handled through standard "product liability" and "NHTSA recall" procedures. From outside the car, one can't tell what type of technology the vehicle may or may not have on board. These vehicles are a consumer choice at time of purchase.

- **Driverless** – This vehicle is responsible for all driving tasks, at least within well-defined locations and driving conditions (termed "Operational Design Domain" (ODD)). No driver or attendant is required during the trip. (The California Public Utilities Commission uses "Drivered" for "Driverless" vehicles that require an attendant to be on-board.) These vehicles are still under development and, to date, operated only in the Drivered mode. Waymo's deployment outside Phoenix in early 2018 remains the first public, commercial application of Drivered Driverless. Driverless cars are a "business play" with a focus on delivering mobility to individuals. Since algorithms, rather than people, tailor the service to meet individual needs, such systems can serve large markets. From outside the car, one can tell that there isn't a driver in the driver's seat. Consequently, public oversight at all levels will be important. A broad range of organizations and individuals are likely to weigh in with perceptions and regulations. This risks a change from the generally supportive attitude of federal and state regulatory agencies. California's Department of Motor Vehicles and Public Utilities Commission are the two leading agencies that have seriously addressed Driverless cars as a mobility business play.

Section 3: News Update

The world of autonomous vehicles is always in the midst of change. This section summarizes major events, ranging from slower deployment, new partnerships, new insurance, regulatory changes, and other news items. This section highlights major changes and is not meant to provide a full description of recent events.

3.1 Slower Deployment – with a few exceptions

A few years ago, public expectations were that driverless vehicles would soon be universally available. That has not happened and hasn't even started. Substantive "Drivered Driverless" service has started in California and Arizona by Waymo. These services could be sustainable and scale rapidly by simply removing the attendant and becoming just "Driverless." Waymo recently announced that customers in Arizona will now have the option to ride in a car without an attendant – true driverless travel. This is very encouraging since we know that "Drivered Driverless" service is economically unsustainable and doesn't scale. Even Waymo (part of Alphabet) has limited resources. Once started, deployment is likely to follow at a measured pace, with vehicles available market by market and location by location. Weather and positive local regulations will help decide where and when driverless vehicles appear. One observer characterized this as similar to a Land War, with progress made slowly and place by place.

Waymo (owned by Google) and Cruise (owned by General Motors) are viewed as the industry leaders (for cars). Cruise originally planned to operate driverless vehicles (most likely with a safety driver) in San Francisco by the end of 2019. They recently said they would not be ready and delayed deployment for some future date, not yet specified. Other companies continue to test, with a variety of promised dates for deployment, most in the 2021-2023-time frame. Recent test efforts include Waymo in Los Angeles, Uber in Dallas, and Cruise in Las Vegas.

3.2 Waymo moves forward – a bit slowly

Waymo has announced plans to purchase 82,000 vehicles, 20,000 from Jaguar and 62,000 minivans from Chrysler. No information is available regarding when actual orders will be placed. While 82,000 is not a large number relative to the overall fleet in the US, because they will be used for most of the day and provide shared rides, they are capable of carrying more than a billion rides a year – equal to about one fourth of total transit bus riders in the US. A logical assumption is that Waymo will focus these vehicles in a limited number of urban areas. This means they will have a noticeable impact in those specific locations. Waymo has not announced where or when they plan to deploy these new vehicles.

Waymo has been providing shared ride service in their automated vehicles in Chandler, Arizona since the end of 2018. They plan to begin expanding this to neighboring jurisdictions late this year, starting with Tempe (home to Arizona State University). The Chandler operation uses about 500 Chrysler Pacifica vans and includes a maintenance facility. Following a period of tests with volunteers, these vehicles are now available to the general public using an app similar to that used by TNCs such as Uber and Lyft. Trips are limited to Chandler and Tempe. Waymo just announced that their customers in Arizona will have a choice of riding with a safety attendant or riding in a fully driverless vehicle.

The Waymo Drivered Driverless vehicle is now available as an option to Lyft customers in Chandler. (Lyft is also working with Aptiv testing driverless vehicle in Las Vegas, Nevada). The City of Chandler recently announced that, rather than using the city's motor pool, employees would use Waymo to move around the city. This should represent a savings to the city. Walmart has offered to pay the costs for customers – an interesting example that could find other applications.

3.3 Trucks

Trucks have always been seen as a logical first market for driverless vehicles. Trucks are already operated by commercial firms, who would receive tangible benefits from cost savings in operations and access to larger markets. Also, the intercity truck industry faces a long-term shortage of drivers. Trucks are also substantially self-insured, a liability that is privately estimated to be roughly $10,000 per truck per year that some estimate could readily be halved by emerging automated driver-assistance technology. As a result, several well-funded technology firms are focused on developing the technology to capture this market opportunity. These include some of the big-name firms, with Waymo and Uber entering the market from time to time (Uber was involved in a major lawsuit over intellectual property on this topic).

After several years of testing, some with US Department of Transportation (DOT) funds, Peloton says they have seven trucking companies that will support a deployment either later this year or early 2020. The Peloton system calls for "truck trains" with trucks benefiting from reduced fuel use while they drive in close proximity to the leader vehicle. Drivers in the following trucks may steer the vehicles or just watch for problems – and drive the vehicle to and from the warehouse. Peloton plans to operate driverless trucks at some point as well. These "trains" may create safety concerns for other vehicles on the road. There is a clear need for systematic data collection regarding safety, including public perceptions.

Other examples include: TuSimple that has been operating trucks between Dallas and Phoenix for the Post Office and between Phoenix and Tucson for UPS. To date, all include a safety driver. UPS has invested in TuSimple. Starsky Robotics plans trucks that are "driven" by remote operators. A Swedish firm has a similar plan using a dramatic new vehicle with not only no steering wheel, but also no cab for a driver. This summer, Starsky did operate a fully driverless vehicle on a short route in Florida but, to date, the firm uses safety drivers.

Each of these firms plan commercial operations within the next year. Despite the current shortage of over-the-road drivers, there are strong public concerns about the loss of jobs. In August, truck drivers staged a demonstration in Missouri in opposition to proposed legislation to allow driverless trucks in the state.

3.4 Safety record – and the need for more data

Safety data regarding Safe and Self-vehicles is largely missing and also inconsistent. One problem is that drivers ignore (often on purpose) the new monitoring systems in their vehicle. Consumer Reports conducted a recent study of this problem that showed many drivers were confused by the large number of "beeps" and often did not know how to respond. This shows,

in part, a lack of careful thought by many auto technology firms and represents a significant gap between the potential benefit of new vehicle technology and actual practice.

Beyond this, the volume of data is limited and often inconsistent. IIHS provides one of the few sources of test data regarding technology in new vehicles. IIHS reports that the performance of intelligent cruise control, automated lane keeping, and automated emergency braking varies substantially among OEM, reflecting the amount of authority the OEM has given to the automation system. For some, system designers have chosen to ignore stationary objects above certain speeds to reduce false alarms due to overpasses, signs, and tree canopies. Related problems are the wide variety in names and claims regarding these technologies. Marketing seems to have taken precedence over technical accuracy.

In time, the National Highway Transportation Safety Administration (NHTSA) will likely become more involved. This requires a large enough sample of vehicles to identify consistent problems. At present, NHTSA is investigating a "false positive" problem with automatic brakes on Nissan cars.

Tesla stands out as a firm that promotes data regarding the safety of its vehicles. For example, they claim only one crash for every 3.27 million miles for drivers using their Autopilot system; one for every 2.19 million miles for those using Tesla's active safety features; and one for every 1.41 million miles for drivers not using these features.[4] These numbers sound very impressive (NHTSA reports an auto crash every 500,000 miles), but are the results consistent with other vehicles or with how NHTSA reports data? Tesla has yet to provide details on the nature of these data and their calculations.

3.5 Implications of Tesla Insurance package

In September, Tesla announced its own auto insurance firm for residents of California (it will be run by an insurance firm, rather than by Tesla itself). This is an important announcement, both for the automated vehicles and for the insurance industry. Tesla promises savings of 20-30% relative to existing commercial auto insurance rates for its vehicles. Tesla plans to expand this insurance program elsewhere in the US. While Tesla claims low crash rates, its cars can be expensive to repair given the aluminum construction, limited parts, and few auto body repair experts.[5]

This allows Tesla to leverage what it views as a major strength of its vehicles – its safety record. Tesla now has a clear incentive to make its safety systems (including Autopilot) even better. This benefits the insurance company – and Tesla's customers. The Tesla insurance firm will have access to detailed data that will help determine responsibility for any crashes. There appears to be implications for other OEMs with technology in their cars to follow this model. In contrast, automobile OEMs in Sweden also have proprietary insurance firms, but seem to view them solely as another profit center.

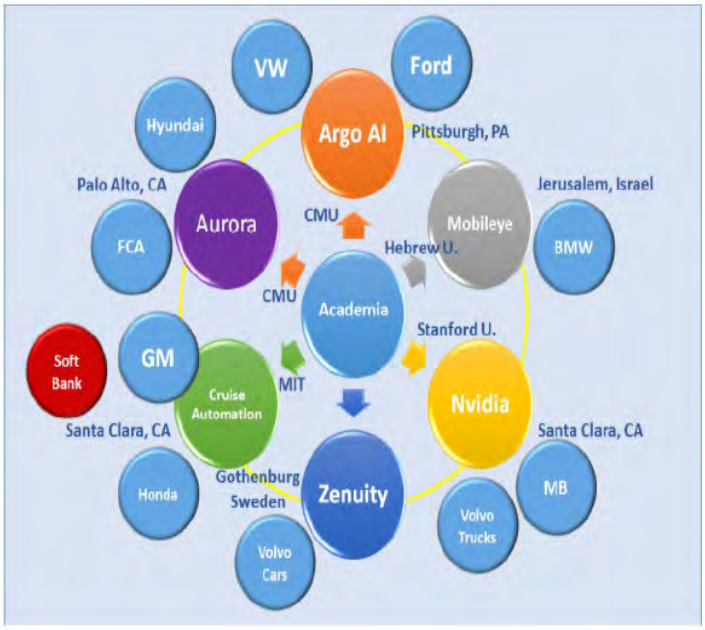
3.6 Company mergers

Over the past five years, private investment in the autonomous vehicle industry has exceeded $100 billion – a large number for any industry, but massive when compared with public

investment in transportation research. Beyond this, there are an increasing number of mergers among technology firms and large OEMs. This has important implications for the marketing of automated vehicles. These large consortia all seem focused on shared riders rather than sales to individual drivers. Serving shared rides allows full use of the vehicle.

A few relevant consortia (see below chart[6] for a summary):

- Ford and VW. Previously, Ford bought Argo AI for $1 billion. This partnership now adds another $2.6 billion in cash and staff from VW's technology group.
- Waymo has partnered with Renault-Nissan, opening up opportunities in Japan and Europe.
- Honda has joined GM/Cruise.
- Aurora (founded by the past lead for Waymo and the technology lead for Tesla) has partnered with Fiat-Chrysler and Hyundai.
- Apple purchased drive Ai – a small deal but one that shows Apple remains interested in this field.



Only a few major firms seem left out, such as Toyota, BMW, and Daimler. Beyond the money, this shows serious interest in deploying the technology on a large scale. There are no new forecasts regarding when this may occur. This discussion of partnership does not cover the truck business.

3.7 Uber and Lyft IPOs

Uber and Lyft are leaders in the business of shared mobility. Both have been able to raise huge sums of investment money despite vast financial losses. Both firms recognize that their current business models cannot be scaled – there is not a large enough supply of part-time drivers and a general lack of economies of scale. Both view autonomous vehicles as required in order to reach profitability.

Both firms underwent their initial public stock offering (IPO) this year. These have not gone well. The valuation at the IPO was substantially less than the most recent private valuation. On top of this, both stocks suffered significant drops in the weeks following the IPO. To make things worse, their initial quarterly reports showed larger than expected losses, partly due to the IPO itself.

The firms face two general options: 1) reduce the number of drivers and focus on higher margin business or 2) use driverless vehicles to reduce costs and stimulate a significant increase in business volume.

Very simply, today Uber carries 4 billion rides a year and loses about $4 billion a year – or roughly one dollar for each ride. To justify a market valuation of some $40 billion, Uber needs to generate a profit of $1 per ride rather than a loss. To be successful, option one described above implies 400 million rides a year, with a profit of $10 per ride – or a total of $4 billion. Option two implies 40 billion rides a year (stimulated by a much lower price per mile) with a profit of ten cents per mile. In fact, this autonomous vehicle model would likely support a larger profit per ride.

Following problems with their IPOs, Uber and Lyft have even larger incentives to deploy autonomous vehicles.

3.8 Regulations

Federal and state regulations regarding autonomous vehicles continue past trends. The USDOT's latest guidance document: ***Preparing for the Future of Transportation: Automated Vehicle 3.0*** (Fall, 2018) continues the position of the Trump and Obama Administrations to encourage innovation, rather than over-regulating or picking winners and losers. Most states follow this process. California has the most detailed regulations. The state's Department of Motor Vehicles recently established new rules that allow companies to test driverless vehicles without a safety driver. This is a major change for California. So far, two companies have applied for this right, but do not appear to have begun such testing. Most states have regulations in place that allow automated vehicles to test or operate. Many states (including California) are open to waivers for local deployments.

No progress has been made regarding the proposed federal legislation that would clarify federal versus state regulations. This legislation almost passed in the last Congress, but was held up by opposition regarding the effect on truck drivers and concerns by safety advocates over the number of exemptions. Another effort will be made to pass this. Meanwhile, individual states are moving forward.

3.9 Local opposition to TNCs

Over the past five (5) years, Transportation Network Companies (TNCs), of which Uber and Lyft are prime examples, have become a viable form of Mobility-as-a-Service. While on a typical day they serve less than one of the daily trips, they have become widely recognizable by the general public and especially business professionals, tech savvy individuals. Part of their allure is that for many they are known as "ride-sharing" firms, even though a very small percentage of their ridership involves real 'ride-sharing': having a single vehicle serve unrelated individuals having portions of their trips going from about the same place to about the same place at about the same time. Overwhelmingly, they serve either single riders or single groups of riders that, for reasons other than transport efficiency, were traveling together, say to go to dinner. The success of these companies has been fueled by the elegant ability of their app-based ride-hailing

features to remove the 'sketchiness' and anxiety associated with hailing a ride, getting into a car with a stranger and paying for the ride (no one touches the money), and the ability to use non-union labor on a part-time basis to substantially reduce it driver labor costs. While such services could be made substantially more affordable by completely replacing the driver with driverless technology, and even more by ride-sharing, existing Uber/Lyft from a level-of-service point of view are essentially an exact forebearer of a driverless autonomousTaxi (aTaxi) service. This correspondence provides an opportunity for aTaxi concepts to learn and improve upon challenges faced by Uber/Lyft.

One of the challenges is the growing opposition to TNCs by local governments. These arguments focus on concerns about increased traffic congestion, riders diverted from transit, lost business for existing taxi owners (often with dramatic losses in the value of taxi medallions), and concerns that drivers have been taken advantage of by the TNCs and do not receive adequate compensation. Actions include:

- Efforts by drivers to organize strikes;
- Higher fees for TNCs (in New York City and Chicago);
- Mandated hourly compensation for drivers (New York City and Chicago);
- Efforts by airports to move TNCs away from the terminals (LA and San Francisco among others); and
- Recent legislation in California that may force TNC firms to treat their drivers as employees rather than "gig" or part-time employees.

While the impact of the California legislation is uncertain, there is clear opposition in some cities to shared ride vehicles that increase vehicle miles travelled (VMT) and divert travelers from transit. This has two implications:

1) Encourages TNCs to move to driverless vehicles sooner (they already have financial incentives to do this), and
2) Worries that cities and states may attempt to limit use of future driverless vehicles to avoid increasing VMT and diverting transit riders.

3.10 AVs and Mobility Impaired

There is debate about the economic and social advantages of driverless vehicles. Safety is often mentioned, although this may be less important as technology is deployed in Safe and Self- vehicles. Shared rides are important, both because it appears to be a logical route to profit and because it can provide significant economic and social benefits by improving access. Another focus is travel for mobility-impaired people—whether due to physical handicaps, low incomes, or lack of access to reliable transit. Such a focus would also generate public support, something that might have value given the apparent growing opposition to TNCs.

In this regard, Volkswagen recently unveiled a plan called Inclusive Mobility Initiative with a focus on people with disabilities. While not yet implemented, this provides another public business model.

Section 4: Trigger Points[7]

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: Safe; Self; and Driverless. These trigger points are organized in three groups:

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

Technology is the only section that shows real change in recent months. Market penetration should start to show some progress given the expected deployment of intercity trucks and the growing number of specialty vehicles (local freight delivery, drones, and low-speed shuttles).

4.1 Policy Triggers

Policy is stalled. This is not helpful, but then regulations have also not regressed other than some local governments trying to place a cap on shared ride firms (TNCs).

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. The USDOT's ***Preparing for the Future of Transportation: Automated Vehicle 3.0*** continues to promote a hands-off policy. State regulations continue past trends – that is encouraging deployment (California now allows testing of fully driverless vehicles). As part of efforts to encourage economic development, many states have encouraged deployment of autonomous vehicles, but with limited results.
   - 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. Congress may make another attempt to pass legislation.

2. Regulatory requirement for a given technology promulgated
   - Results: No change. Thus, 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 others do (mostly US-designed vehicles). 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 (a) slow innovation, and (b) encourage firms to slow deployment in order to wait for action by NHTSA. New regulatory actions appear unlikely in today's environment.

3. Requirement to include vehicle technology information in Vehicle Identification Number (VIN)
    - Results: This is increasingly mentioned at regulatory meetings but, so far, no movement. 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.
    - 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 the analysis of technology effectiveness.

4.2 Technology Triggers

Some progress here. New Safe vehicles are increasingly equipped with safety features (emergency braking, lane tracking, etc.). The number of Self-vehicles is growing. Tesla leads the field, but other firms have begun to deploy vehicles with some self-driving abilities. A correlation suggests there may have been a positive impact of these recent trends regarding reduced auto fatalities in 2018. Sensor costs have dropped significantly (Lidar is a good example). More experience is needed regarding reliability of Lidars. Some firms say that Lidar sensors need to be replaced within two years. There is continued interest in using optical sensors, perhaps in place of Lidar. In time, this would reduce costs further.

4. Automated Emergency Braking (AEB)
    - Results: Forty-five percent of new car sales in 2018 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 (witness Uber crash in Tempe and several Tesla crashes) and fake negatives (witness NHTSA investigation of Nissan). One hopes that, with experience (and perhaps pressure from the insurance industry), the severity of these issues will reduce.
    - Commentary: AEB is one of the most important automation applications with value for Safe, Self, and Driverless vehicles. In addition to confusing marketing terminology, 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 (more than 50 firms versus only one ten 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 around $10,000 per car in the next 2-3 years.
    - Commentary: Lidar units are generally considered central to effective Self-Driving and Driverless systems. A year or so ago, these costs totaled tens of thousands of dollars for each unit (down from more than one hundred thousand dollars 4-5 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 retro-fits. These changes are occurring despite recent trends toward the 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.

7. Growth in vehicle Cyber Insurance
    - Results: No significant change.
    - Commentary: Cyber Insurance is expected to become increasingly important in the AV 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 cyber-attacks.

4.3 Vehicles and Vehicles Use

Deployment has been limited, so there is little hard data regarding vehicle use. Exceptions, including low-speed shuttles, continue to grow, but their market share is low and there are few signs of sustainable business case; intercity truck market appears ready to begin commercial use; and interesting examples of local freight delivery exist. However, to date, none of these trends show significant growth. Shared rides in TNCs (Uber, Lyft, etc.) continue to grow, although the rate of growth has slowed a bit. A few jurisdictions (individual cities plus California) have begun to add costs to TNCs in order 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 important to watch since it has implications about possible efforts to limit the growth of autonomous vehicles.

8. Privately-owned light vehicles and commercial light vehicles with Safe and Self-technology
    - Results: There has been noticeable growth in safety technologies in new Safe vehicles and not just for high-end vehicles. About 45% of new cars now include automatic braking (AEB), although no guarantee exists that consumers will take advantage of this technology. More firms are promoting Self-vehicles. These help to generate comfort with the “feel” of driverless vehicles.
    - Commentary: Share of personally-owned vehicles with “Safe” and “Self-driving” systems should be tracked, with a focus on the type of technology. Within this group of vehicle types, share could be tracked by new vehicles manufactured (easiest) or VMT (more difficult) and PMT (passenger miles traveled, most difficult). Variation across type of region is important (CBD, suburban, rural, etc.). IIHS offers an opportunity to test vehicles prior to collecting large volumes of data.

9. Ride sharing – measured by total number of shared rides and average occupancy
    - Results: Growth continues, with the number of shared rides now exceeding the number of national transit bus riders. 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 that is made up by 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.

10. Driverless vehicle share of VMT or passenger miles travelled (PMT) in a given market. This should be examined by type of market – CBD, metro area, rural, etc. and by region of country (areas with poor weather versus good weather).
    - Results: These numbers round to zero – with nothing other than a few hundred vehicles in Chandler, Arizona. Major OEMs and technology firms still talk in terms of deploying automated vehicles in the near (undefined) future. Where remains a question as well.
    - Commentary: Driverless 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 location and by region of country.

11. Driverless commercial vehicles. Detail by region is important – Western states may grow faster than more densely populated Eastern states.
    - Results: To date, experience has involved tests. This is about to change with several firms planning deployment later this year or in 2020. Few details exist on the geographic extent of these plans.
    - Commentary: Because of its economic value, Commercial VMT should be measured in two ways:
        a. 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.
        b. Full automation: True end-to-end Driverless VMT.

Section 5: Acknowledgements

The researchers' deepest gratitude goes to those without whose efforts this project could not have come to fruition, namely the Project Oversight Group and others for their diligent work reviewing this report for accuracy and relevance.

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Endnotes

[1] https://finance.yahoo.com/news/amazon-rolls-robots-trying-automated-211424167.html
[2] Luminar announces a $500 Lidar device. https://cleantechnica.com/2019/07/12/500-lidar-from-luminar-could-move-autonomous-driving-forward/
[3] https://www.tesla.com/support/insurance
[4] https://tesla-info.com/blog/tesla-safety-report-and-the-need-for-caution.html
[5] Data from IIHS, however, does not show savings in repair costs for Tesla vehicles.
[6] Chart from Michael Sena's *The Dispatcher (September **2019**.*)
[7] These were developed in a previous report by the Society of Actuaries. "Market Framework and Outlook for Automated Vehicle Systems"; (March, 2018)

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