

# What Will it Take to Commercialize Autonomous Vehicles?

## INTRODUCTION

Media coverage regarding the development of autonomous vehicles (AVs) is ubiquitous and for good reason – the automotive industry is undergoing a level of change not seen since horse drawn carriages were replaced by cars and the internal combustion engine. Beyond the reporters who track autonomous initiatives and the engineers who design the components, systems and applications, the majority of people do not comprehend what constitutes an AV. Before proceeding further, SAE’s (Society of Automotive Engineers) definition of autonomous driving and the major categories that comprise an AV will be reviewed to establish a foundation.

### Defining Autonomous Driving

SAE created specific definitions for levels of autonomous driving to promote collaboration and communication around a complex and rapidly evolving subject. Referring to Table 1, SAE’s six levels of autonomy are defined as:

**Table 1: SAE Autonomous Driving Levels<sup>1</sup>**

SAE Autonomous Level	Description
L0: No Driving Automation	Driver performs all tasks.
L1: Driver Assistance	There are driver assist functions, but the driver controls the vehicle at all times.
L2: Partial Driving Automation	Enhanced driver assist features exist but the driver is engaged and continuously monitors surroundings.
L3: Conditional Driving Automation	Driver does not continuously monitor surroundings but is prepared to assume control at any point when notified.
L4: High Driving Automation	Vehicle can operate autonomously in specified conditions; driver may have the option to assume control.
L5: Full Driving Automation	Driver is completely out of the loop, and the vehicle can operate in all conditions.

### Major Categories of an AV

For the purposes of this paper, an AV is disaggregated into four categories: the vehicle, redundant systems, autonomous driving solution (ADS) and sensors. Table 2 provides an overview of each category and its role in autonomy.

<sup>1</sup> SAE International, Standard J3016 JUN2018 – “Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles”

**Table 2: AV Categories**

Category	Description
Vehicle	Regardless of how sophisticated autonomous algorithms and sensors are, an AV is not possible without a validated vehicle that complies with government regulations; e.g., FMVSS. <sup>2</sup>
Redundant Systems	Redundancy in safety systems is paramount to enable autonomy and realize SAE levels 4 and 5. Steering wheels and brakes require redundant critical components (e.g., actuators) to ensure that if one fails then the other assumes control or activates fail-safe protocols. Other systems with redundancy include: computing platform, power and sensors.
ADS	In its simplest form, an autonomous algorithm processes reams of data concerning its surroundings and renders decisions on how to operate the vehicle, respond to atypical situations, etc.
Sensors	There are four primary sensors that analyze and interpret surroundings: <sup>3</sup> <ul style="list-style-type: none"> <li>- Cameras: Also referred to as image sensors, sense colors and print which enables them to analyze lane dividers, traffic lights and signs.</li> <li>- Ultrasonic: When operating at low speeds, these sensors emit sound waves and the resulting echoes indicate cars, pedestrians, obstacles, etc., within close proximity</li> <li>- Radar: Short and long-range sensors emit electromagnetic waves to detect vehicles and their respective distance and velocity.</li> <li>- LiDAR: Low energy laser beams are pulsed to scan surroundings, resulting in a 3D rendering of the vehicle's environment. Coupled with the camera's data, LiDAR can distinguish amongst objects; e.g., pedestrian v. bicycle v. car</li> </ul>

### Current State of Autonomy

AV programs are global in scope and supported by corporations in and outside of the automotive industry and by governments at federal and local levels. Beyond the large-scale enthusiasm and numerous pilots, it is important to recognize that a commercially available L4/5 AV does not exist today. As noted by Mr. Matthias Müller, the previous Volkswagen AG CEO, "It will take many years before we see a car with level 5 autonomous-driving functions on the roads."<sup>4</sup> That being said, there are autonomous products from other industries in the marketplace, for instance:

- Skydio launched R1, its civilian autonomous drone that follows and records bikers, runners, hikers etc., on their routes<sup>5</sup>
- Northrup Grumman's autonomous Bat UAS is a military drone that has been used in the field and on missions<sup>6</sup>
- Autonomous robots are used for warehouse operations
  - Amazon purchased Kiva in 2012 and deployed their robots throughout their facilities<sup>7</sup>
  - inVia Robotics entered the market in 2017 with their Picker product<sup>8</sup>

This raises the question as to why other industries have already commercialized their autonomous products. The primary difference lies in the fact that the domain

<sup>2</sup> Federal Motor Vehicle Safety Standards (FMVSS) is overseen by NHTSA (National Highway Traffic Safety Administration), which falls under the Department of Transportation, and sets the standards for vehicles to be qualified as roadworthy  
<sup>3</sup> Companies pursuing AVs may not use all of the sensors noted in Table 2; e.g., Tesla does not use LiDAR whereas Waymo and GM apply this technology to their driverless programs. To learn more, please refer to the Verge's February 2018 article: <https://bit.ly/2EuwChw>  
<sup>4</sup> Bloomberg, "It's a Good Thing Europe's Autonomous Car Testing Is Slow," <https://bloom.bg/2Md7oFe>  
<sup>5</sup> Skydio R1's product information: [www.skydio.com/product/](http://www.skydio.com/product/)  
<sup>6</sup> Bat UAS product information: [www.northropgrumman.com/Capabilities/BATUAS/Pages/default.aspx](http://www.northropgrumman.com/Capabilities/BATUAS/Pages/default.aspx)  
<sup>7</sup> Forbes, "New Robotic Solutions For The Warehouse," <https://bit.ly/2yDBTBR>  
<sup>8</sup> Ibid

where drones, warehouse robots, etc., operate is more constrained. By contrast, the operational design domain (ODD<sup>9</sup>) for AVs is more complex and, at times, unpredictable. To illustrate, consider the following scenarios:

- Managing a 4-way stop sign with manually operated vehicles at 3 of the 4 positions, pedestrians crossing the intersection and a bicyclist pedaling through without observing the stop sign
- Merging onto a highway at 70 KPH (~44 MPH) during rush hour and after a snowfall where snow removal has yet to occur causing lane dividers to be hidden
- Government, without warning, shuts down several city blocks and detour information is not provided

These pertinent situations and other market challenges to achieve commercialization will be discussed in greater detail throughout the paper.

### Market Potential

Though forecasts vary by source, consensus demonstrates that AVs will impact global markets. Two recent headlines of note:

- “The global autonomous driving market is expected grow up to \$173 billion by 2030...”<sup>10</sup>
- “Driverless cars will be part of a \$7 trillion market by 2050.”<sup>11</sup>

What is unclear is how the market potential will be realized. This question is further compounded given that AVs are not currently generating revenue even though investment levels are significant. The Brookings Institution calculated investments between 2014 and 2017 at \$80B USD.<sup>12</sup> To fully commercialize and achieve scale will require greater outlays, yet the return on these investments remains ambiguous. To help frame the potential and, in general, the business model, this paper provides a strategic assessment of AVs.

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<sup>9</sup> ODD defines where an AV can operate in terms of road types, velocity, weather, geography, day/night time driving, etc.

<sup>10</sup> PR Newswire, “Global Autonomous Driving Market Outlook, 2018,” <https://pr.to/2yDBTlo>

<sup>11</sup> Fortune, “Driverless Cars Will Be Part of a \$7 Trillion Market by 2050,” <https://for.tn/2qYwxYA>

<sup>12</sup> The Brookings Institute, “Gauging Investment in Self-Driving Cars”, [www.brookings.edu/research/gauging-investment-in-self-driving-cars/](http://www.brookings.edu/research/gauging-investment-in-self-driving-cars/)

## STRATEGIC OVERVIEW OF THE AUTONOMOUS LANDSCAPE

To grasp the landscape of autonomous programs requires an understanding of competitors, global initiatives, regulations that encourage AV development, impacts to other industries, and the overall business model. Taken together, these elements enable a viewpoint of a dynamic market that traditional OEMs (Original Equipment Manufacturers), new entrants, media, research institutes, investors, regulators, etc., are striving to define.

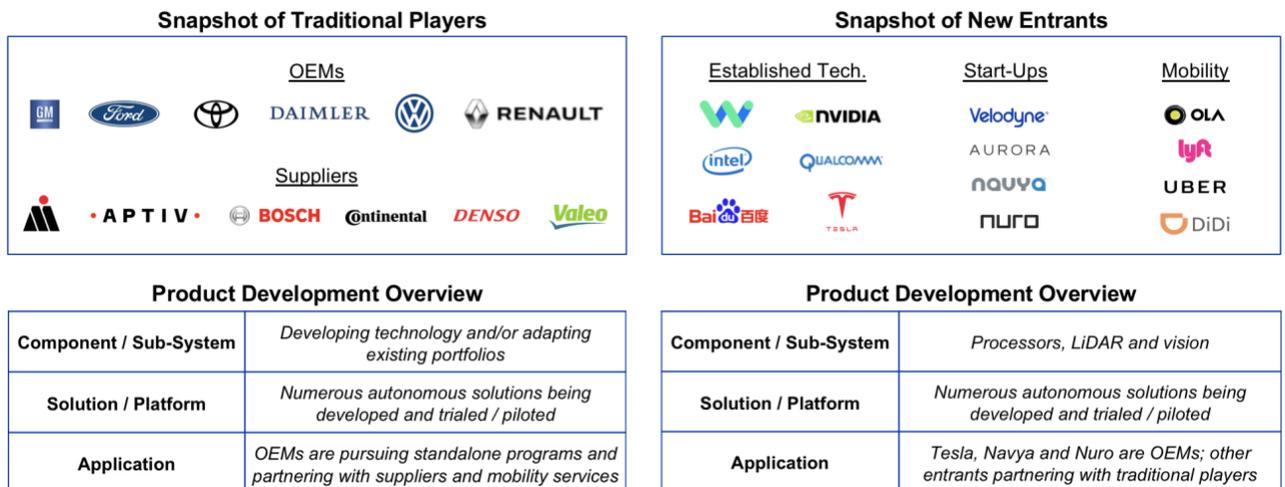
### Competitors

As noted in the introduction, the current consensus around the potential of AVs is significant. The resulting excitement has motivated traditional players and new entrants to pursue new developments. From a traditional perspective, automotive OEMs and suppliers are using their engineering and manufacturing expertise to devise new autonomous products (from components to applications). Hi-tech firms are also entering this space due to the advanced computational requirements for AVs. Based on this technological need, three types of hi-tech entrants have been observed:

1. Established technology companies – Large organizations with notable engineering talent and the funds needed to pursue long term initiatives.
2. Start-ups – Scrappy and fledgling firms that see an opportunity to design and launch sensors, systems and/or applications.
3. Mobility providers – The opportunity to remove drivers from vehicles and focus on fleet management is accelerating their efforts to get driverless cars on the road.

The following illustration provides a cross-section of traditional and hi-tech players, and an overview of each group’s product development efforts.

### Illustration 1: Autonomous Market Entrants and Offerings



## Global Initiatives

Autonomous is a global endeavor where numerous programs are in-flight. Corporations, governments, and universities are actively involved in determining how to validate and commercialize AVs. To provide a stratum of various initiatives, Table 3 examines programs underway in the US and China.

**Table 3: Snapshot of Global AV Programs**

USA	China
<p>Beyond Detroit, 29 states and D.C. have enacted AV legislation.<sup>13</sup> Examples of driverless programs include:</p> <ul style="list-style-type: none"> <li>Ann Arbor, MI: University of Michigan established Mcity, a public-private program focused on connected and autonomous vehicles. There are 60 partners ranging from Detroit OEMs to Silicon Valley tech. As of June 2018, two autonomous shuttles are operating on a 1-mile campus route.<sup>14</sup></li> <li>California took an early position to promote driverless research, development and testing. To date, 56 permits were issued for AV testing with a driver.<sup>15</sup> In March the DMV began accepting applications for AV trials without drivers; Waymo applied in April.<sup>16</sup> Additionally, California PATH is recognized as a research leader in AV transportation and technology.</li> <li>Other locations with active programs include: Las Vegas NV, Pittsburgh PA, Austin TX and Boston MA.</li> </ul>	<p>China is the automotive manufacturing leader; 2017 output was 29M which represented 30% of global volumes.<sup>17</sup> Given their manufacturing strength and issues with congestion and emissions<sup>18,19</sup>, it is understandable that the government and corporations are pursuing AV programs:</p> <ul style="list-style-type: none"> <li>The government set a 2030 target where 10% of vehicle sales will be driverless cars.<sup>20</sup></li> <li>Baidu announced it will begin producing its autonomous shuttle in July 2018 (manufactured by King Long), which uses its Apollo autonomous driving software. For now, the ODD footprint will be limited to certain airports and tourist regions.<sup>21</sup></li> <li>At the end of 2017 Beijing became the first Chinese city to approve driverless testing on public roads<sup>22</sup>, and Baidu was the first to receive permission to trial its AV on nearly 105 kms of suburban streets.<sup>23</sup></li> </ul>

## Regulations to Promote Development and the Current Regional Leader

The good news is that regulators are taking an accommodating approach when it comes to AV development and pilots. This ‘light touch’ method results from two key factors: First, the predicted benefits of AVs – reduction in accidents, injuries and congestion – are urgently needed. Second, there is a global race to be the leader in driverless vehicles and related technologies. This minimal approach, however, should not be interpreted as relaxing safety while AV trials are underway. Regardless of location, methodology or incidents, governing bodies have emphasized that safety is paramount.

Examining how three major automotive centers manage regulations depicts regional advantages and shortcomings and provides early indications of the current regional AV leader.

<sup>13</sup> NCSL, [www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx](http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx), accessed 27 June 2018

<sup>14</sup> Mcity, <https://mcity.umich.edu>, accessed 27 June 2018

<sup>15</sup> California DMV, [www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/permit](http://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/permit), accessed 28 June 2018

<sup>16</sup> San Francisco Chronicle, “Exclusive: Waymo applies for no-driver testing in California,” <https://bit.ly/2LZjUv0>

<sup>17</sup> OICA, 2017 Production Statistics, [www.oica.net/category/production-statistics/2017-statistics/](http://www.oica.net/category/production-statistics/2017-statistics/)

<sup>18</sup> USA Today, “Thousands stuck in 50-lane traffic jam in Beijing,” <https://usat.ly/2ltUkbL>

<sup>19</sup> NY Times, “Beijing, Bracing for 5 Days of Heavy Pollution, Issues Red Alert,” <https://nyti.ms/2MZNUVn>

<sup>20</sup> Forbes, “China Aims To Be No. 1 Globally In EVs, Autonomous Cars By 2030,” <https://bit.ly/2Kbwx6k>

<sup>21</sup> Abacus, “Baidu’s Self-Driving Buses to Begin Production,” <https://bit.ly/2KcF9cF>

<sup>22</sup> Sixth Tone, “Beijing to Allow Self-Driving Cars on Public roads,” [www.sixthtone.com/news/1001416/beijing-to-allow-self-driving-cars-on-public-roads](http://www.sixthtone.com/news/1001416/beijing-to-allow-self-driving-cars-on-public-roads)

<sup>23</sup> Reuters, “China’s Baidu gets green light for self-driving vehicle tests in Beijing,” <https://reut.rs/2Kqh2U4>

**USA:** NHTSA (National Highway Traffic Safety Administration) provides voluntary guidance on safety and encourages AV programs to publish annual reports. Their latest release, A Vision for Safety 2.0, recommends 12 safety elements for the development of L3 to L5 AVs. The previous release identified 28 behavioral competencies that an AV will likely encounter when operating in traffic and its ability to manage each one.<sup>24</sup> At the state level, transportation departments are regulating AV operations and trials. Though the degree of regulation varies by state, officials are supportive of autonomous programs. It is important to note that a noninterventionist approach is not recommended as evidenced by Uber and the pedestrian death in Arizona; the state initially provided minimal oversight but then suspended Uber's tests after the fatality.<sup>25</sup> What transpired in Arizona, along with incidents in other states, may partially explain why the AV START Act (S. 1885)<sup>26</sup>, which is designed to regulate and promote AV development, stalled in the Senate and is experiencing resistance from public interest groups.<sup>27</sup>

**Europe:** In spite of not having an EU regulatory framework for driverless cars, the Commissioner of Transport wants to close the AV gap with the US and China.<sup>28</sup> Sensing the disconnect, countries are pursuing their own legal constructs to promote autonomous programs. To illustrate, consider the UK and Germany:

- Germany – Known for its automotive engineering expertise, it does not come as a surprise that there are at least 43 AV programs across the country.<sup>29</sup> One example is the Federal Ministry for Transport and Digital Infrastructure's (BMVI) Digital Motorway Test Bed. Here, a portion of the A9 highway is digitized to promote AVs and connected testing.<sup>30</sup> Additionally, the BMVI established initial safety regulations where ADS must be designed to avoid harming or causing the death of people.<sup>31</sup>
- UK – The Law Commission of England and Wales, and the Scottish Law Commission are conducting a three-year study to determine how laws need to change with the advent of AVs. In the interim, there are at least 21 stand-alone and multinational driverless initiatives underway<sup>32</sup>; e.g., UKAutodrive is testing AVs in Milton Keynes and Coventry.<sup>33</sup>

**China:** The Ministry of Transport enacted national guidelines earlier this year where AV testing must start in non-public zones before proceeding to public trials. Further, the Ministry designated which roads can be used for testing

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<sup>24</sup> Visit [www.nhtsa.gov](http://www.nhtsa.gov) to learn more about NHTSA's voluntary guidance and behavioral competencies

<sup>25</sup> Reuters, "Uber shuts Arizona self-driving program two months after fatal crash," <https://reut.rs/2KiGJGw>

<sup>26</sup> Visit [www.congress.gov/bill/115th-congress/senate-bill/1885](http://www.congress.gov/bill/115th-congress/senate-bill/1885) to learn more about The AV START Act

<sup>27</sup> CNET, "Public interest groups urge Congress to change AV START Act," [www.cnet.com/roadshow/news/public-wants-changes-av-start-act-congress/](http://www.cnet.com/roadshow/news/public-wants-changes-av-start-act-congress/)

<sup>28</sup> Financial Times, "EU motors ahead with rules for self-driving cars," [www.ft.com/content/f3a76e4c-5772-11e8-b8b2-d6ceb45fa9d0](http://www.ft.com/content/f3a76e4c-5772-11e8-b8b2-d6ceb45fa9d0)

<sup>29</sup> Visit <https://connectedautomateddriving.eu/research/> for an overview of European AV initiatives and government programs

<sup>30</sup> BMVI, [www.bmvi.de/SharedDocs/EN/Articles/DG/digital-test-beds.html](http://www.bmvi.de/SharedDocs/EN/Articles/DG/digital-test-beds.html), accessed 28 June 2018

<sup>31</sup> Reuters, "Germany draws up rules of the road for driverless cars," <https://reut.rs/2yWT15Q>

<sup>32</sup> Refer to footnote 29

<sup>33</sup> Visit [www.ukautodrive.com](http://www.ukautodrive.com) to learn more about the UKAutodrive project

and that a safety operator must be in the driver's seat at all times.<sup>34</sup> These rules are facilitating AV programs across the country, as noted in Table 3 from the previous section.

Considering the above information around development, the US is the current leader in terms of the government enabling autonomous programs. The basis of this conclusion stems from the following points:

- The EU recognizes that they are lagging the US and China
- China's Vice Industry Minister indicated that China would "slip behind" the US if they did not "seize" the AV initiative<sup>35</sup>
- Favorable regulations have attracted international organizations to pursue development in the US, as shown in Table 3
- Navigant Research's latest analysis of companies pursuing driverless programs identified GM and Waymo, which are headquartered in the US, as the current leaders<sup>36</sup>

### Impact to Other Industries

Multiple industries and government services will be affected once AVs become commonplace on streets and highways. At this time, quantifying the levels of impact is an estimate as it is difficult to gauge when driverless technology will achieve critical mass. Taking this into account, Table 4 discusses several organizations that will be affected by autonomy and whether the impact will be beneficial to or impinge on their business model.

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<sup>34</sup> Reuters, "China lays out self-driving rules in global race: China Daily," <https://reut.rs/2KyN9B8>

<sup>35</sup> Ibid

<sup>36</sup> Navigant Research, [www.navigantresearch.com/research/navigant-research-leaderboard-automated-driving-vehicles](http://www.navigantresearch.com/research/navigant-research-leaderboard-automated-driving-vehicles), accessed 29 June 2018

**Table 4: AV Impact**

Industry / Government Service	Potential Impact from AV
Insurance	<ul style="list-style-type: none"> <li>The current business model relies on premiums from insuring car owners. As AVs take hold and drivers are out of the loop, this will affect insurance's revenue source. On top of that, it is expected that commercial vehicles and fleets will follow suit and hasten topline erosion.</li> <li>Given these factors, amongst others, HBR predicts that the industry could contract by \$25B come 2035.<sup>37</sup></li> </ul>
Public Transportation	<ul style="list-style-type: none"> <li>US public transportation funding is under pressure<sup>38</sup> and to compensate local governments are turning to ride sharing services.<sup>39</sup></li> <li>Public transportation budgets may be further reduced as a result of autonomous mobility services costing less than bus or subway fare, leading riders to switch to autonomous providers.<sup>40</sup></li> </ul>
Automotive Dealerships	<ul style="list-style-type: none"> <li>In 2017 franchised US auto dealers realized more than \$1T in sales on 17M+ new vehicles, while performing nearly 317M repairs totaling more than \$114B in revenue.<sup>41</sup> Gross retail sale margins were, on average, 2.5% and gross profit for service and parts was 46%.<sup>42</sup></li> <li>With the transition to AVs the dealership model may be disrupted as follows: (1) Car owners become paying mobility passengers resulting in fewer car sales and diminished topline. (2) AVs operate according to their ODD and OEM specs resulting in fewer collisions and mechanical / electrical issues. This is a positive gain for society but will be detrimental to franchisees given the outsized margins they earn from service and parts. This impact will be exacerbated should mobility providers manage their own fleets or contract to third parties.</li> </ul>
Infrastructure	<ul style="list-style-type: none"> <li>Beyond federal support, states / provinces, counties and cities rely on various vehicle registration fees (license, plate tags, city permits, etc.) and fines (speeding, parking, etc.) to fund infrastructure.</li> <li>AVs pose a challenge in terms of reducing the amount of government levies collected as consumers transition to autonomous mobility users. Additionally, driverless cars will operate according to local and state laws thereby reducing revenue from vehicular penalties. This calls into question how current infrastructure will be maintained and new projects funded.</li> </ul>
Car Rentals	<ul style="list-style-type: none"> <li>It is posited that car rental organizations stand to gain from AVs. To start, consider their current business and operating models: generating revenue by renting and managing large and dispersed fleets of vehicles. These models can be reasonably extended to encompass driverless products. Second, mobility providers and hi-tech companies do not have fleet management experience. This presents a business opportunity for car rental companies to become fleet management contractors. There are early market indicators that support this hypothesis:             <ul style="list-style-type: none"> <li>- Hertz signed an agreement with Aptiv to manage their AV fleet in Las Vegas.<sup>43</sup></li> <li>- Avis is managing Waymo's driverless fleet in Phoenix, AZ.<sup>44</sup></li> </ul> </li> </ul>
Logistics	<ul style="list-style-type: none"> <li>Based on ATRI's latest analysis, drivers are the largest cost variable at 33% of total carrier costs.<sup>45</sup> In view of this and an increasing shortage of operators<sup>46</sup>, logistic companies and OEMs have been pursuing autonomy programs; e.g., Volvo, Daimler and Tesla all have driverless carriers under development.</li> <li>There are numerous pilots underway as well, such as the joint venture amongst Embark, Ryder and Frigidaire to autonomously deliver household appliances.<sup>47</sup></li> <li>Autonomous carriers have the potential to solve an urgent issue for long-haul transportation companies and the e-commerce retailers who rely on them.</li> </ul>

<sup>37</sup> HBR, "Driverless Cars Will Change Auto Insurance. Here's How Insurers Can Adapt," <https://bit.ly/2Aylyfd>

<sup>38</sup> Eno Transportation Weekly, "FY19 Budget Request: Mass Transit Again Faces "New Start" Cuts," <https://bit.ly/2KIYLv9>

<sup>39</sup> Financial Times, "How Uber and Lyft are reinventing the bus," [www.ft.com/content/733e4108-a88c-11e7-ab55-27219df83c97](http://www.ft.com/content/733e4108-a88c-11e7-ab55-27219df83c97)

<sup>40</sup> CNN, "How free self-driving car rides could change everything," <https://cnmmon.ie/2evGe0J>

<sup>41</sup> National Automobile Dealers Association, "NADA DATA 2017," [www.nada.org/2017NADAdata/](http://www.nada.org/2017NADAdata/)

<sup>42</sup> Ibid, pp. 24, 29

<sup>43</sup> Reuters, "Hertz partners with Aptiv for managing driverless car fleets," <https://reut.rs/2M9GJsM>

<sup>44</sup> MIT Technology Review, "Why Waymo's Partnership with Avis Makes Sense," <https://bit.ly/2tOehUA>

<sup>45</sup> American Transportation Research Institute (ATRI), "An Analysis of the Operational Costs of Trucking: 2017 Update," <http://atri-online.org>

<sup>46</sup> CNBC, "Companies are complaining they can't find enough truck drivers...," <https://cnb.cx/2l4TqUN>

<sup>47</sup> Business Wire, "Embark, Frigidaire®, and Ryder Partner to Pilot Automated Driving Technology," <https://bit.ly/2u8D07T>

## Autonomous Business Model

Two conditions need to be met in order for AVs to take hold: One, they can be commercialized and, two, there is a viable business model. The previous section regarding the impact of AVs identified use cases and customer groups which are important elements to any enterprise. Realizing topline while controlling for costs, however, needs to be understood. As discussed in the introduction, this becomes more pressing given the magnitude of investment and current lack of revenue streams.

### *What Will be Sold?*

The logistics business model is the most clear-cut; OEMs will sell their product to logistics companies and, in turn, they will charge their customers for autonomous transportation services. The automotive sector, on the other hand, is less obvious. The following scenarios present challenges that traditional and new entrants are contending with:

1. Will hi-tech companies sell or license their ADS to suppliers and/or OEMs?
2. Will hi-tech companies attempt to disrupt OEMs and sell their own autonomous products?
3. Suppliers are developing ADS as well; can they compete with hi-tech firms?
4. How will hi-tech and suppliers respond if OEMs develop their own driverless algorithms? Similarly, what if mobility providers commercialize an internal ADS that can be adapted to numerous vehicles?
5. Will OEMs continue to sell via dealerships or will mobility providers become their primary customers?

These questions will play out over time but there are several early indicators of how competitors are positioning themselves. Table 5 reviews three business narratives currently unfolding.

**Table 5: Generating Revenue from AVs**

Company	Description of Business Opportunity
General Motors	<ul style="list-style-type: none"><li>• GM announced at the beginning of the year that they will launch the Cruise AV in 2019.<sup>48</sup> The vehicle will be without steering wheel or pedals suggesting that it is an L5 autonomous product. Furthermore, GM petitioned NHTSA to allow for the annual production of up to 2,500 Cruise AVs to operate in the US.<sup>49</sup></li><li>• GM's traditional model realizes revenue from car sales. In this case, GM wants to control their AVs because the lifecycle revenue, they reckon, will be hundreds of thousands of dollars per car.<sup>50</sup> Without question this changes their conventional paradigm.</li><li>• The aforementioned lifecycle revenue will likely derive from data monetization which will be discussed later in this section</li></ul>
Waymo	<ul style="list-style-type: none"><li>• Waymo established an early position in driverless solutions and is engaged in several Arizona pilots that are demonstrating potential commercial value, including:<sup>51</sup><ul style="list-style-type: none"><li>– Round-trip service to Phoenix Walmart stores and the Ahwatukee Foothills Towne</li></ul></li></ul>

<sup>48</sup> GM Corporate Newsroom, "Meet the Cruise AV: The First Production-Ready Car With No Steering Wheel or Pedals," <https://bit.ly/2JbNx2>

<sup>49</sup> Automotive News, "GM ride-hailing fleet would ditch steering wheel, pedals in 2019," <https://bit.ly/2m5Emfh>

<sup>50</sup> Reuters, "No pedal to the metal in GM's planned self-driving Cruise AV car," <https://reut.rs/2DnNDXT>

<sup>51</sup> Reuters, "Waymo self-driving cars to ferry Walmart shoppers in Arizona trial," <https://reut.rs/2uP5vHV>

	<ul style="list-style-type: none"> <li>Center <ul style="list-style-type: none"> <li>- Replacing loaner cars for AutoNation, and providing customer pick-up and drop-off for Avis</li> <li>- Targeting the launch of an autonomous taxi service by the end of 2018<sup>52</sup></li> </ul> </li> <li>• Based on these programs and others, Morgan Stanley revised Waymo's value from \$75B to \$175B<sup>53</sup></li> </ul>
Bosch	<ul style="list-style-type: none"> <li>• Bosch's Mobility Solutions division acquired Splitting Fares, a carpool startup in Detroit; it is also pursuing driverless solutions with Mercedes-Benz.<sup>54</sup> These positions demonstrate Bosch's transformation to compete in the autonomous field.</li> <li>• Though not stated, revenues may result from: <ul style="list-style-type: none"> <li>- Selling sensors and ADS to OEMs and mobility services</li> <li>- Technical advisory on validating autonomous systems and applications</li> <li>- Autonomous fleet management strategies and implementation</li> </ul> </li> </ul>

### Cost Management

A critical component in AVs is the LiDAR sensor. As explained in the introduction, it enables 3D renderings of a vehicle's environment. The challenge, however, is the price tag: Velodyne's LiDAR which enables a 360° view of up to 300 meters costs \$75,000.<sup>55</sup> Compounding matters, certain AVs require an array of LiDAR amongst other sensors. This has led some analysts to proclaim driverless cars as unaffordable – Morgan Stanley estimated that, "...a GM Cruise self-driving test car, packed with up to 40 lidar, radar and camera sensors, may cost \$250,000 – \$300,000..."<sup>56</sup>

Fortunately, OEMs and suppliers are pursuing alternative engineering designs that maintain performance while controlling for cost. In October, GM acquired Strobe which focuses on LiDAR technology and may be able to reduce the sensor's cost to \$300.<sup>57</sup> Another promising avenue is Luminar. They optimized LiDAR takt time from one day to eight minutes and reduced the cost of a critical component (the receiver) from tens of thousands of dollars to \$3.<sup>58</sup> These cost management efforts bolster the likelihood of realizing a first-generation AV priced less than \$100,000.

### Data Monetization

Quoting The Economist's May 2017 article on data in the new economy, "Data are to this century what oil was to the last one: a driver of growth and change."<sup>59</sup> There is little doubt of data's potential in the AV business model; e.g., targeted advertising based on location and passenger profiles. The challenge at hand is how to sift through and analyze reams of information that result in meaningful insights and lead to new revenue sources. To bring this into focus, WardsAuto noted that one driverless test car generates nearly 30 TB of data per day; by contrast Twitter produces 100 GB of data.<sup>60</sup> Further complicating the issue, the inflow of information

<sup>52</sup> The Street, "Alphabet's Autonomous Driving Unit Waymo Not Worth \$75 Billion, But \$175 Billion," <https://bit.ly/2vN4tMt>

<sup>53</sup> Ibid

<sup>54</sup> Reuters, "Bosch starts new division, acquires U.S. carpooling start-up," <https://reut.rs/2Hh1pwc>

<sup>55</sup> Wired, "Luminar's New Lidar Could Bring Vision to Every Robocar in the World," [www.wired.com/story/luminar-lidar-self-driving-cars/](http://www.wired.com/story/luminar-lidar-self-driving-cars/)

<sup>56</sup> Investor's Business Daily, "Self-Driving Cars: Why 2018 Will Be The Year The Rubber Hits The Road," <https://bit.ly/2FFk1pl>

<sup>57</sup> Ibid

<sup>58</sup> MIT Technology Review, "Cheap lidar gets a big win in deal with Volvo," <https://bit.ly/2NhAF1A>

<sup>59</sup> Visit <https://econ.st/2uRnmOw> to learn more about The Economist's report on data monetization

<sup>60</sup> WardsAuto, "Storage Almost Full: Driverless Cars Create Data Crunch," <https://bit.ly/2Ocbqz7>

will intensify as sensors and algorithms improve their capabilities to, respectively, capture and process more data and as AVs gradually proliferate.

One possible solution is to keep only what is needed, which is favored by some OEMs and suppliers.<sup>61</sup> This raises a concern about what data are deemed essential. Consider a product marketer and an engineer – the former will gather information on the user’s experience and the latter will concentrate on performance. These are primarily different data sets and both groups will defend the relevancy of their respective information. Another factor is regulators. It is plausible that they will require all AV data to be captured, especially during the incipience of commercialized driverless cars. A more probable remedy resides with AI and its ability to learn while simultaneously analyzing large swaths of information.<sup>62</sup> Over time this could allow all groups to study data streams from tens of thousands of AVs on a daily basis and identify value-creating opportunities.

## MARKET CHALLENGES

Bringing a high-volume commercial car, SUV, truck, etc., to market is an engineering and operational feat that is difficult to comprehend unless one has worked directly in a vehicle development program. This is best evidenced by Tesla’s endeavors to achieve scale for its mass-market Model 3<sup>63</sup> and Mr. Elon Musk’s (CEO of Tesla) reaction to production issues: “...I’m back to sleeping at factory. Car biz is hell...”<sup>64</sup> Fortunately, established OEMs and suppliers possess the technical and manufacturing expertise to design, develop and launch vehicles. For new entrants, resources are available to aid them with delivering their product, such as engineering consultancies, retired automotive engineers and partnerships with OEMs.

Beyond scale there are three issues that all driverless players must contend with if they are to successfully commercialize their products: functional safety, validation and consumer trust.

### Functional Safety

Autonomous functional safety<sup>65</sup> (AFS) standards have yet to be established as governments promote development and trials. In the near term, this approach makes sense; e.g., companies are incentivized to pilot their programs, technical capabilities are matured, etc. These initial benefits, however, are not sustainable over the long run. Defined requirements inform OEMs, suppliers, hi-tech companies, etc., about what is needed to achieve a roadworthy designation. They also create a competitive advantage as governing bodies can provide guidance on what is needed to certify an AV.

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<sup>61</sup> Ibid

<sup>62</sup> MIT Sloan Management Review, “How Big Data Is Empowering AI and Machine Learning at Scale,” <https://bit.ly/2IVRPGM>

<sup>63</sup> Popular Mechanics, “Can Tesla Keep Up the Model 3 Pace?,” <https://bit.ly/2AcYg1V>

<sup>64</sup> Quote capture from Mr. Elon Musk’s twitter feed from 2 April 2018: <https://twitter.com/elonmusk>

<sup>65</sup> Functional safety refers to the mitigation of external and internal hazards

Enacting AFS regulations requires balancing standards that mitigate hazards while not overburdening companies with administration. To square the two, it is recommended that transportation ministries / departments and corporations coordinate efforts on the following items:

**Table 6: Establishing AFS Regulations**

Point of Coordination	Description
Collaborate with Smart City Development <sup>66</sup>	Smart cities play an important role in enabling driverless cars in terms of V2X connectivity. <sup>67</sup> Having a defined V2X legal framework with flexibility to accommodate local regulations clarifies functional safety designs and corresponding policy.
Use Root Cause Analyses (RCA) from Trial and Pilot Failures	Failures will happen and they need to be used to inform policy and mitigate future occurrences. Outputs from RCA should be signed-off by the corporation(s) involved in the trials and, ultimately, approved by the governing body(ies). Moreover, the final approved report should become inputs for creating or modifying AFS regulations.
Standardize ODD	Given the differences in seasons, state and municipal laws, road types, geography, etc., establishing a standard ODD informs OEMs what is required to be an L5 driverless product. Additionally, ODD should be revisited on a set cadence to determine if updates are required based on improvements to AV technologies and capabilities.
Benchmark ISO 26262 <sup>68</sup> and ISO/IEC 27001:2013 <sup>69</sup>	26262 addresses functional safety in the development of electrical and electronic systems in vehicles and specifies ASIL risk requirements. <sup>70</sup> 27001 addresses requirements for information security management. Regulators and corporations should assess the standards and determine what is applicable for AFS legislation.

## Validation

Validation, in the context of this paper, evaluates product performance at the end of the development lifecycle against a defined set of requirements. The requirements are translated into use cases that emulate real world scenarios and, until recently, assumed there was a driver behind the wheel. Autonomy changes this assumption and calls into question how many use cases and corresponding derivatives are needed to sufficiently validate a driverless car. To illustrate the challenge this presents, revisit the 4-way intersection example from the introduction:

- Managing a 4-way stop sign with manually operated vehicles at 3 of the 4 positions, pedestrians crossing the intersection and a bicyclist pedaling through without observing the stop sign

<sup>66</sup> To learn more about smart cities, please see Ms. Lauren Goldenberg's publication: "3 Reasons Why We Need Smart Mobility Now," [www.libertyadvisorgroup.com/insight/smart-mobility-transportation/](http://www.libertyadvisorgroup.com/insight/smart-mobility-transportation/)

<sup>67</sup> V2X (vehicle to everything) pertains to vehicle connectivity with infrastructure (V2I), pedestrians (V2P), network (V2N), and other vehicles (V2V). It establishes the communication ecosystem for AVs and their surroundings

<sup>68</sup> Visit [www.iso.org/home.html](http://www.iso.org/home.html) to learn more about ISO 26262

<sup>69</sup> Visit <https://www.iso.org/standard/54534.html> to learn more about ISO/IEC 27001:2013

<sup>70</sup> Visit [www.iso.org/standard/51365.html](http://www.iso.org/standard/51365.html) and [www.sae.org/standards/content/j2980\\_201804/](http://www.sae.org/standards/content/j2980_201804/) to learn more about ASIL (automotive safety integrity level) risk classifications A through D

A reasonable requirement for this use case is that an AV must legally navigate the 4-way intersection and all possible derivatives, including:

- 1.0 Varying ratios of AVs to manually operated cars
  - 1.1.0 For each ratio, a varying number of the manually operated cars ignore the stop sign
- 2.0 Varying number of bicycles at each position
  - 2.1.0 For each bicycle scenario, a varying percentage of them ignore the stop sign
- 3.0 Varying number of pedestrians crossing the intersection at different points
  - 3.1.0 For each pedestrian scenario, a varying percentage of them ignore the stop sign
- 4.0 Scenarios 1.0 to 3.1.0 occur at night
- 5.0 Scenarios 1.0 to 4.0 occur during snowfall

Considering the above example and all possible situations with urban, suburban, rural and highway driving, it is unsurprising that the number use cases and derivatives could be in the tens of millions. To avoid running the gamut and still be able to validate, competitors are pursuing the following complementary approaches: edge cases, simulations and mileage accumulation. Table 7 discusses the pros and cons of each method.

**Table 7: Complementary Methods for AV Validation**

Method	Overview	Benefits	Drawbacks
Edge Cases	Test maximum and/or minimum parameters where extreme issues can occur.	Saves time and money by concentrating on the most severe issues.	Passes over intermediary situations that are less severe but occur more frequently; e.g., pedestrian suddenly runs into an intersection versus they are using a crosswalk as the light turns from yellow to red.
Simulations	Powerful algorithms and hardware create realistic environments to test AVs; e.g., Nvidia's DRIVE Constellation Simulation System. <sup>71</sup>	Simulations are easier to expand / scale than road tests, and testing in VR saves time and money.	As noted by Prof. P.Koopman and Mr. M.Wagner, there is bias risk in simulated data <sup>72</sup> as models are dependent on designers' inputs. For now, simulations cannot capture all nuances of driving.
Mileage Accumulation	Miles are collectively amassed through trials, tests and pilots on closed tracks, streets, highways, etc. After reaching a threshold, the total miles are a proxy for validating a majority of use-cases.	Road and closed course miles accelerate validation testing time while representing a cross section of real-world scenarios.	The Rand Corporation's 2016 analysis indicated that 100 AVs driving 25 MPH (average) and operating 24 hours / day / year need 275M failure-free miles to demonstrate ~1 fatality per 100M miles at a 95% CI; barring delays, issues, etc., this study would take ~12.5 years to complete. <sup>73</sup> Clearly, this is unrealistic for AV programs.  Another concern is the difference in miles; i.e., miles on a closed track in Arizona or the suburbs of Mountain View are not comparable to Chicago Loop miles in January. Without providing mileage categories and their respective composition, it is difficult to gauge the legitimacy of an aggregate number as a proxy for validation.

<sup>71</sup> Visit <https://bit.ly/2pJv8r9> to learn more about Nvidia's DRIVE Constellation Simulation System

<sup>72</sup> Koopman, P., and M. Wagner, "Challenges in Autonomous Vehicle Testing and Validation." Carnegie Mellon University, Edge Case Research LLC, 2016

<sup>73</sup> Kalra, N., and S.M. Paddock, "Driving to Safety." The Rand Corporation, Document Number: RR-1478-RC, 2016

To enable autonomous validation that leverages the right number of use cases and derivatives without encumbering driverless projects, the following hybrid framework is suggested:

- Use all three complementary approaches in conjunction with comprehensive use cases to reduce overall timelines, specifically:
  - Test edge cases in closed courses; in addition to timing, this allows for a safe testing environment when studying extreme situations
  - Use simulations to assess normal highway driving conditions
  - Streamline rural and suburban analyses via mileage accumulation and, when appropriate, simulations
  - Continue to employ comprehensive use cases and their derivatives for city driving and nuanced, but not severe, situations; e.g., merging onto a highway during snowfall

It is also recommended to continually reassess simulation testing's capability to undertake more complicated use cases, like city driving. This presents a future opportunity to accelerate validation and overall commercialization timeframes. Additionally, creating a centrally managed repository for use cases would standardize AV validation methods for all competitors. One possible solution is to establish an industry consortium for use cases and link them to regulatory standards.

### Consumer Trust

2018 has been witness to high profile autonomous incidents, for instance:

- Tempe, AZ (March 2018) – Pedestrian fatally injured after being struck by a self-driving Uber vehicle<sup>74</sup>
- Mountain View, CA (March 2018) – Driver fatally injured after Tesla Model X, operating in Autopilot mode, struck a concrete divider<sup>75</sup>

Additionally, data breaches and the unwanted sharing of personal information, e.g., Facebook scandal<sup>76</sup>, continue to make headlines and raise concerns about the privacy and security of data.

These serious episodes may have affected American sentiment towards AVs, which is best illustrated by AAA's May 2018 publication:<sup>77</sup>

- As of April 2018, 73% of U.S. drivers would be too afraid to ride in a fully self-driving vehicle; previous results were 63% (12/2017) and 78% (01/2017)
- Millennials had the largest change from 49% in 12/2017 to 64%

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<sup>74</sup> AZ Central, "Self-driving Uber vehicle strikes, kills 49-year-old woman in Tempe," <https://bit.ly/2ICqXFz>

<sup>75</sup> The Mercury News, "Report: Feds say Tesla driver didn't have hands on wheel at time of fatal Mountain View crash," <https://bayareane.ws/2v661li>

<sup>76</sup> NBC, "Facebook data harvesting scandal widens to 87 million people," <https://nbcnews.to/2JintbG>

<sup>77</sup> AAA, "American Trust in Autonomous Vehicles Slips," <https://newsroom.aaa.com/2018/05/aaa-american-trust-autonomous-vehicles-slips/>

In order for driverless cars to be adopted, autonomous players must be transparent about ongoing challenges and provide progress reports on a set cadence; e.g., Waymo and GM publish annual safety reports. Another option is to host virtual townhalls that allow participants to submit questions. For pilots, orchestrating a public kickoff event followed by quarterly or semiannual interactive sessions (held on weekends) can engage a community and be seen as a gesture of goodwill. The effort and cost to realize these suggestions is not trivial. That said, this upfront investment to restore and maintain the trust of the consumer has the potential to generate long-term and sustained benefits for autonomous players.

## **FINAL THOUGHTS**

Driverless vehicles present opportunities to expand mobility, reduce accidents and injuries, and create new business models. Numerous programs are underway, and there is line of sight on commercially available L4 and L5 cars driving on streets and highways. To achieve commercialization, however, it is recommended that autonomous players and regulators address the following items as early as possible:

- Develop federal autonomous standards and incorporate them into vehicle regulations to streamline the requirements that OEMs, hi-techs, and other interested parties must comply with in order to certify their products as roadworthy
- Form a consortium dedicated to creating and actively managing use cases for validation testing. Further, link the use cases to specific country regulations to facilitate the certification process
- Moderate ODD to support current capabilities and reevaluate it on a set cadence to determine if it can be expanded based on the progression of AV technologies. For example, if autonomous cars are presently unable to drive at night when it is snowing then establish this as an ODD limit. Once technology demonstrates that it can manage this driving scenario then the aforesaid limit can be modified.
- Study the effects of a multimodal driving environment where AVs gradually proliferate with emphasis on the early stages of adoption
- Look for ways to expand the capabilities of simulation testing in order to shorten commercialization timelines
- Establish autonomous business models with clear metrics, e.g., ROIC and % revenue from data monetization, to justify current CapEx levels and demonstrate that programs are underpinned by sound commercial principles



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