Self-Driving Cars: Disruptive or Incremental?

Abstract

Are self-driving cars in our near future? How Google’s self-driving car project disrupting the auto-industry? How are the auto manufacturers addressing this challenge, what suppliers will benefit from this technological revolution? Will the standards and regulations industries be ready? This article aims to answer some of these questions and describe an overall state of the market for self-driving vehicles.

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Introduction: The future of self-driving cars and its disruption to the automotive industry

There has been a flurry of news about self-driving cars in the media. As of the end of 2014, most of the biggest car manufacturers are building their own versions of self-driving cars. Google has moved its focus from highway-oriented autonomous driving to driving on local streets. Companies like Baidu have announced their intention to enter the self-driving car market. Everyone seems to have realized that self-driving cars are the future of automotive industry.

What is just becoming clear, however, is that a major split is occurring in the self-driving industry. This split centers on the approach that companies are taking toward achieving the goal of fully autonomous driving. On one side, we have auto manufacturers, who are adopting incremental approach: cars that are becoming more and more autonomous over the years. On the other side, we have Google which is aiming to release a fully autonomous vehicle straight to the market. This split is best articulated in the words of Carlos Ghosn, CEO of Nissan Motor Co., Ltd.:

*Autonomous drive is about relieving motorists of everyday tasks, particularly in congested or long-distance situations. The driver remains in control, at the wheel, of a car that is capable of doing more things automatically. Self-driving cars, by comparison, don’t require any human intervention – and remain a long-way from commercial reality. They are suitable only for tightly-controlled road environments, at slow speeds, and face a regulatory minefield.* [1]

It has become clear that Mr. Ghosn is speaking on behalf of all car manufacturers, laying out their vision of achieving fully autonomous vehicles. In his vision, drivers will remain behind the vehicle’s steering wheel, ready to take over control of the vehicle whenever the driving conditions aren’t conducive to autonomous driving. Initially, for example, cars may drive themselves only on highways and under good weather conditions. Over the years, however, cars will be able to take over under more and more conditions, eventually relieving the driver entirely of the need to steer, thus achieving the fully-autonomous status.

The unstated company that Mr. Ghosn is comparing his approach to is Google, which aims to release a fully autonomous car straight to the market. The difference in approach is best exemplified in the concept car Google recently unveiled: the car doesn’t have a steering wheel or gas/break pedals. In Google’s vision, there is no driver to take over the control of the vehicle: the vehicle has to drive itself regardless of the conditions.
As Mr. Ghosn states, Google’s approach is not only technically difficult, it also faces a number of regulatory issues. In this paper, we focus on a number of these issues.

- Section 1 presents a detailed roadmap for self-driving cars, both from the automakers’ and Google perspective.
- Section 2 presents a global overview of the market for self-driving vehicles.
- Section 3 focuses on the technology adopted by the automakers and Google.
- Section 4 dives into the legal and regulatory issues facing automakers and Google in their pursuit of fully autonomous cars.
- Section 5 presents the main expected winners and losers in the self-driving vehicle reality.
- Section 6 summarizes the main ideas and talks about the most likely unfolding scenarios for all players.
Section 1: Roadmap for Self-Driving Car

Automaker Roadmap for Self-Driving Car

The Automaker is adding Autonomous features in existing cars which help them monetize these features and as well as test in real conditions. Following Features are considered to lead us to self-driving cars

Automated Park Assist technology (Available Now)

- Intelligent Park Assist Technology is developed by Toyota and first appeared in Toyota Prius and then in Lexus in USA. This technology allows steering car automatically in tight parking spots. [2]

- Ford Automated Park Assist can be operated from outside of car to park itself. It is available in all Ford Car model after 2011 [3]

- European Company like BMW and Volkswagen also have produce initial version of Automated Park Assist Technology [3]

- Tesla announced Model D electric Car which has Park assist technology [4]


- Radar and Laser based Adaptive cruise control system has been in cars for last 15 years. This technology allows car to maintain a safe distance from vehicle ahead. Audi, Volkwagon, BMW, Toyota, Subaru has deployed in various variation in their vehicles.

- Super Cruise (GPS aided ACC): The GPS navigation intelligent guidance to ACC for predicting the entry and exit for freeway and helping ACC to take intelligent decision. It also integrates other sensor to take autonomous decision if a car cut into the lane ahead. [6]

Automated Highway Driving Assistant (2018)

- Toyota's Automated Highway Driving Assistant is a two-part system that takes over acceleration, deceleration and lane maintenance on highways. The AHDA system represents a more capable, next generation version of features that are available today. The Toyota cars with this features will be available by 2016 [7]

- BMW recently unveiled one of the most advanced driverless technology pilot projects in early 2014. BMW’s ActiveAssist is one of the most advanced auto-pilots unveiled to date, able to navigates its way at breath taking speeds on a test track avoiding all sorts of obstacles. While the commercial version of an autopilot is years away from availability to the public, the predicted time-line is 2018. [8]
Autonomous Highway Driving (2020)

In autonomous Highway driving, driver can fully cede control of all safety-critical functions in certain conditions. The car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so. This is same as Level 3 definition put forward by NHTSA. Currently Mercedes-Benz, Nissan, Volvo, BMW and Audi has test model, which are slated to go for production by 2020. [9]
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Name</th>
<th>Extent of Automation</th>
<th>Expected Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMW</td>
<td>Traffic Jam Assist</td>
<td>Assist in traffic jam situation up-to 25mph</td>
<td>2014</td>
</tr>
<tr>
<td>Cadillac</td>
<td>Super Cruise</td>
<td>Full Range Hands free</td>
<td>2018</td>
</tr>
<tr>
<td>Ford</td>
<td>Traffic Jam Assist</td>
<td>Stop and go Highway traffic</td>
<td>2017</td>
</tr>
<tr>
<td>Mercedes-Benz</td>
<td>Stop-and-Go Pilot</td>
<td>Stop and go Highway traffic</td>
<td>2014</td>
</tr>
<tr>
<td>Volvo</td>
<td>Traffic Jam Assist</td>
<td>Assist in traffic jam situation up-to 25mph</td>
<td>2018</td>
</tr>
<tr>
<td>Tesla</td>
<td>Auto Pilot</td>
<td>Detect and avoid pedestrian</td>
<td>2014</td>
</tr>
<tr>
<td>Audi</td>
<td>Auto Pilot</td>
<td>Take control of steering in Traffic Jam</td>
<td>2016</td>
</tr>
</tbody>
</table>
Google Roadmap for Self-Driving Vehicles

Google is building prototypes of fully autonomous vehicles that reject car makers' plans to gradually enhance existing cars with self-driving features. The Google self-driving car even doesn't have a steering wheel. Google will be ramping production version of their car by 2020. [11]

The long-term vision of the self-driving car involves moving from an ownership model to a service model, in which large numbers of people simply call cars whenever they want them. The new business model from Google favor Robo-Taxi model, where car ride will be provided on demand. Google also want to dominate market for providing Maps and software for the Self driving car.
Section 2: Global Overview for Market of Self Driving Car [12] [13]

**Market for automaker autonomous cars**
- The Automaker is already introducing various Autonomous features in the car which bring additional High margin revenues. It is the fastest growing market for Car Makers for next 10 years. Car makers are charging anywhere from $3000 on mid-range to $7000 on luxury models for these features.
  - Autonomous Features bring in $30B additional revenue in 2014
  - Autonomous features Expected to grow to $250B by 2030
  - Autonomous Features revenue will grow 15% CAGR for 2014-2024
  - 50% of the cars will be Autonomous Car by 2035

**Market for Self Driving Cars**
- Google SDC is in prototype stage in 2014
- SDC will bring in additional $80B revenue by 2030
- 25% of car by 2035 will be SDC
- New entrant Google will capture 8% of total Car market by 2035

**Global Market for Cars**
- Total cars sold globally will cross 90 Million units in 2014
- Autonomous cars volume will cross 15 Million units in 2014
- Total cars in use globally will exceed 900 Million in 2014
- Total cars in use globally will exceed 2 Billion by 2030
- 50% of the car sold by 2030 will be either Autonomous or Self driving cars
- The Volume will grow 15-17% CAGR over next 10 years for Autonomous and Self driving cars
Global Market for Cars by Region [14]

- US and Europe will lead early adoption of Autonomous and SDC cars
- China will take over Europe as second biggest Market for Autonomous and SDC Cars by 2030

SDC Market Share Forecast by Region by IHS (2030)

- USA: 27%
- Europe: 29%
- China: 24%
- Others: 20%

Bar chart showing projections for Rest of World, China, Europe, and North America from 2014 to 2036.
Key Hurdles for SDC Penetration [14]

One of the key hurdles for Google Self driving car is cost. It cost $200,000 to build SDC in 2014. By next year it will come down to $50,000. There will be a rapid decline in building SDC car as volume increase and technology matures. The adoption will rise rapidly once cost of SDC features will be less than $7000.
Component Suppliers share of Self Driving Car [9]

As per Lux Research, Self-driving technology will create a new opportunity for the automotive value chain, and bringing in outsiders to join incumbents looking to capitalize on a new market. Software will be the biggest autonomous vehicle value chain winner, with $25 billion in revenues in 2030, a 28% CAGR.

Optical cameras and radar sensors will amount to $8.7-billion and $5.9-billion opportunities in 2020.

Computers will be the biggest hardware opportunity on-board autonomous cars, amounting to a $13-billion opportunity.

Prospective suppliers in the value chain should anticipate significant changes both inside and outside the vehicle over time, inevitably creating opportunities for new entrants.

The electronics and software will become 50% of car cost by 2030.
The Impact on Adjacent Markets

Auto Insurance Industry
- $200B Auto Insurance industry will transformed as Premium will go down due to less accidents. It is estimated that the accidents will be go down by 90% as autonomous car become widespread.
- Since Self-driving car cannot be manipulated, Most of the crashes will result in to product liability claims. The product manufacturer will sell master policies with SDC to cover these claims.

Rental Car Industry
- Rental Car Industry, Taxi Service and Ride share will merged and evolve into Robo-Taxi Model
- Once SDC become popular, People will move toward fractional ownership or “Car sharing Subscription service. The service will provide flexibility to summon cars without drivers to wherever you are and have them take you where you want to go.

Auto Service Industry
- Auto Service industry will be consolidated into few big automated service companies
Section 3: Technologies behind Self-Driving Car

Google’s Self-Driving Car

Google’s driverless car uses a lot of very advanced hardware. It needs to be able to detect and avoid obstacles just like other cars as well as understand if it is a curb or a pedestrian or cyclist. Google’s driverless car uses a host of detection technologies – sonar devices, stereo cameras, lasers and radar. [15]

The Velodyne 64-beam laser (LIDAR – light detection and ranging) mounted on the roof of the Google car is at the heart of its object detection. It measures the distance between the vehicle and the object surfaces facing the vehicle by spinning on its axis and changing its pitch and takes 1.3 million readings per second. The laser has a horizontal field of view of 360 degrees, a vertical field of view of approximately 30 degrees, and a maximum distance of 100 meters.

The radar has a horizontal field of view of 60 degrees for the near beam, 30 degrees for the far beam, and a maximum distance of 200 meters. The radar mounted on the front and back bumper of the car is used to monitor the speed of other cars in real-time. Based on this
information, to prevent an impact, the Google car adjusts the throttle and brakes continuously. It is essentially an adaptive cruise control.

The sonar has a horizontal field of view of ~60 degrees for a maximum distance of 6m. The stereo cameras have an overlapping region with a horizontal field of view of ~50 degrees, a vertical field of view of ~10 degrees, and a maximum distance of 30m.

Since both radar and sonar sensor have a narrow field of view, the car knows things are about to get messy if another vehicle crosses the radar and sonar beams. This signal is used to swerve the vehicle or apply the brakes.

Google mounts regular cameras around the exterior of the car in pairs with a small separation between them. The overlapping fields of view create a parallax not unlike your own eyes that allow the system to track an object’s distance in real time. As long as it has been spotted by more than one camera, the car knows where it is. These stereo cameras have a 50-degree field of view, but they’re only accurate up to about 30 meters. [15]

Google has built the entirety of California’s road system (about 172,000 miles) in software, along with accurate simulations of traffic, pedestrians, weather, and so on. Google has built the data needed for their cars to process by mapping each road that their cars will drive on
by ultra-precise digitizations of the terrain. Google’s software integrates all the data from these remote sensing systems (~ 1GB per second) to build a map of the car’s position. Its algorithms then process data based on observing deltas.

To summarize, Google has no intention to challenge the auto makers on their playing field. It will change the game and introduce a disruption in the auto-industry by providing various technologies and services rather than selling cars. It plans to release these technologies within 4 years.

- Autonomous mobility services such as “robo-taxi” (this has the potential of reducing the car ownership by a factor of 3)
- Producing and selling specialized maps and software
- Technology for monitoring systems to reduce congestion
- Technology for robotics (probabilistic inference, planning & search, localization, tracking & control)

Technologies used by Auto-makers:

The auto-manufacturers are focusing on driver assistance systems and expect to have someone in the driver seat to take charge in between “self-driving” modes. Their strategy is to enhance the driving experience in the automobile and remove the “stress” aspect of it. Another key differentiation in technology is that mapping of the terrain in which the car drives is done “real-time” instead of the “delta” approach that Google is taking starting with pre-mapped routes and terrain information.

Here are some interesting technologies available which shows the incremental approach to self-driving cars by auto manufacturers.

**Lane Change Assist:**
This driver assistance system consists of two radar units. The devices are invisibly mounted in the corners of the rear bumper. One sensor operates as system master, the second unit is configured as slave. By using a private data link, the data of both radars are combined in a sensor data fusion tracking algorithm. This technology is in volume production since Q1/2006 and is used for example by Audi, Volkswagen, BMW, Porsche and Mazda. [16]
Parking Assist:
The Fully Assisted Parking Aid is now available in Ford. It can now park cars in tight spaces, backs into perpendicular and angled parking spaces. This is particularly much needed in Europe and Asia. This technology uses ultrasonic sensors to scan for an open parking space at speeds as high as 19mp. When the car finds a suitable spot, it alerts the driver, who can stay in the car or get out and use a remote to finish the parking job. The car then backs itself into the parking space.

Other auto-makers such as Mercedes Benz S-Class and E-Class sedans also have similar technology available today. [17]

Adaptive Cruise Control:
Adaptive cruise control (ACC) is an intelligent form of cruise control that slows down and speeds up automatically to keep pace with the car in front of you. The distance is measured
by a small radar unit behind the front grille or under the bumper. Some cars employ a laser, while some use an optical system based on stereoscopic cameras.

ACC is ideal for stop-and-go traffic and rush hour commuting that swings from 60 mph to a standstill. Regardless of the technology, ACC works day and night, but its abilities are hampered by heavy rain, fog, or snow. On an autonomous driving car, ACC needs to track the car in front but also cars in adjacent lanes in case a lane change becomes necessary. [18]

**Vehicle-Vehicle Communication:**
On Feb 6, 2014, Obama Administration announced that it plans to push the V2V communications technology forward. Cars will talk to other cars, exchanging data and alerting drivers to potential collisions. They’ll talk to sensors on signs on stoplights, bus stops, even ones embedded in the roads to get traffic updates and rerouting alerts. And they’ll communicate with your house, office, and smart devices, acting as a digital assistant, gathering information you need to go about your day.

Vehicle-to-vehicle (V2V) communications comprises a wireless network where automobiles send messages to each other with information about what they’re doing. This data would
include speed, location, and direction of travel, braking, and loss of stability. Vehicle-to-vehicle technology uses dedicated short-range communications (DSRC), a standard set forth by bodies like FCC and ISO. Sometimes it’s described as being a WiFi network because one of the possible frequencies is 5.9GHz, which is used by WiFi, but it’s more accurate to say “WiFi-like.” The range is up to 300 meters or 1000 feet or about 10 seconds at highway speeds (not 3 seconds as some reports say).

V2V would be a mesh network, meaning every node (car, smart traffic signal, etc.) could send, capture and retransmit signals. Five to 10 hops on the network would gather traffic conditions a mile ahead. That’s enough time for even the most distracted driver to take his foot off the gas. [19]

Another technology used in this is Cloud based computing. Automobiles today are already packed with an impressive amount of processing power, because some 100 million lines of software code help run the typical luxury vehicle. But as connected cars before were sophisticated rolling wired devices, the amount of information flowing back and forth from them will skyrocket. And so they will demand for the cloud’s scalability and storage capabilities.
In summary, auto-manufacturers predict that fully autonomous vehicles may not reach mainstream for at least another decade but incremental technologies are already in prototype phase and some have launched. They are betting and working on incremental automation technologies but not a driverless future.

Industries that will benefit from Self-Driving Cars:

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Purpose</th>
<th>Key Players</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LIDAR</strong></td>
<td>Obstacle detection and avoidance</td>
<td>Velodyne, Quanergy, Leddar Tech, ASCar Inc</td>
</tr>
<tr>
<td><strong>Imaging Sensors</strong></td>
<td>Viewing objects, Reading traffic signs, Reading speed limits</td>
<td>Omnivision, ON Semiconductor, SONY</td>
</tr>
<tr>
<td><strong>Compute Power</strong></td>
<td>Si with greater compute power, Low Power Consumption</td>
<td>Intel, Qualcomm</td>
</tr>
<tr>
<td><strong>Artificial Intelligence &amp; Robotics</strong></td>
<td>GPS, Localization Maps, Cognitive Learning, Augmented Reality</td>
<td>Google, Trimble, CSR, Samsung, Facebook</td>
</tr>
</tbody>
</table>
Section 4: Challenges for Self-Driving Vehicles

Regulatory Landscape

Previous to 2011, no existing state or federal legislation could be cited as explicitly prohibiting self-driving cars. Auto manufacturers continued to innovate on and incrementally roll-out driver assistance features in their premium class vehicles with no perceived need - publically, politically, or within the greater auto industry ecosystem (e.g. including the insurance companies) itself - to craft regulations governing their legality. Features like self-pumping brakes, adaptive cruise control, and lane departure warning systems happily co-existed with existing regulatory terminology like “driver” or “vehicle operator” that did not even explicitly identify (nor likely ever anticipate the need to state) that the operator in question should be a human being.

Figure 1: Automated Vehicles Are Probably Legal in the United States

A detailed study of the Geneva Convention on Road Traffic, the Federal Motor Vehicle Safety Standards, and the motor vehicle codes of all 50 states finds many provisions that may complicate or constrain automated driving - but few if any that would outright prohibit it. Curiously, recent state laws intended to clarify the legal status of automated driving actually fail to address many of these driver-relevant provisions.

Near-term recommendations:
1. Experts to develop common vocabularies and definitions — ongoing
2. United States to monitor proceedings re Vienna Convention on Road Traffic
3. NHTSA to provide public guidance on potential future actions — ongoing
4. States to closely examine current vehicle codes for automation implications
5. Lawyers to study trucks, buses, tanks, minivans, sport utility vehicles, and powered model cars

For a model state bill, see part 6.3 of the paper.

In November 2012, Bryant Walker Smith, an affiliate scholar at the Center for Internet and Society at Stanford Law School (and an assistant professor at the University of South Carolina School of Law), painstakingly examined the statutes of The Geneva Convention on Road Traffic, the Motor Vehicle Codes of each U.S. state, and the Federal Motor Vehicle Safety Standards, for existing regulations that might impact the status of autonomous vehicles. He summarized and published his titular conclusion in the academic paper “Automated Vehicles are Probably Legal in the United States” [20] with the accompanying poster (included above) highlighting the numerous questions still open to interpretation.

State Legislative Action

However, in 2011 no attempt to even aggregate and codify the legislative gaps even existed. Companies with more ambitious and immediate agendas for autonomous vehicle testing had to be satisfied operating in this vacuum of robust inquiry. Google, ill-contented with millions in R&D investment already in play, took the issue into its own hands and lobbied the Nevada state legislature to pass bill SB-140, which - whether by design or not - opened the door to a flurry of state congressional activity summarized in the figure below:

Figure 2: Status of Legislative Action by States

http://cyberlaw.stanford.edu/wiki/index.php/Automated_Driving:_Legislative_and_Regulatory_Action