# Self-Driving Cars: Disruptive or Incremental?

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Are self-driving cars in our near future? In what ways do Google's self-driving car project disrupt 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 paper aims to answer some of these questions and describe an overall state of the market for self-driving vehicles.

# I. THE FUTURE OF SELF-DRIVING CARS AND ITS DISRUPTION TO THE AUTOMO-TIVE INDUSTRY

There has recently been a flurry of news about self-driving cars in the media. As of the end of 2014, most of the biggest car manufacturers have been building their own versions of self-driving cars. Google has moved its focus from highway-oriented autonomous driving to driving on local streets. Companies such as Baidu, a Chinese web services corporation, 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. This new prospect, however, is elucidating the major split that is occurring in the self-driving industry. This separation originates in the approach that companies are taking to achieve the goal of fully autonomous driving. On one side, auto manufacturers are adopting the incremental approach; cars are becoming more and more autonomous over the years. On the other side, Google 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<sup>1</sup>."

Mr. Ghosn speaks on behalf of all car manufacturers to lay out their vision of achieving fully autonomous vehicles. In his vision, drivers will remain behind the vehicle steering wheel, ready to take over control of the vehicle whenever the driving conditions are not 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 self-sufficient under more and more conditions and will eventually relieve the driver entirely of the need to steer, thus achieving the fully autonomous status. Mr. Ghosn is implicitly comparing his approach to 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 does not have a steering wheel or gas and 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. In Section I, we present a detailed roadmap for self-driving cars from both the automakers' and Google's perspectives. In Section II, we present a global overview of the market for self-driving vehicles. In Section III, we focus on the technology adopted by the automakers and Google. In Section IV, we dive into the legal and regulatory issues

facing automakers and Google in their pursuit of fully autonomous cars. In Section V, we present the main expected winners and losers in the self-driving vehicle reality. In Section VI, we summarize the main ideas and talk about the most likely unfolding scenarios for all players.

# II. ROADMAP FOR SELF-DRIVING CARS

#### Automaker Roadmap for Self-Driving Cars

The automaker will incrementally add autonomous features in existing cars, which allows them to monetize these features and as well as test them in real conditions. The following features are considered as incremental changes that may lead us to the development of self-driving cars.



\*Image Courtesy of Nissan

#### Automated Park Assist Technology (Available Now)

Intelligent park assist technology was developed by Toyota. In the United States, this feature first appeared in the Toyota Prius, followed by the Lexus. This technology allows the car to automatically steer itself into tight parking spots<sup>2</sup>. The Ford automated park assist can be operated from outside of the car. It is available in all Ford models manufactured after 20113. European companies such as BMW and Volkswagen have also produced initial versions of automated park assist technology<sup>3</sup>. Most recently, Tesla announced that their Model D electric car will include park assist technology<sup>4</sup>.

#### Adaptive Cruise Control Technology (2016)<sup>5</sup>

Radar and laser based adaptive cruise control (ACC) systems have been installed in cars for the last fifteen years. This technology allows cars to maintain a safe distance from the vehicle in front of them. Audi, Volkswagen, BMW, Toyota, and Subaru have deployed this technology in a variety of ways in their vehicles. Super Cruise is a GPS oriented intelligent navigation technology that predicts freeway entries and exits; it aids ACC in assessing freeway conditions and making intelligent decisions. It also integrates additional sensors in order to make autonomous decisions if a car cuts into the lane ahead<sup>6</sup>.

#### 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 feature will be available by 2016<sup>7</sup>. BMW recently unveiled one of the most advanced driverless technology pilot projects in early 2014. BMW's ActiveAssist is one of the most advanced autopilots unveiled to date. It is able to navigate its way at breathtaking speeds on a test track, avoiding all obstacles. While the commercial version of an autopilot is years away from availability to the public, the predicted time-line is 2018<sup>8</sup>.

#### Autonomous Highway Driving (2020)

In autonomous highway driving, the 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 identical to the Level 3 definition put forward by NHTSA. Currently, Mercedes-Benz, Nissan, Volvo, BMW, and Audi have test models, which are slated to go to production by 2020<sup>9</sup>.

Manufacturer	Product Name	Extent of Automation	Expected Introduction
BMW	Traffic Jam Assist	Assist in traffic jam situations up to 25mph	2014
Cadillac	Super Cruise	Full range hands- free	2018
Ford	Traffic Jam Assist	Stop and go highway traffic	2017
Mercedes-Benz	Stop-and-Go Pilot	Stop and go highway traffic	2014
Volvo	Traffic Jam Assist	Assist in traffic jam situations up to 25mph	2018
Tesla	Auto Pilot	Detect and avoid pedestrians	2014
Audi	Auto Pilot	Take control of steering in traffic jam	2016

#### Current Announcement Of Autonomous Features<sup>10</sup>

Table 1: Announcement of Autonomous Features<sup>10</sup>

#### Google Roadmap For Self-Driving Vehicles

Google is building prototypes of fully autonomous vehicles that reject carmakers' plans to gradually enhance existing cars with self-driving features. The Google self-driving car does not even have a steering wheel. Google will ramp up the production version of their car by 2020<sup>11</sup>. 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 favors the Robo-Taxi model, where car rides will be provided on demand. Google also wants to dominate the market for providing maps and software for the self-driving car.

# III. GLOBAL OVERVIEW FOR MARKET OF SELF-DRIVING CAR<sup>12,13</sup>

#### Market For Automaker Autonomous Cars

The automaker is already introducing various autonomous features in the car, which bring additional high margin revenues. It is projected to be the fastest growing market for carmakers for next ten years. Carmakers are charging anywhere from \$3000 on mid-range to \$7000 on luxury models for these features. Autonomous features will bring in \$30B in additional revenue in 2014. Additionally, autonomous features are expected to grow to \$250B by 2030. The revenue from autonomous features will grow 15% in Compound Annual Growth Rate (CAGR) from 2014 to 2024. Finally, 50% of cars are projected to be autonomous by 2035.

#### Market For Self-Driving Cars

The Google self-driving car is in the prototype stage as of 2014. The vehicles are projected to bring in an additional \$80B in revenue by 2030. Additionally, 25% of cars will be self-driving by 2030. The new entrant, Google, is expected to capture 8% of the total car market by 2035.

#### **Global Market For Cars**

The number of total cars sold globally will pass 90 million units in 2014. The number of autonomous cars will exceed 15 million units in 2014. Additionally, the total number cars in use globally will exceed 900 million in 2014. By 2030, however, the number of cars in use globally will exceed 2 billion. It is estimated that 50% of the cars sold by 2030 will be either autonomous or self-driving cars. The number of autonomous and self-driving cars will grow by 15-17% in CAGR over the next ten years.



Figure 1: Global Market For Cars

#### **Global Market For Cars By Region**

The United States and Europe will lead in the early adoption of autonomous and self-driving cars. However, China is projected to take over Europe as the second biggest market for the vehicles by 2030.







Figure 3: SDC Market Share Forecast by Region by IHS (2013)

#### **Key Hurdles For SDC Penetration**

One of the key hurdles for Google's self-driving car is cost. It cost \$200,000 to build a self-driving car in 2014. By 2015, these costs are expected to decrease to \$50,000. There will be a rapid decline in building self-driving cars as volume increases and technology matures. The adoption will rapidly rise once cost of self-driving car features will be less than \$7000.



Figure 5: SDC Volume Forecast by IHS

#### Component Suppliers Share Of Self-Driving Cars<sup>14</sup>

According to Lux Research, self-driving technology will create a new opportunity for the automotive value chain. It will bring 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 on board autonomous cars, amounting to a \$13-billion opportunity. Prospective suppliers in the value chain should anticipate significant changes in both the inside and outside of the vehicle over time, inevitably creating opportunities for new entrants. The electronics and software will become 50% of car cost by 2030.



Figure 6: Behind-the-Scenes Software Will Capture the Largest Share of SDC Opportunity

#### The Impact On Adjacent Markets

The \$200 billion auto insurance industry will be transformed as premiums decline due to fewer accidents. It is estimated that car accidents will decline by 90% as autonomous cars become widespread. Because self-driving cars cannot be manipulated, most of the crashes will result in product liability claims. The product manufacturer will sell master policies with SDC to cover these claims. Secondly, the rental car, taxi service and rideshare industries will merge and evolve into Robo-Taxi Model industries. Once SDCs become popular, people will move toward fractional ownership or "car sharing subscription service." The service will provide flexibility to summon cars without drivers to your location and have them take you where you want to go. Finally, the auto service industry will be consolidated into a few big automated service companies.

# IV. TECHNOLOGIES BEHIND SELF-DRIVING CARS

#### 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, as well as understand if an object is a curb, a pedestrian or cyclist. Google's driverless car uses a host of detection technologies such as sonar devices, stereo cameras, lasers and radar<sup>15</sup>. 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 object surfaces facing the vehicle by spinning on its axis, changing its pitch and taking 1.3 million readings per second. The laser has a 360-degree horizontal field of view, a 30-degree vertical field of view and a maximum distance of 100 meters. The radar has a horizontal field of view of 60 degrees for the near beam and 30 degrees for the far beam, as well as 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, the Google car adjusts the throttle and brakes continuously to prevent an impact. It is essentially an adaptive cruise control. The sonar has a 60-degree horizontal field of view for a maximum distance of 6 meters. The stereo cameras have an overlapping region with a 50-degree horizontal field of view, a 10-degree vertical field of view, and a maximum distance of 30 meters.

Both the radar and sonar sensors have a narrow field of view; therefore, the car knows things are about to get messy if another vehicle crosses both beams. This signal is used to swerve the vehicle or apply the brakes. Google mounts regular cameras around the exterior of the car in spaced-out pairs. 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 are only accurate up to about 30 meters<sup>15</sup>.



Figure 7: Google's Self-Driving Car (Source: Google)

Google has built the entirety of California's road system (about 172,000 miles) in software, along with accurate simulations of traffic, pedestrians and weather. Google has built the data the cars need to process by mapping each road that the cars will drive on by ultra-precise digitization 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.



Figure 8: Google's Road Map Simulation (Source: Google)

To summarize, Google has no intention of challenging the automakers 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 the following four technologies within four years:

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

#### **Technologies Used By Automakers**

Auto manufacturers are focused 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. Mapping of the terrain in which the car drives is done in "real-time" as opposed to using the "delta" approach that Google is taking, starting with pre-mapped routes and terrain information. The following sections cover some interest-ing technologies available, illustrating 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<sup>16</sup>.



Figure 9: Lane Change Assist Simulation (Source: Audi)

#### **Parking Assist**

Fully Assisted Parking Aid is now available in Ford. It can now park cars in tight spaces and back 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 19mph. 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 automakers such as Mercedes also have similar technology available in their cars<sup>17</sup>.

#### 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. A small radar unit behind the front grille or under the bumper measures the distance. Some cars employ a laser while others 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. In an autonomous driving car, ACC needs to track not only the car in front but also the cars in adjacent lanes in case a lane change becomes necessary<sup>18</sup>.

#### 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 will talk to sensors on signs on stoplights and bus stops and even sensors embedded in the roads to get traffic updates and rerouting alerts. They will 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 comprise a wireless network where automobiles send messages to each other with information about what they are doing. This data includes speed, location, 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 is described as a WiFi network because one of the possible frequencies is 5.9GHz; this frequency is used by WiFi, but it is more accurate to say that DSRC is "WiFi-like." The range is up to 300 meters or 1000 feet for about ten seconds at highway speeds (not three 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 ten 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<sup>19</sup>.



Figure 10: Vehicle-to-Vehicle Communication (Source: United States Department of Transportation) 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. Therefore, they will be an increased 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.

Technologies	Purpose	Key Players
LIDAR	Obstacle detection and avoidance	<u>Velodyne</u> Quanergy Leddar Tech ASCar Inc
Imaging Sensors	Viewing objects Reading traffic signs Reading speed limits	Omnivision ON Semiconductor SONY
Compute Power	Si with greater compute power Low Power Consumption	Intel Qualcomm
Big Data & Security	Data Security Systems Traffic Monitoring Systems Communication Systems (V2V)	Google IBM GM, BMW, Daimler, Honda, Audi, Volvo
Artificial Intelligence & Robotics	GPS, Localization Maps, Cognitive Learning, Augmented Reality	Google Trimble CSR Samsung Facebook

#### Industries That Will Benefit From Self-Driving Cars

Table 2: Industries That Will Benefit From Self-Driving Cars

#### V. 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 such as 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 11: Automated Vehicles Are Probably Legal in the United States (Graphic by Sien Susumu Riviera)

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"<sup>20</sup> 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 12: Status of Legislative Action by States (Source: Driverless Transportation)

	Bill		Year	License	Routes	Driver's Seat Occupant <sup>(1)</sup>	Distracted Driving Ban <sup>(2)</sup>	Vehicle OEM Liability	Safety & Operating Standards
NV	AB 511 SB 140	1	2011	Testing for now	Designate d state highways	Licensed driver & passenger required	Exempt when autonomous	Exempt	TBD by NV DOT
CA	SB 1298	1	2012	Mandate for testing and public operation	Not explicitly restricted	Licensed driver required	Exempt when autonomous	Not exempt	Due from CA DMV before Jan 2015 (3)
FL	HB 1207 SB 1768		2012	Testing only	Not explicitly restricted	Licensed driver required		Exempt	Drafter report was due Feb 2014
MI	SB 169	×	2013	Testing only	Not explicitly restricted	Licensed driver required			MI DOT to submit report by Feb 2016
со	SB 13-016	×	2013	Testing only		Licensed driver required with kill switch	Exempt when autonomous		Bill indefinitely tabled by Sen. Brophy citing transportation committee opposition

(1) Driver's seat occupant must be a licensed driver with access to steering, throttle, and brake controls.

(2) Ban on use of cell phones and texting while driver is operating the vehicle.

(3) Intent for public operation by June 2015.

Table 3: Summary of State Legislative Activity

#### Nevada Sb-140 & Ab-511

Google began its Nevada campaign with the hiring of Las Vegas based lobbyist David Goldwater, tasked with shepherding two bills through the state legislature<sup>21</sup>:

- SB-140: allowing for the licensing of autonomous vehicles on designated Nevada highways for testing purposes.
- AB-511: granting the driver an exemption to the "distracted driving ban" against texting when the vehicle is not under manual operation.

Early socialization of the technology simplified the passage of the bills; state lawmakers, including the governor, were given rides in Google's "fleet" of modified Prius vehicles and came away as enthusiastic backers. The bills passed easily; opposition from automakers was unable to affect the outcomes. As with other state bills to follow, the Nevada legislation set high level directives and stipulated desired outcomes without specifying actual procedures. Specifics of how to author regulations for issuing licenses were left to the state Department of Transportation to complete later, leaving many state employees scratching their heads on how to write regulations for a technology they knew basically nothing about. However, Google found an enthusiastic ally in David Breslow, the head of the Nevada DMV. Breslow directed his staff to work closely with Google employees in crafting the regulations. Within nine months, the first autonomous vehicle license was issued to a Google car, complete with an infinity branded symbol on its license plate.

#### California Sb-1298

In 2012, Google forged ahead again, this time in California, with a more ambitious agenda in mind. The playbook was essentially the same and the outcome equally predictable, now buoyed with a sense of urgency created by the quick passage of the Nevada bills. California lawmakers were primed to act and state senator Alex Padilla authored SB-1298. Opposition from the Alliance of Automobile Manufacturers was overcome and Governor Jerry Brown signed the bill into law in November 2012. Of specific note are the following points:

- SB-1298 contains a mandate not only for licensing for testing purposes, but also for public operation.
- SB-1298 contains language opening the door to the possibility of vehicles without a licensed human driver standing by. This is in opposition to the Nevada bill, which not only required a licensed human driver be available behind the wheel, but that a 2nd licensed driver be present as a passenger.
- SB-1298 directs the California DMV to complete detailed regulation by the end of 2014, with the intent of review and revisions leading to public licensing by June of 2015.

An important test in the gap between imprecise legislative intent and actual regulatory behavior occurred in May of 2014, when Google proposed a new version of its prototype vehicle without a steering wheel for testing in California. This eventuality had been foreseen by Howard Posner, who in 2012 as a member of the California assembly's transportation committee had unsuccessfully suggested the bill be altered to explicitly require a human driver present in the car<sup>22</sup>. The California DMV, however, insisted on a steering wheel and the presence of a human driver. In September 2014, Google relented and installed a "temporary" steering wheel<sup>23</sup>. Although legislative action had been very successfully steered by Google in both Nevada and California, state regulatory departments tasked with the actual implementation of the laws maintain degrees of autonomy—if perhaps only in delaying certain aspects of the technological momentum until fully satisfied.

#### Michigan Sb-169 & Colorado Sb-13-016

Also worthy of brief discussion are the 2013 legislative actions proposed in Michigan and Colorado. Unlike the bills in Nevada and California, these bills did not receive support from Google and it seems relatively clear why; neither advances the precedent already established in California. In fact, both bills—while perhaps more permissive that Nevada's SB-140, which permitted testing only on designated state highways—pulled back on important advancements in California: the mandate for public operation and language permissive for a future of autonomous operation without a licensed driver present. Google, which had initially participated in the Michigan's SB-169, publically pulled away its support citing the testing-only limitations. Regardless, SB-169 passed, with the full weight and backing of its champion Governor Rick Snyder and the approval of Detroit's "big three" and Toyota<sup>24</sup>. On the other hand, in Colorado, SB-13-016 was "indefinitely withdrawn" by its sponsor, Republican state senator Greg Brophy. Brophy cited Google's influence on Democratic opponents on the state senate's transportation committee as the reason for his decision<sup>25</sup>.

### Federal Regulation By Nhtsa

On May 13, 2013, NHTSA (National Highway Transportation and Safety Administration) released a "Preliminary Statement of Policy" regarding self-driving cars, primarily to act as a set of guidelines for states to follow. Perhaps the potential for contradictory legislation by individual states, and the resulting chaos this could introduce (into a national vehicular code system previously harmonized by decades of cross state agreements honoring each other's licenses), was a call to action.NHTSA's policy statement establishes a definition of autonomous vehicles around four levels, shown below.

Level	Definition	Example / Explanation
Level 0	No Automation	Driver always in complete control
Level 1	Function-specific Automation	E.g. stability control or brake assist
Level 2	Combined Function Automation	Two or more automated functions
Level 3	Limited Self-Driving Automation	Google car circa 2013, BMW_X5 w/traffic jam assist
Level 4	Full Self-Driving Automation	Driver not available at any time

Table 4: NHTSA Policy Statement

Of note is the classification of Google's test vehicle at the time, as only Level 3. NHTSA essentially did not recognize any existing technology of being capable of (or approved for) Level 4 operation, a finding in line with other recommendations issued in their statement. These included the following:

- A statement encouraging states to allow testing of self-driving cars.
- Suggestions that states should not include provisions for public operation at this time.
- However, in the event of a state not heeding the recommendation against public operation, that specific provisions for a licensed driver in the driver's seat be included.
- That special training and licensing requirements be met for human operators of self-driving vehicles.

The NHTSA statement also indicates the agency's commitment to running their own technology study, scheduled to conclude in 2017. They explicitly mention the inclusion of V2V ("vehicle to vehicle") and V2I ("vehicle to infrastructure") technology in the study, a clear indication of their intent to evaluate the technological directions of both Google as well as the traditional automakers. It seems possible that the response of the California DMV to Google's steering wheel free prototype was made with one eye focused on staying within some level of current compliance with NHTSA's policy statement.

#### The Insurance Industry

Questions of liability in an accident involving at least one party operated by a self-driving vehicle are also unclear and open to interpretation. Nevada's regulations indicate the operator who pushes the start button remains liable<sup>26</sup>, a resolution only possible in conjunction with regulations requiring a licensed driver to be present in the vehicle. Michigan's SB-169 states nothing to otherwise contradict the state's existing "Owner Liability Law" placing liability with the vehicle owner. But SB-169 does go on to absolve auto manufacturers of product liability for conversions of standard automobiles to autonomous driving vehicles by a third party<sup>27</sup>. The Alliance of Automobile Manufacturers unsuccessfully petitioned Governor Brown of California not to sign into law SB-1298 over similar concerns of not being absolved from product liability if one of their vehicles, modified for self-driving by another party (i.e. Google), were to be involved in an accident, and publically voiced their displeasure with the bill<sup>28</sup>.

Ultimately, however, it should not be forgotten that basic auto insurance liability practice dictates that

insurance policies "follow the vehicle" and not the driver. In this sense at least, the unit of issuance of automotive insurance policies line up well with self-driving cars. But when a car meets the standards of NHTSA's Level 4 autonomous vehicle, what is actually being insured, the vehicle or the manufacturer of the self-driving tech? In the eyes of many, the logical conclusion is the latter. In essence, this predicts a future model of liability coverage that moves from a per vehicle policy to a manufacturer product liability policy<sup>29</sup>—a cost which would be passed on to the consumer by being built into the sticker price of the vehicle itself. Even in a scenario where market forces conspire to keep individual vehicle policies in place, the automobile insurance industry could still face a complete disruption of its current business model. Predictions of a 90% reduction in vehicle accidents in a world fully populated with Level 4 autonomous vehicles would have enormous revenue implications.

Total Crashes per year in U.S. <sup>11</sup>	5.5 million
% human cause as primary factor <sup>12</sup>	93%
Economic Costs of U.S. Crashes <sup>13</sup>	\$300 billion
% of U.S. GDP <sup>14</sup>	2%
Total Fatal & Inurious Crashes per Year in U.S.	2.22 million
Fatal Crashes per Year in U.S. <sup>15</sup>	32,367
% of fatal crashes involving alcohol	31%
% involving speeding	30%
% involving distracted driver	21%
% involving failure to keep in proper lane	14%
% involving failure to yield right-of-way	11%
% involving wet road surface	11%
% involving erratic vehicle operation	9%
% involving inexperience or overcorrecting	8%
% involving drugs	7%
% involving ice, snow, debris, or other slippery surface	3.7%
% involving fatigued or sleeping driver	2.5%
% involving other prohibited driver errors	21%
(e.g. improper following, driving on shoulder, wrong	
aide of read improvement type improvement reading ate)	

side of road, improper turn, improper passing, etc.)

Figure 13: Human Cause as Primary Factor in Accidents

According to the NAIC (National Association of Insurance Commissioners), the US auto insurance industry collected roughly \$200B in insurance premiums<sup>30</sup>—87% in private policies and 13% in commercial. Of this windfall, 68% of premium cost was applied to paying accident claims, including actual cost of repairs, determination of fault and rental replacements. The cost breakdown of collected premiums is illustrated in the figure below.



Figure 14: Breakdown of Auto Insurance Premiums<sup>31</sup>

Assuming these ratios hold true, a 90% reduction in accidents and the resulting 90% costs in claims could theoretically reduce the auto insurance industry to a \$20B industry, leaving little room for today's larger insurance firms. This is very coarse math, but regardless of the specifics, a world full of Level 4 autonomous vehicles can only be perceived as a massive threat and disruption to the health of the existing industry.

#### **Privacy Concerns**

In March 2014, the Consumer Watchdog society voiced its concerns over SB-1298 to the CA DMV. John Simpson, the director of the Privacy Project, made the following statement in his published report<sup>32</sup>: "The DMV's autonomous vehicle regulations must provide that driverless cars gather only the data necessary to operate the vehicle and retain the data only as long as necessary for the vehicle's operation." He then went on to single out concerns over Google.

"Failure to act will mean substantial privacy risks from the manufacturers' driverless car technology if there are not protections from what Google is best known for: the collection and use of voluminous personal information about us and our movements." Though based on different motives, his concerns were somewhat reinforced by an earlier event in August 2013. The acting head of the NTSB at the time, Deborah Hersman, the top ranking safety official in the United Sates government, spoke directly about requiring EDRs (electronic data recorders, i.e. "black boxes") in driverless cars<sup>33</sup>, a comment targeted squarely at Google's test vehicles. Hersman's comments were based on safety concerns and the need for analyzable data should a traffic incident occur, especially one resulting in no survivors. Google had in fact already acknowledged that their test vehicles were logging telemetry information for analysis and operational improvement. Perhaps lost in this Google focused discussion was the fact that 96% of 2013 model vehicles already had EDRs on-board due to a NHTSA proposal to create a mandatory requirement for EDRs on new cars<sup>34</sup>.

# VI. WINNERS VS. LOSERS

## Winner: Semi And Fully Autonomous Car Adopters

In the short term, we expect auto manufacturers who produce premium semi-autonomous features to enjoy increased sales and brand recognition. Software makers, such as IBM, that process large volumes of sensor data and wirelessly connect cars will be a significant part of the value chain as well. Many technical, regulatory and governmental support uncertainties remain for fully autonomous cars. We expect Google to be an important player in licensing maps/traffic data and software to automakers. It is likely that, over the long term, fully autonomous cars will become reality and Google will be

a leader of the new robo-taxi ecosystem.

#### Winner: Component Suppliers And Sensor Manufacturers

The number of sensors and electronic devices in cars is increasing quickly, resulting in more revenue for sensor and component suppliers. As an example, both Google and IBM are working with supplier Continental to develop parts for autonomous cars.

#### Winner: Rental & Ride Sharing Companies

Rental, taxi and ride sharing businesses will converge with the robo-taxi model. The market size will grow substantially as more people move from car-owners to ride-sharers. The younger generation and older adults will be early adopters of the new model.

#### Loser: Traditional Auto Manufacturers

Auto manufactures that do not embrace autonomous driving technologies will see their brand connected to inferior cars. They will suffer from lower margins and reduced sales. The robo-taxi model will further squeeze their market size, making them irrelevant over the long term.

#### Loser: Taxi Services And Professional Drivers

The lower cost robo-taxi model will disrupt traditional taxi services. This will significantly reduce the need for professional drivers. The role of professional driver could be replaced with crisis control personnel, who may patrol around or remain in a service center to perform remote diagnostics and manual intervention of autonomous cars. The way passengers interact with the car will also be significantly different. Instead of relying on steering wheels and brake pedals, passengers will be able to use natural user interface such as spoken commands or gestures to control their cars.

#### Loser: Auto Insurance Companies

The number of accidents will drop sharply, leading to reduced insurance premiums. There will be new models for liability and collision coverage due to the driving responsibility shift from the driver to the car.

#### Loser: Auto Service Industry

There will be fewer accidents and potentially fewer cars with the robo-taxi model. The auto service industry will be consolidated with few survivors.

# VII. SUMMARY AND PREDICTION OF OPPORTUNITY

In the previous sections, we discussed the main differences in approach taken by automakers and Google toward delivering self-driving cars to the market. We can best describe these approaches as incremental and disruptive, respectively. We have also seen the effects that autonomous vehicles will have on the market. In Section 3, we described the technologies used by automakers and Google. Next, in Section 4, we presented a study on the legal hurdles and challenges faced by automakers and more so by Google. Finally, in Section 5, we predicted the winners and losers in the overall market. In this section, we will attempt to predict the overall release trajectory for self-driving cars and estimate areas of future opportunity.

As previous sections state, automakers plan to release their self-driving technology piecemeal. At first, newer features will be released in the luxurious car segment only, slowly trickling down to mass-market vehicles. This trajectory follows their existing mode of operation in releasing features such as adaptive cruise control and lane departure warning/correction. The self-driving reality will therefore be reached gradually.

Google, on the other hand, plans to design a fully autonomous car from the get-go. There has been a lot of speculation about how exactly Google plans to release its vehicles to the market. A previous course research paper states that Google may lease its technology to or enter into a partnership with an automaker. We, however, believe that a more likely scenario is that Google will enter a taxi-service market. This approach has numerous benefits for Google. It allows Google to release its vehicles in markets where regulatory requirements are most lenient. It also allows Google to build a standalone and quirky set of cars without having to worry whether the consumers will want to buy them. Google can likely avoid going through an established car manufacturer in building these cars. Finally, it fits best with Google's model of being driven, as opposed to driving.

In terms of areas of opportunity, we will only focus on a few. Generally, manufacturers of laser/sonar/ camera components will likely see a large growth in demand. Some of the components, such as lidar technology used by Google cars, are still extremely expensive; therefore, a new entrant into the market has a better chance to be profitable. On the taxi service front, we expect a number of interesting services to mushroom up, be it driving seniors to the doctors or driving kids to soccer practices. Ride sharing will become more common and instrumental in reducing congestion in urban areas. Startups focusing on any of these technologies are likely to benefit greatly. Finally, the goods transportation industry will see a phenomenal benefit from self-driving vehicles. We expect service focused on maintenance, resupplying and management to benefit greatly from the development of self-driving vehicles.

Clearly, the future is bright for self-driving vehicles. The question that remains is how fast we can expect to see a fully autonomous vehicle on our roads. Our guess is: sooner than everybody thinks!

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