Self Driving Cars

Ratan Hudda
Clint Kelly
Garrett Long
Jun Luo
Atul Pandit
Dave Phillips
Lubab Sheet
Ikhlaq Sidhu

College of Engineering
University of California, Berkeley

Fung Technical Report No. 2013.05.29
http://www.funginstitute.berkeley.edu/sites/default/files/Self_Driving_Cars.pdf

May 29, 2013
The Coleman Fung Institute for Engineering Leadership, launched in January 2010, prepares engineers and scientists – from students to seasoned professionals – with the multidisciplinary skills to lead enterprises of all scales, in industry, government and the nonprofit sector.

Headquartered in UC Berkeley’s College of Engineering and built on the foundation laid by the College’s Center for Entrepreneurship & Technology, the Fung Institute combines leadership coursework in technology innovation and management with intensive study in an area of industry specialization. This integrated knowledge cultivates leaders who can make insightful decisions with the confidence that comes from a synthesized understanding of technological, marketplace and operational implications.
Abstract: Since its inception of the commercial auto industry in the late 1890s, cars have become increasingly safe and convenient. Recently, carmakers have begun to introduce advanced driver-assistance systems such as adaptive cruise control (which automates accelerating and braking) and active lane assist (which automates steering.) These systems have become capable enough that new luxury vehicles can drive themselves in slow-moving highway traffic. Research into autonomous cars has progressed remarkably since the first demonstrations in the 1980s. In 2010, four driverless vans traveled from Italy to China. In August of 2012, Google announced that its self-driving cars had completed over 300,000 miles of accident-free autonomous driving. Although self-driving cars may still seem like science fiction, Google, many industry analysts, auto suppliers, and carmakers project that such cars will be available before 2020.

This report begins by describing the landscape and key players in the self-driving car market. Current capabilities as well as limitations and opportunities of key enabling technologies are reviewed, along with a discussion on the impact of such advances on society and the environment. This report also reviews legal and regulatory uncertainties. Finally, predictions about changes in the car-industry are made, including potential industry winners and losers.
Background and Observation

For generations, the automobile industry has been a source of innovation and economic growth. The ability to drive is a symbol of mobility and independence that spans generations. Clearly, automobiles play a significant role in our lives and afford many benefits to society.

Yet for all the benefits conferred on society, no other invention in the history of civilian technology has caused as much harm as the automobile. Every 30 seconds, someone dies in a traffic accident, adding up to well over 1 million deaths each year\(^1\). In the U.S., automobile accidents are the leading cause of death for people between the ages of 3 and 34. Moreover, human error is the cause of over 90% of automobile accidents.\(^2\)

In addition, the inefficiencies related with the automobile usage is staggering. Most automobiles sit unused more than 95% of their lifespan, and a freeway operating at maximum efficiency has automobiles on only 5% of its surface. In congested urban areas, 40% of all gasoline used is spent when cars circle to look for parking spaces\(^4\). Furthermore, in some U.S. cities, parking lots comprise more than a third of the land, becoming the single salient landscape feature of our built environment\(^3\).

Data from the U.S. Department of Transportation also evokes concerns about quality of life. It estimates that people spend an average of 52 minutes of each working day commuting. The opportunity cost of this time is high, whether it is measured in lost productivity, the inability to spend more time with friends and family, or increased stress.

Autonomous vehicles could alleviate or completely solve these serious problems. The technology behind autonomous driving is typically divided into two categories: sensor-based implementation or a “Connected Vehicle” implementation. A sensor-based implementation is often an extension of current advanced safety features, while connected-vehicle technology (V2X) involves cars communicating with each other (V2V) and with infrastructure (V2I).

Hypothesis

The authors of this paper believe that there are sufficient motivations for both the consumer and manufacturer to make self-driving cars a reality, and sooner than most might think. The long-term changes to the automobile industry and the lifestyles of consumers will be far-reaching. However, these changes are most likely to occur gradually over the next 3-10 years.
1. Existing Landscape

The existing landscape for autonomous vehicles consists of two parts:

- **Traditional players** are companies and industries already in the automotive business that are introducing autonomous features as a natural evolution of their product offering. Traditional players are commonly focused on incremental innovation. Major carmakers view driverless technologies as enablers to enhance the current driving paradigm and, more importantly, to preserve their existing business model. A gradual introduction of driverless technologies provides companies a long stream of premium-priced safety features that are consistent with current designs.

- **Disruptive players** are companies and industries that currently have no existing business model or revenue stream attached to the automotive industry. They typically favor pursuing innovation that moves directly to fully autonomous vehicles.

1.1. Traditional: Auto Manufacturers

The biggest players in the autonomous automobile industry as it exists today are major automotive manufacturers like Ford, GM, Toyota, BMW, Mercedes Benz, Audi and Volkswagen. Most manufacturers have recently introduced models with advanced safety features called advanced driver-assist systems (ADAS) that resemble partial self-driving capabilities. Several manufacturers have announced that they will release cars in the next two years that will be capable of driving themselves under certain conditions.

1.2. Traditional: Automotive Suppliers

Automobile manufacturers purchase components such as power train, electrical systems, and chassis for their vehicles from external suppliers. ABI research predicts that the global ADAS market will expand from $10B in 2011 to $130B in 2015, mainly due to the introduction of adaptive cruise control, lane-departure warning, and low-speed collision mitigation in non-luxury vehicles. Key suppliers of these technologies include Continental AG (one of the top five overall global OEM parts suppliers) and Hella and Bosch. All of these suppliers list technology for autonomous driving as one of their key strategic goals. For example, Continental’s 2012 investor presentation lists safety as the company’s primary “megatrend.” The company also issued a press release declaring the development of systems for automated driving to be one of the central themes of its long-term technology strategy. Other key suppliers for ADAS and self-driving features include producers of microcontrollers (like Texas Instruments) and video decoders.
1.3. Disruptive: Google

The most deeply involved player in the autonomous automobile market from outside of the automobile industry is Google. Google has worked to develop autonomous cars for the past six years. CEO Larry Page approaches this as a “big bet” problem, noting the high accident rate, very low utilization of existing vehicles and the cost of car parking facilities. Google’s motivation for the car, as described by the lead developer of the project Sebastian Thrun are captured in the sidebar, Benefits of the Driverless Car.

Google’s stated mission is to “organize the world’s information and make it universally accessible and useful.” It is approaching autonomous vehicles as an opportunity to organize and process mapping and geographic information to many mobile computers - the vehicles themselves. Google sees this problem as parallel to the technical infrastructure and techniques required to organize very large, complex and rapidly changing data sets such as the Internet.

1.4. Disruptive: Research Programs

There are many other active research programs concerning autonomous vehicles, many of them featuring collaborations between universities and carmakers. Oxford University, for example, demonstrated a self-driving Nissan LEAF in 2012. Volkswagen and a research team from Stanford University have created a driverless Audi sports car, which has been zipping around US race tracks. In another research project funded by the European Union, Volvo successfully drove a convoy of five vehicles that only had a human driver in the lead car.

2. Evidence of Technology Leading to Self-Driving Cars

There is significant ongoing investment and activity by traditional and disruptive players that will make autonomous vehicles a reality. This section highlights the autonomous technologies of the traditional players, autonomous technologies of the disruptive players, and the current limitations and opportunities of key enabling technologies. All of these factors are expected to coalesce to bring self-driving cars to market, as summarized in the figure below.
2.1. Self-driving cars – available NOW!*

New features are typically introduced first in high-end automobiles before eventually trickling down to mainstream models. For the last 40 years, Mercedes Benz strategy has been to introduce innovations in their flagship S-Class (Sonderklasse or "Special class") first. Many features taken for granted today were first piloted in the S-Class, including padded interior in 1972, ABS 1978, airbag and seatbelt pre-tensioner in 1981, passenger airbag in 1988 and electronic stability control in 1995. The 1998 S-Class introduced Distronic, a cruise control system with sensors for measuring and maintaining the vehicle’s distance from the car in front of it.¹⁰

The 2013 S-Class model is no exception to this 40-year-old strategy. It takes a decisive step toward autonomous driving, as it is capable of steering itself. This makes it the first to fulfill all the criteria of what is constituted as fully automated driving. However, it will do so only in congested traffic. When the vehicle is traveling at walking speed, the driver can choose to switch on cruise control and take his or her feet off the pedals and hands off the steering wheel. The car then automatically accelerates, brakes and steers. The Intelligent Drive: How it Works graphic highlights the technology subsystems involved to achieve “self-driving” status.¹¹

Ford¹² and GM¹³ have announced similar systems, called Traffic Jam Assist and Super Cruise respectively, which they expect to release between 2015 and 2017. Audi has a similar system which is rumored to be planned for the 2016 Audi A8.¹⁴

2.2. Current Capabilities of Traditional Players

Technology that paves the way to autonomous cars is available from several manufacturers in more mainstream vehicles such as the 2011 Ford Focus.¹² Table 1 summarizes several of these technologies

*Conditions apply.
which, when considered collectively, represent a vehicle capable of autonomous driving. Future versions of these features will start to support V2V and V2X implementations.

Table 1: Adoption Metrics for Currently Available Driver Assist Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>System Description</th>
<th>Adoption Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Cruise Control</td>
<td>Monitors distances to adjacent vehicles in the same lane, adjusting the speed with the flow of traffic</td>
<td>6.9M yearly installs by 2017&lt;sup&gt;15&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lane Assist</td>
<td>Monitors the vehicle's position in the lane, and warns the driver when vehicle is leaving lane (or corrects for driver)</td>
<td>More than 10 automakers offer such feature&lt;sup&gt;16&lt;/sup&gt;</td>
</tr>
<tr>
<td>Parking Assist</td>
<td>Assists the driver in parallel parking</td>
<td>65 models in 2013&lt;sup&gt;17&lt;/sup&gt;</td>
</tr>
<tr>
<td>Blind Spot Monitoring</td>
<td>Detects objects in a driver's blind spot</td>
<td>Over 20 models in 2013&lt;sup&gt;18&lt;/sup&gt;</td>
</tr>
<tr>
<td>Forward Collision Monitoring</td>
<td>Detects objects in front of a vehicle presenting immediate collision risk, typically assists in braking for driver</td>
<td>All major makers&lt;sup&gt;19&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

2.3. Current Capabilities of Disruptive Players

Google’s fleet of autonomous cars is continuously learning from each other through expanded digital mapping, and up-to-the second information from the Google “cloud” information ecosystem about road conditions, traffic and travel times. Google’s model is simple: its vehicles communicate with other Google resources. In support of this approach, Google “Streetview” cars have driven more than 5 million miles across 50+ countries and in addition to taking high-definition photography have used light detection and ranging (LIDAR) technology to capture an incredibly detailed 3D map of the world to 15 cm resolution.<sup>20</sup>

Google has also built the world’s largest traffic jam surveillance network by providing the operating system for some 500+ million smart phones.<sup>20</sup> The mapping function on an Android device sends Google anonymous data on position and current speed that are used to calculate traffic flows. If multiple independent Android devices geo-positioned on a freeway that are traveling at 60 mph suddenly slow to a crawl, Google knows that traffic is particularly bad at that location. This information is tracked and trended over time. Additionally, as users travel from A to B using local knowledge to overrule a satellite navigation derived route, Google algorithms can learn and adapt to that better route and thinking process<sup>20</sup>.

2.4. Enabling Technologies

Both existing players and new entrants rely on a number of distance measurement and satellite positioning technologies. These are summarized in Table 2 with more detail on LIDAR in Appendix A. Significant investments are ongoing to develop solutions to address current limitations of these technologies. For example, Continental is evaluating the use of artificial intelligence to increase the car’s ability to extrapolate a reaction from current conditions. Governments are investing in digital GPS (DGPS), and Google continues to increase digital mapping around the world. LIDAR is the
cornerstone of autonomous driving technology: it uses sensors to measure the distance of objects and create 3D maps in real time, so the car knows when to stop, start and react. The biggest challenge is reducing noise caused from weather. Like human eyes, blinding sunlight, snow and sleet impair the vision of LIDAR equipment. Hella, Google and Siemens are all working to tackle this problem. Another challenge is the price tag, which is about $70,000 a unit. This cost is expected to drop as volume increases.

Table 2: Enabling Technologies for Autonomous Vehicles

<table>
<thead>
<tr>
<th>Technology</th>
<th>What it does?</th>
<th>Limitations &amp; Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self Steering</td>
<td>Steering systems that use cameras that watch road markings and radar and laser sensors that track other objects</td>
<td>Machines do not yet do a good enough job of extrapolation – artificial intelligence can improve this capability</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Optical remote sensing technology to measure distance to target by illuminating with light</td>
<td>Noise removal, including weather. Interpolation to fixed point spacing. Triangulation issues</td>
</tr>
<tr>
<td>GPS</td>
<td>Space based satellite navigation system that provides time and location information anywhere</td>
<td>Accuracy of a GPS receiver is ±10 meters, not practical for locating a car which is 3 meters</td>
</tr>
<tr>
<td>DGPS</td>
<td>Enhancement to GPS to improve location accuracy to 10 cm</td>
<td>Shadowing from buildings, foliage causes temporary losses of signal</td>
</tr>
<tr>
<td>Digital Maps</td>
<td>Process by which a collection of data is compiled and formatted into a virtual image</td>
<td>Only parts of the world mapped; need critical mass to enter and cross validate data in order to achieve required accuracy</td>
</tr>
</tbody>
</table>

It is certain that a combination of current capabilities and new developments will lead to the ultimate systems to enable autonomous cars. What remains to be seen is the rate at which features and technologies are adopted, and how the revenue associated will be divided.

3. Environmental Factors

Driving a car requires more than simply a car and a driver. A state issued license is needed as well as the appropriate regulatory framework, insurance and infrastructure. The political, environmental, and social impacts of autonomous cars are wide-ranging; there is much incentive behind enabling autonomous vehicles that will move the industry towards autonomous vehicles. However, there are also several concerns about autonomous vehicles that may impede adoption of the technology.

3.1. Positive: Safety

As discussed previously, the human toll associated with automobiles is sobering, and the vast majority of preventable deaths are attributable to human error. Furthermore, with projected wealth increases in developing economies, the number of cars and drivers, and therefore the number of fatalities, is expected to increase. The World Health Organization estimates that road traffic injuries
will become the fifth leading cause of worldwide death by 2030, accounting for 3.6% of the total—rising from the ninth leading cause in 2004, when it accounted for 2.2% of the world total\textsuperscript{22}.

The economic impact of car accidents is also significant. According to research from the American Automobile Association (AAA), traffic crashes cost Americans $299.5 billion annually.

3.2. Positive: Commute Reduction

Americans currently spend almost an hour on average commuting every day. Based on simulation studies Ford projects that if one in four cars had Ford’s Traffic Jam Assist or similar self-driving technologies, travel times would reduce by 37.5% and delays would reduce by 20%\textsuperscript{12}. This is due to the fact that adaptive cruise control (ACC) is better at pacing the car ahead without continual brake, speed-up, and brake cycles.

3.3. Positive: Infrastructure & Fuel Efficiency

Currently a freeway operating at maximum efficiency has automobiles on only 5% of its surface\textsuperscript{3}. Autonomous cars can be packed together in platoons, as shown in the graphic, with just inches between the bumpers adapting speed as needed. Research indicates that platooning could increase highway lane capacity by up to 500%. Platooning enables follow cars to “draft” behind the lead car to reduce the effective drag coefficient on following vehicles reducing fuel use by up to 20%\textsuperscript{23}. The federal government spent $6B in 2009 on road widening and expansion, and state agencies spend more than $22B annually\textsuperscript{3}. Autonomous driving technology could save this money.

3.4. Positive: Potential Early Adopters

Most industry observers identify two main initial customer demographics for autonomous vehicles: aging baby boomers and older adults who make up 42% of the population and “Digital Natives” and “Gen Now” groups who make up 44% of the population\textsuperscript{2}. An aging population with serious purchasing power and a hunger to retain their mobility as they age will likely be the reason autonomous vehicles will be adopted into the mainstream according to Nissan CEO Carlos Ghosn\textsuperscript{24}. Younger generations will likely be the most receptive to autonomous driving as their identity is less likely to be attached to the “driving experience.” They also have the least purchasing power, and are therefore likely to embrace pay-by-the-mile car-share models. More detail on car-share models is provided in Appendix B.

3.5. Uncertain: Laws and Regulations
Regulatory and legal factors are frequently cited as critical enablers and obstacles of self-driving cars. Although the future is murky for laws and regulations of fully autonomous vehicles, advances toward autonomous cars through improved ADAS are able to continue under current frameworks. Given the safety benefits, the government may promote the adoption of autonomous vehicles. As it has done with hybrid and electric vehicles, the government may offer tax incentives to manufacturers and purchasers of autonomous vehicles, provide special high occupancy vehicle (HOV) lanes for such cars, and possibly even mandate certain self-driving capabilities, as it has done in the past with seatbelts and airbags. Four U.S. states (Nevada, Florida, Texas and California) have already passed laws permitting autonomous vehicles as of September 2012\(^8\).

3.6. Negative: Insurance

Insurance underwriting is a complex issue for autonomous vehicles. The question of who “owns” the risk if an autonomous vehicle is in an accident will need to be addressed for convergence solutions to gain mass-market adoption. Automobile makers and Google have lobbied state governments to absolve them of any such liability successfully in Nevada and unsuccessfully in California\(^25\).

4. Winners and Losers

To assess the winners and losers in the autonomous vehicle industry, the authors considered three possible scenarios for the next decade, which are outlined in Table 3. Moderate change to the industry appears to be the most likely. Existing car manufacturers will likely retain control over the manufacture and distribution of vehicles, but technology will create a new link in the value chain through licensing technology from big data provider entrants like Google.

4.1. Winner: Suppliers of Self-Driving Software for Cars

Many industry analysts expect Google to try monetizing the autonomous vehicle industry by licensing its software and information ecosystem to car manufacturers. The emergence of an industry for licensed software for autonomous vehicles is one of the largest potential disruptions in the automobile industry.

To imagine the transformative value of differentiated self-driving software, consider that car buyers frequently cite safety as the most important factor in selecting a car. Currently, however, almost all safety ratings systems consider only the crashworthiness of a car, or how it fares once it is in a crash. This is also known as “passive” safety. The National Highway Traffic Safety Administration, for example, does not perform any analysis of a car’s crash-avoidance, or “active” safety features. Self-driving cars have the potential to dramatically reduce and eventually eliminate car accidents. The automobile industry will likely soon face a pivot in the most critical factor consumers consider when buying a car, from a passive to an active safety technology. Moreover, differentiation in safety features may in the future come from, or at least heavily depend on, the software industry.
Table 3: Autonomous Vehicle Adoption Scenarios – Winners & Losers

<table>
<thead>
<tr>
<th>Defining Characteristics</th>
<th>Traditional Players</th>
<th>Disruptive Players</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conservative Adoption</strong></td>
<td>Winner: Status quo preserved. Existing manufacturers continue to control market and</td>
<td>Loser: Minor non-critical role</td>
</tr>
<tr>
<td>Slow and incremental feature deployment, delayed</td>
<td>have sufficient time to generate fully autonomous vehicle tech in-house</td>
<td></td>
</tr>
<tr>
<td>regulatory support for fully autonomous vehicles</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Moderate Adoption</strong></td>
<td>Neutral: Existing manufacturers continue to control market but need to give up part</td>
<td>Winner: Significant new revenue streams through licensing</td>
</tr>
<tr>
<td>Moderate deployment, mid-term regulatory support for</td>
<td>of value chain to new entrants. TBD if a large shared ownership model takes hold.</td>
<td></td>
</tr>
<tr>
<td>fully autonomous vehicles</td>
<td>See Appendix B.</td>
<td></td>
</tr>
<tr>
<td><strong>Aggressive Adoption</strong></td>
<td></td>
<td>Winner: Capture majority of value chain, relegate mechanical car to commodity and</td>
</tr>
<tr>
<td>Extremely rapid deployment of autonomous tech,</td>
<td>Loser: Disrupted. Significant reduction in number of cars sold, several automakers</td>
<td>later acquire car companies to customize</td>
</tr>
<tr>
<td>regulations cleared, government subsidized</td>
<td>collapse</td>
<td></td>
</tr>
</tbody>
</table>

4.2. **Winner: Manufacturers of Sensors and Other Electronics**

The number of electronics in cars is increasing rapidly: the auto industry has the highest projected CAGR of any semiconductor market over the next five years\textsuperscript{26}. Much of the differentiation in the autonomous vehicle industry will come from the sophistication of the sensors, positioning systems, and software. The software will require more and more computing capacity. Additionally, passengers will desire more options for entertainment and productivity while their cars drive themselves.

4.3. **Neutral: Current Carmakers**

The emergence of autonomous vehicles creates opportunities and risks for existing carmakers. Certainly, carmakers that are first to market vehicles with superior self-driving capabilities will significantly differentiate themselves, especially as consumers see safety benefits, better fuel economy, enhanced productivity, and quicker commutes. Self-driving features may compel owners of existing cars, particularly the aging boomers and older adults, to upgrade more quickly than they would have otherwise. On the other hand, self-driving technology may change the ownership model of cars, encouraging more sharing and less ownership, particularly among Gen Now and Digital Natives, resulting in fewer cars sales. This is discussed in Appendix B.

Software companies like Google will play an important new role in the automotive value chain. At a minimum, Google will obtain license fees for software; and at a maximum possibly commoditize the non-software aspects of cars.
4.4. Loser: Professional Drivers

The arrival of fully autonomous cars will likely reduce the demand for professional drivers of taxis, limousines, and trucks. The industries employing these workers will benefit from removing the costs associated with drivers. The freight transport industry would benefit even from limited self-driving capabilities. A platoon of trucks (“truck train”) could include tens of trucks traveling across the country with only a single driver. Unions for the various drivers will likely respond by introducing doubt about the safety of self-driving vehicles and lobbying against them, as the taxi industry has done with Uber\textsuperscript{27}.

5. Summary

In conclusion, there are many strong socio-economic motivators for the adoption of autonomous vehicles. Human safety, infrastructure efficiency, quality of life and a ready customer base are just a few of the key factors that will help make self-driving cars a reality. Technology is converging rapidly, both incrementally from existing vendors and from new entrants. A car equipped with existing systems can take in more information quickly and reliably, and then process it to implement a correct decision about a complex situation. Yet to be solved are the complex issues associated with the legal and liability infrastructure. Gradual introduction of these features combined with strong economic motivators are sure to overcome such obstacles. The future will surely include autonomous vehicles; the only question is how quickly.
Appendix A – LIDAR (Eyes On The Road)

LIDaR (Light Detection and Ranging, also LADAR, sometimes Laser Imaging Detection and Ranging) is an optical remote sensing technology that can measure the distance to, or other properties of, targets by illuminating the target with laser light and analyzing the backscattered light.

Google's self-driving car uses Velodyne LIDAR to electronically "see" the environment. HDL-64E and HDL-32E modules use an array of either 64 or 32 lasers. On Google's car, the module is set inside a rotating drum. Its lasers complement Google's own mapping software and GPS data, which help orient the car on the road. The LIDAR provides additional positional data, but also identifies other cars, bicycles, pedestrians, and road hazards.

The car sends out a pulse of light in a certain direction, and an on-board sensor records the reflected pulse’s time-of-flight. By sending out laser beams in all directions, collecting the reflected energy, and performing some nifty high-speed computer processing, the vehicle can create a real-time, virtual map of the obstacles in its path. Because laser light is higher in energy and shorter in wavelength than radio waves, it reflects better from non-metallic objects and provides mapping advantages over RADAR. By coupling novel roof-mounted LIDAR systems with vision cameras, advanced computer processing, and GPS to position the vehicle in global coordinates, it has become possible to create a self-driving machine.

Google's driverless test cars have about $150,000 in equipment including a $70,000 LIDAR (laser radar) system which makes it too expensive for consumers today but reasonably priced LIDAR systems are expected relatively soon.
Appendix B – New Business Model – Shared cars

It’s possible that self-driving cars can enable an entirely new paradigm in car ownership. In a world that doesn’t require cars to sit idle 95% of the time, there exist incredible options for maximizing resources. Combining self-driving cars with shared vehicle systems create new opportunities to provide better mobility at a lower cost. The new automated mobility system would enable a shared pay-by-the-mile or monthly subscription business model rather than outright ownership.

A service like Zipcar may emerge, in which people borrow cars. As per the Ann Arbor case study, a shared driveless car can reduce a trip cost by 80%. If a proportion of automated cars are in nearly constant use and can come when called, the need for individual ownership and parking reduces significantly. It will also free up the time required for driving and parking the vehicle, hence enhancing convenience, relaxed travel, shorter travel time and improved safety.

Eran Ben-Joseph, a professor at M.I.T., points out that “in some U.S. cities, parking lots cover more than a third of the land area, becoming the single most salient landscape feature of our built environment.” Other estimates say there are as many as 2 billion parking spaces in the US, an area about the size of Connecticut and Vermont combined. This real estate could be put to more productive use, if there was no need to park 250 million vehicles.

Carmakers are responding to these opportunities and risks by aggressively researching and promoting their own self-driving technology. Automakers are facilitating owners to earn money by renting their unused cars out to strangers. General Motors has partnered with RelayRide to create a peer-to-peer car sharing marketplace using GM’s OnStar technology. This allows car owners to connect with individuals who need to rent a car. The whole process is managed using a smartphone app. This is a good deal for both RelayRides and GM as RelayRides get access to six million OnStar subscribers to participate in its program and GM can attract young and urban users who might not otherwise consider GM cars.

This development may cause automakers to consider a car a platform like an iPhone on which to allow others to build apps to create and enhance various functionalities in car. Driverless shared cars will create opportunities to serve their occupants; all of them will be free to be entertained and ready to consume other products.

It is likely that at least a portion of the driving population will rely completely on a shared ownership business model. Such a model could pose drastic implications for the existing $500B automobile industry, as net units sales would decrease over time.
References

2. Self Driving Cars, The Next Revolution, KPMG
5. Continental Investor Presentation October, 2012
17. http://autos.aol.com/car-finder/option-parking+assist/
28. http://www.pcmag.com/article2/0,2817,2402516,00.asp
Biographies

**Ratan Hudda** is Director of Engineering at Yahoo! with responsibility over the Yahoo! Mail Frontend Team. He is a hands-on Leader/Web Architect with expertise in bringing high-technology products from vision to reality. Ratan has 15+ years of experience in enterprise and consumer software development. Before joining Yahoo, he was software architect at Purisma and founding member/software architect at eGain Communications. Ratan holds a bachelor’s degree in computer science from NIT Hamirpur, India.

**Clint Kelly** is co-founder and vice president of core technology for Achronix Semiconductor Corp., a semiconductor company that builds high-performance FPGAs. At Achronix, Clint leads hardware research and development. Clint has built and led teams that have designed and implemented high speed, low power synchronous and asynchronous FPGAs in numerous process technology nodes.

**Garrett Long** is Director of Marketing at SanDisk. He has worked in the semiconductor industry for nearly 20 years. Garrett has held leadership positions in marketing, applications and engineering, and is currently focused on new business segment creation at SanDisk. His experience base comes from both Fortune 500 companies and start-ups. He graduated from Carnegie Mellon University with a bachelor’s degree in Electrical Engineering.

**Jun Luo** is a Software Engineer at Google Inc. Jun has 17 years of software industry experience spanning four technology companies in Silicon Valley. During his nine years at Google, Jun has been a key contributor, playing the role of technical leader as well as engineering manager of four different large-scale mission critical distributed storage systems. Jun holds a master’s degree in computer science from the University of Wisconsin.

**Atul Pandit** is Principal Software Engineer in data protection business units at NetApp. Atul is responsible for leading architecture and development of industry leading disk-to-disk backup products. During eight years at NetApp, Atul has focused on building strong teams to deliver innovative data protection and storage-efficiency products to customers. Atul has over 15 years of industry experience and holds a master’s degree in computer science from the Indian Institute of Technology.

**Dave Philips** is a Senior Engineering Manager at Google’s Mountain View Headquarters, where he has been responsible for Google’s Network Engineering Team since 2009. Google’s network connects Google’s worldwide datacenters to each other and to the world’s Internet service providers. Dave has 15 years of experience in the telecommunications industry. Dave previously ran Viatel’s Pan-European network in London. Dave holds an MBA and bachelor’s degree in Physics. Dave is interested in all aspects of large-scale networks, Internet infrastructure and datacenter technology.

**Lubab Sheet** is Director of Corporate Technology Development at the Lam Research Corporation. Reporting to the Chief Technology Officer, she supports innovation strategy, collaboration and communications. Lubab also leads government affairs and is skilled in mergers & acquisitions, playing a key role in the $3.3B acquisition of Novellus Systems. She has a Bachelor of Science in materials science & engineering from San Jose State and an MBA from Santa Clara University.
Copyright © 2013, by the author(s).
All rights reserved.

Permission to make digital or hard copies of all or part of this work for
personal, educational, or classroom use is granted without fee provided that
copies are not made or distributed for profit or commercial advantage and that
copies bear this notice on this page. To copy otherwise, to republish, to post
on servers or to redistribute to lists, requires prior specific permission.

Acknowledgement: This paper was created in an open classroom
environment. There should be no proprietary information contained in this
paper. No information placed in this paper is intended to affect or influence
public relations of any firm affiliated with any of the authors.

The Coleman Fung Institute for Engineering Leadership, launched in January
2010, prepares engineers and scientists – from students to seasoned
professionals – with the multidisciplinary skills to lead enterprises of all
scales, in industry, government and the nonprofit sector.

Headquartered in UC Berkeley’s College of Engineering and built on the
foundation laid by the College’s Center for Entrepreneurship & Technology,
the Fung Institute combines leadership coursework in technology innovation
and management with intensive study in an area of industry specialization.
This integrated knowledge cultivates leaders who can make insightful
decisions with the confidence that comes from a synthesized understanding of
technological, marketplace and operational implications.

National rankings consistently place UC Berkeley’s undergraduate and
graduate programs among the world’s best. Berkeley is home to top scholars
in every discipline, accomplished writers and musicians, star athletes, and
stellar scientists—all drawn to this public university by its rich opportunities for
groundbreaking research, innovative thinking and creativity, and service to
society.