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Self-driving cars: The next revolution

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A message from Gary Silberg and Richard Wallace

For 125 years the automotive industry has been a force for innovation and economic growth. Now, in the early decades of the 21st century, the pace of innovation is speeding up and the industry is on the brink of a new technological revolution: "self-driving" vehicles.

The new technology could provide solutions to some of our most intractable social problems—the high cost of traffic crashes and transportation infrastructure, the millions of hours wasted in traffic jams, and the wasted urban space given over to parking lots, just to name a few. But if self-driving vehicles become a reality, the implications would also be profoundly disruptive for almost every stakeholder in the automotive ecosystem. As one industry executive put it, "Everything, from how we move goods to how we move ourselves around, is ripe for change."

KPMG LLP and the Center for Automotive Research (CAR) collaborated on this report, interviewing leading technologists, automotive industry leaders, academicians, and regulators to develop hypotheses on how self-driving vehicle technology could unfold and its potential impacts. It is clear from our research that any company remaining complacent in the face of such potentially disruptive change may find itself left behind, irrelevant.

For those who embrace innovation and opt to lead rather than follow, a new frontier is opening in the realm of mobility services.

We hope you will find our report illuminating and that we will have opportunities to discuss our findings with you in the near future.

Gary Silberg
Partner, KPMG LLP
National Sector Leader Automotive

Richard Wallace
Director, Transportation Systems Analysis
Center for Automotive Research

On the cusp of revolutionary change

For the past hundred years, innovation within the automotive sector has brought major technological advances, leading to safer, cleaner, and more affordable vehicles. But for the most part, since Henry Ford introduced the moving assembly line, the changes have been incremental, evolutionary. Now, in the early decades of the 21st century, the industry appears to be on the cusp of revolutionary change—with potential to dramatically reshape not just the competitive landscape but also the way we interact with vehicles and, indeed, the future design of our roads and cities. The revolution, when it comes, will be engendered by the advent of autonomous or "self-driving" vehicles. And the timing may be sooner than you think.

KPMG LLP and the Center for Automotive Research (CAR) joined forces in developing this white paper to examine the forces of change, the current and emerging technologies, the path to bring these innovations to market, the likelihood that they will achieve wide adoption from consumers, and their potential impact on the automotive ecosystem.

Our research included interviews with more than 25 thought leaders, automotive and high-tech executives, and government officials as well as analysis of industry trends. This white paper presents our findings, with an emphasis on the convergence of sensor-based and communication-based vehicle technologies and its implications.

The revolution, when it comes, will be engendered by the advent of autonomous or "self-driving" vehicles. And the timing may be sooner than you think.

The findings are outlined in four sections:

1 **Market dynamics** examines the market dynamics and the social, economic, and environmental forces that are making change inevitable.

2 **Convergence** discusses the ongoing convergence of the key enabling technologies.

3 **Adoption** focuses on the path to widespread adoption of advanced automated driving solutions, which we believe will take place in stages, leading over time, to reliance on increasingly autonomous or "self-driving" vehicles.

4 **Implications for investment** addresses the social, political, and economic implications of self-driven automobiles and their impact on the entire automotive ecosystem.

Market dynamics

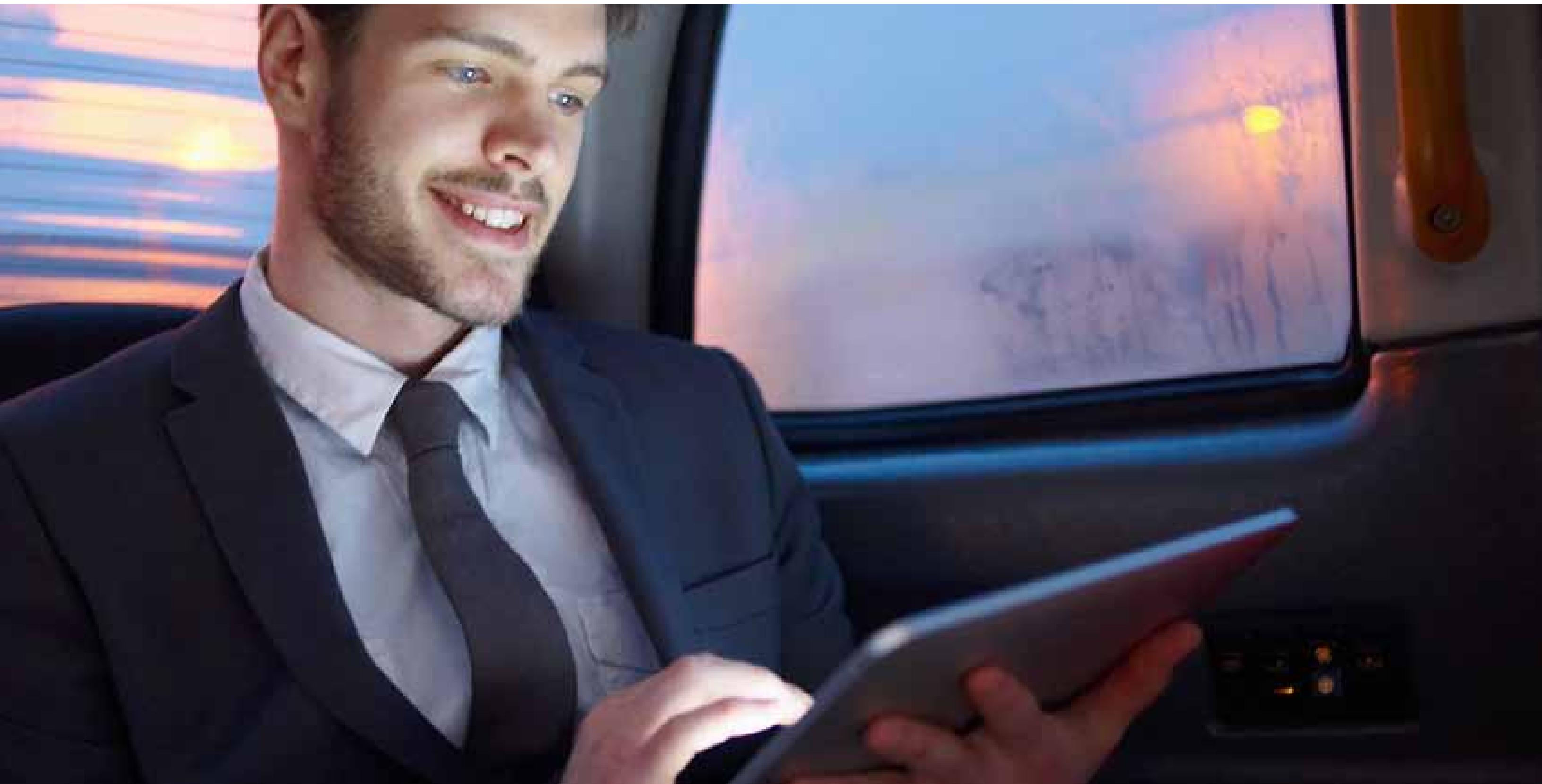
Imagine. It's 6:25 p.m. and you've just wrapped up a meeting. You still have several items on your "must-do" list before you can call it a night and a 25-minute commute that used to take as long as 90 minutes in the bad old days of rush-hour traffic.

But no worries today. You flick open an app on your phone and request a pick-up at the office; a text confirmation comes back and a few minutes later a car pulls up. "Home," you say, as you launch a call to your client in Shanghai. The car slips easily into the self-drive lane, checking road conditions and flashing a message that you will arrive home in 24 minutes. In that time, you will have reviewed a report with your client, answered e-mails, and set your pick-up time for tomorrow morning. You arrive home ready to relax and focus on your family. You step out of the car and it moves off to its next pick-up.

A Self-Driving Car?

Even now that military drones have become a familiar topic, the idea of self-driving cars sounds pretty far fetched. But is it still just science fiction? Something that gets batted around in robotics labs and think tanks? Or are self-driving vehicles on the verge of becoming a viable form of personal mobility? Will the market accept them, want them, and pay for them?

We think the answer is a resounding yes: The marketplace will not merely accept self-driving vehicles; it will be the engine pulling the industry forward. Consumers are eager for new mobility alternatives that would allow them to stay connected and recapture the time and psychic energy they squander in traffic jams and defensive driving. Or as Stanford University's Sven Beiker put it, "The paradigm shift in the consumer's mind relative to personal mobility is a key factor for self-driving vehicles."[1]



The Status Quo: The High Cost of Mobility

The desire to go where we want whenever we want has been a powerful market force for centuries. And the automotive industry has been—and continues to be—a critical component of the U.S. economy, employing 1.7 million people (across manufacturers, suppliers, and dealers) and providing $500 billion in annual compensation, as well as accounting for approximately 3 percent of GDP.[2] But mobility is increasingly expensive and inefficient. First, of course, is the total cost of vehicle ownership, which can bring the price of a $21,000 car driven an average of 15,000 miles per year to more than $40,000 over five years—for a machine that sits unused on average, almost 22 hours out of every day.[3]

We also pay heavily to build and maintain our roads. The U.S. Department of Transportation (USDOT) estimates that new construction of four-lane highways in an urban area costs between $8 million and $12 million per mile. Even resurfacing that road, at an estimated $1.25 million per mile, can be daunting for cash-strapped governments.

The average American commuter now spends 250 hours a year behind the wheel of a vehicle; whether the value of that time is measured in lost productivity, lost time pursuing other interests, or lost serenity, the cost is high. Today, those commuters inch along during rush hour traffic; they drive in circles around city streets looking for parking spaces; and, according to a report published by the MIT Media Lab, "In congested urban areas, about 40 percent of total gasoline use is in cars looking for parking."[4]

Safety and the Human Toll

We pay in other important ways. In 2010, there were approximately six million vehicle crashes leading to 32,788 traffic deaths, or approximately 15 deaths per 100,000 people. Vehicle crashes are the leading cause of death for Americans aged 4–34. And of the 6 million crashes, 93 percent are attributable to human error.[5] The economic impact of crashes is also significant. More than 2.3 million adult drivers and passengers were treated in U.S. emergency rooms in 2009. According to research from the American Automobile Association (AAA), traffic crashes cost Americans $299.5 billion annually.[6]

The pursuit of improved vehicle safety has spurred the National Highway Traffic Safety Administration (NHTSA) to focus attention on self-driving vehicles. As NHTSA's Associate Administrator for Vehicle Safety, John Maddox, explained in early 2012, the goal is not merely to make self-driving vehicles as "safe" as human drivers, who, as the evidence shows, are not very safe at all. The goal is to develop "crash-less" cars.[7]

Driving Demographics

Will people willingly cede control to a machine and give up driving their own car? For baby boomers, especially, turning 16 and getting a driver's license was a rite of passage. But demographics are changing, as are attitudes towards driving. Younger generations, the ones who grew up with game consoles and smart phones, are not so in love with cars. They live perpetually connected lives, and while they may have the same desire for mobility on demand, some see the act of driving as a distraction from texting, not the other way around.[8] Their antipathy towards driving may be a good thing, given these statistics: Distractions account for 18 percent of crashes with injuries, and 11 percent of drivers under age 20 involved in crashes with fatalities were reported to have been distracted.[9]

This group—members of the "Gen Now" generation (see Figure 2 below)—are not rushing to get driver's licenses the way baby boomers did. In 1978, nearly half of all 16-year-olds and 75 percent of all 17-year-olds had licenses; by 2008, those numbers had dropped to 31 percent and 49 percent, respectively.[10]

Figure 2

Demographic breakdown

Demographic	Population	Percentage of Total
Digital Natives (0–14 years)	49 million	16%
Gen Now (15–34 years)	84 million	28%
Gen X (35–44 years)	43 million	14%
Baby Boomers (45–65 years)	80 million	26%
Older Adults (66+ years)	47 million	16%

- Denotes segment of population that is untapped today due to being below driving age
- A percentage of older adults are driving impaired. The trend of self-driving will provide them added mobility
- A percentage of baby boomers will enter the older adults category when the trend of self driving sees market introduction

Together, the "Gen Now" generation and "Digital Natives" comprise 133 million current and future drivers, or more than 43 percent of the U.S. population. Older adults, the 47 million Americans aged 66 and over, face different mobility challenges. While they still cherish their autonomy, they are prone to develop age-related impairments to their driving ability.

Even aging boomers are increasingly distracted by cell phones and other gadgets; they, too, will soon move beyond safe driving age. Among the boomers we interviewed, even those who owned premium cars said they would willingly give up driving to work in exchange for an easier commute.

Self-driving cars open up new possibilities and new markets, and not just for those who are legally eligible to drive, but also for younger people, older people, and those with disabilities. For them self-driving promises greater freedom and mobility and greater control over their lives.

Running Out of Space

In the early days of the automobile, America was expanding, conquering the vast open spaces with a network of highways. It was the work of the 20th century, planning and building the 3.9 million miles of paved public roads that now connect Seattle to Miami, Bangor to Baton Rouge, and Detroit to Mountain View. Americans mythologized their cars and the freedom of the open road. We shaped our towns and villages around the highways, building vast suburbs miles beyond our gritty urban centers, adding "big-box stores" and mega-malls surrounded by acres and acres of parking lots.

But now population density is increasing and the trend in the U.S. and worldwide is one of rapid urbanization. The United Nations reports that 82.1 percent of Americans lived in urban areas in 2010, up from 79.1 percent in 2000, meaning that 14.1 percent more Americans lived in urban areas in 2010 compared to 2000. By 2020, the UN estimates that 84.4 percent of Americans will live in urban areas, with more than 28 percent living in urban areas of more than five million people.[11]

Over the past 50 years, increased population density in the United States coincided with an increase in household wealth and growth in the number of multi-car families. From 1960 to 2010, the number of registered vehicles in the United States tripled, from 74.4 million in 1960 (one car for every 2.4 people) to 250.2 million registered vehicles in 2010 (one for every 1.2 people).[12]

Parking lots and garages form urban dead zones, draining the vitality from city streets. In his book *ReThinking a Lot* (2012), Eran Ben-Joseph notes, "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."[13]

In summary, current trends are unsustainable over the long-term, and new alternatives are emerging—not just from within the automotive sector, but from a host of new players and unlikely suspects. From universities, such as MIT, Stanford, Carnegie Mellon, and Columbia, to leading high-tech companies, such as Google and Intel, to start-ups, the shape of personal mobility is changing—and could ultimately transform every aspect of how we use, purchase (or not), insure, and even finance our vehicles. This transformation will have profound implications for any company within the automotive ecosystem.

[1] KPMG Interview, 5/30/2012.

[2] Contribution of the Automotive Industry to the Economies of All Fifty States and the United States Kim Hill, Adam Cooper and Debbie Maranger Menk. Center for Automotive Research. Prepared for The Alliance of Automobile Manufacturers, The Association of International Automobile Manufacturers, The Motor & Equipment Manufacturers Association, The National Automobile Dealers Association and The American International Automobile Dealers Association. April 2010.

[3] Using Edmunds.com TCO calculator at http://www.edmunds.com/tco.html, 7/12/2012.

[4] http://h20.media.mit.edu/pdfs/wjm2007-0509.pdf.

[5] Maddox, John, "Improving Driving Safety Through Automation," NHTSA, 2012.

[6] http://newsroom.aaa.com/2011/11/aaa-study-finds-costs-associated-with-traffic-crashes-are-more-than-three-times-greater-than-congestion-costs/, 6/28/2012.

[7] Maddox, John, op. cit.

[8] http://adage.com/article/digital/digital-revolution-driving-decline-u-s-car-culture/144155/, 7/18/2012.

[9] http://www.distraction.gov/content/get-the-facts/facts-and-statistics.html.

[10] Ad Age, op cit.

[11] World Urbanization Prospects, United Nations Department of Economic and Social Affairs, 2011.

[12] Research and Innovative Technology Administration, Bureau of Transportation Statistics, http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html, 7/24/2012.

[13] Ben-Joseph, Eran, ReThinking a Lot, MIT Press 2012, http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=12874&mode=toc, 7/20/2012.

> "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."
>
> *– Eran Ben-Joseph, MIT Press*

Convergence

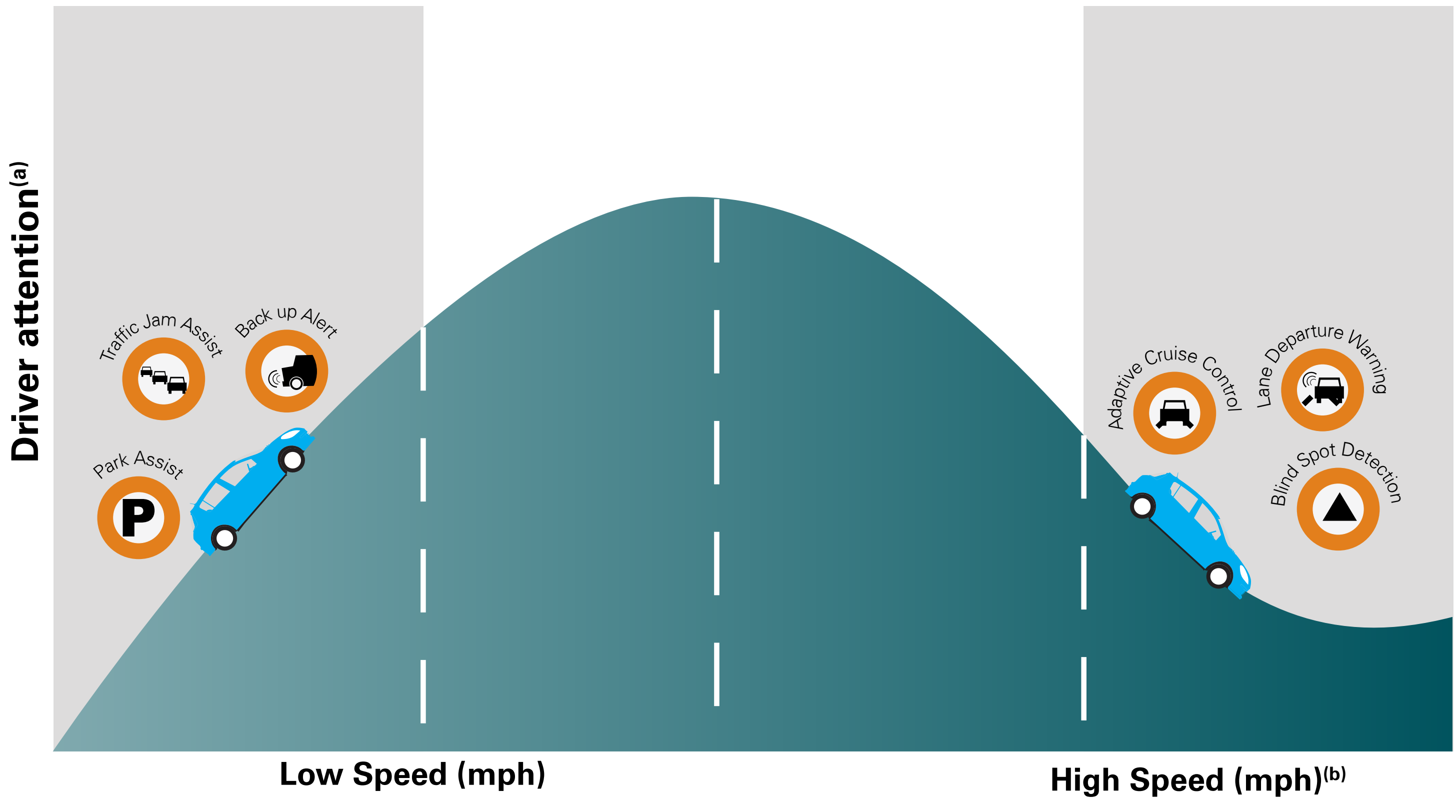
Can we build a safe, self-driving vehicle? Yes. In fact, Google has already logged more than 200,000 miles in a fleet of self-driving cars retrofitted with sensors. And Google is not alone; traditional automakers and suppliers have also developed self-driving functionality using sensor-based solutions and have a host of new applications in the pipeline. At the same time, a number of organizations, including automotive and high-tech companies and the USDOT, have been focused on the potential for using connected-vehicle communication technologies for collision avoidance and traffic management.

What's missing, so far, is the convergence of sensor-based technologies and connected-vehicle communications that is needed to enable truly autonomous vehicles. In this section we discuss the existing technologies, their current limitations, and why we believe they are likely to converge in the not-so-distant future.

Sensor-Based Solutions

The automotive industry is currently developing sensor-based solutions to increase vehicle safety in speed zones where driver error is most common: at lower speeds, when the driver is stuck in traffic, and at higher speeds, when the driver is cruising on a long stretch of highway (see Figure 3). These systems, known as Advanced Driver Assist Systems (ADAS), use a combination of advanced sensors, such as stereo cameras and long- and short-range RADAR, combined with actuators, control units, and integrating software, to enable cars to monitor and respond to their surroundings. Some ADAS solutions, such as lane-keeping and warning systems, adaptive cruise control, back-up alerts, and parking assistance, are available now. Many others are in the pipeline.

Figure 3: Speed zones for driver assist systems



Key: Industry focus speed zones

Note: (a) May not consider acceleration and driving conditions e.g., handoff of control residential versus highway

(b) Indicative of situation where driver is cruising along empty stretches of highway at steady high speeds

The next generation of driver-assist systems will likely offer greater vehicle autonomy at lower speeds and may reduce the incidence of low-impact crashes. For example, traffic jam assist solutions work at speeds up to 37 mph and could be on the market as early as 2013.

Companies are also developing sensor-based, driver-assisted solutions, which use stereo cameras and software and complex algorithms "to compute the three-dimensional geometry of any situation in front of a vehicle in real time from the images it sees."[14]

[14] http://www.daimler.com/dccom/0-5-1418048-1-1418642-1-0-0-1418049-0-0-135-7165-0-0-0-0-0-0-0.html

The next generation of driver-assist systems will likely offer greater vehicle autonomy at lower speeds and may reduce the incidence of low-impact crashes.

Such sensor-based systems offer varying degrees of assistance to the driver, but, in their current form, are not yet capable of providing self-driving experiences that are complete and cost-competitive. Their limitations include:

a) **Perception of the external environment:** So far, the fusion of available sensors and artificial intelligence is not capable of "seeing" and understanding the vehicle's surroundings as accurately as a human being can. Humans use a combination of stored memories and sensory input to interpret events as they occur and anticipate likely scenarios. For example, if a ball were to roll onto a road, a human might expect that a child could follow. Artificial intelligence cannot yet provide that level of inferential thinking, nor can it communicate in real time with the environment. "These algorithms are very complex and will need to replace over 16 years of human learning," explained Christian Schumacher, Head of Systems & Technology for Continental Automotive Systems, N.A.[15]

b) **Cost:** Creating a 360-degree view of the vehicle's environment requires a combination of sensors and may cost more than consumers are willing to pay. Light Detection and Ranging (LIDAR)-based systems provide 360-degree imaging but are complex, expensive, and not yet ready for the market. The LIDAR system used in the Google car, for example, cost $70,000. Value chain stakeholders will need to have a clear and compelling business case before investing in this technology. *(Please refer to the Adoption section for more in-depth analysis on cost and investment considerations.)*

Connectivity-Based Solutions

Connected-vehicle systems use wireless technologies to communicate in real time from vehicle to vehicle (V2V) and from vehicle to infrastructure (V2I), and vice versa. *(Note that we use the expression V2X as shorthand for communication between vehicles and any other object.)* According to the USDOT, as many as 80 percent of all crashes—excluding those in which the driver is impaired—could be mitigated using connected-vehicle technology.

Dedicated Short-Range Communication (DSRC), which uses radio waves, is currently the leading wireless medium for V2V communication. It operates at 5.9 GHz frequency, using standards such as SAE J2735 and the IEEE 1609 suite (protocols that establish what messages are sent, what the messages mean, and how they are structured),[16] and is being tested rigorously to see if it can fully support V2V cooperative safety applications. Currently, DSRC offers the greatest promise, because it is the only short-range wireless alternative that provides all of the following:

- Fast network acquisition
- Low latency
- High reliability
- Priority for safety applications
- Interoperability
- Security and privacy

These features are especially important for active safety applications, because safety-critical communication must be reliable, immediate, network and device "agnostic," and secure. Another benefit of DSRC is that it operates using free spectrum, which is already reserved by the U.S. government for transportation applications.

Within the automotive industry, two entities have emerged for testing and developing V2V and V2I communications. The Vehicle Infrastructure Integration Coalition (VII-C) is a collaboration among federal and state departments of transportation and automobile manufacturers. In 2009, the coalition published the results of its connected vehicle concept testing; it is now focused on policy issues that must be resolved before the technology can be deployed. Another group, the Crash Avoidance Metrics Partnership (CAMP) held driver clinics in six U.S. locations as part of a Connected Safety Pilot.

[15] KPMG Interview, 5/2/2012.

[16] SAE (sae.org) and IEEE (ieee.org) re two major associations of engineers and other technical professionals who establish industry standards for engineering.

[17] KPMG Interview, 5/2/2012.

To move beyond the test phase and set the stage for self-driving vehicles, a number of obstacles must be overcome:

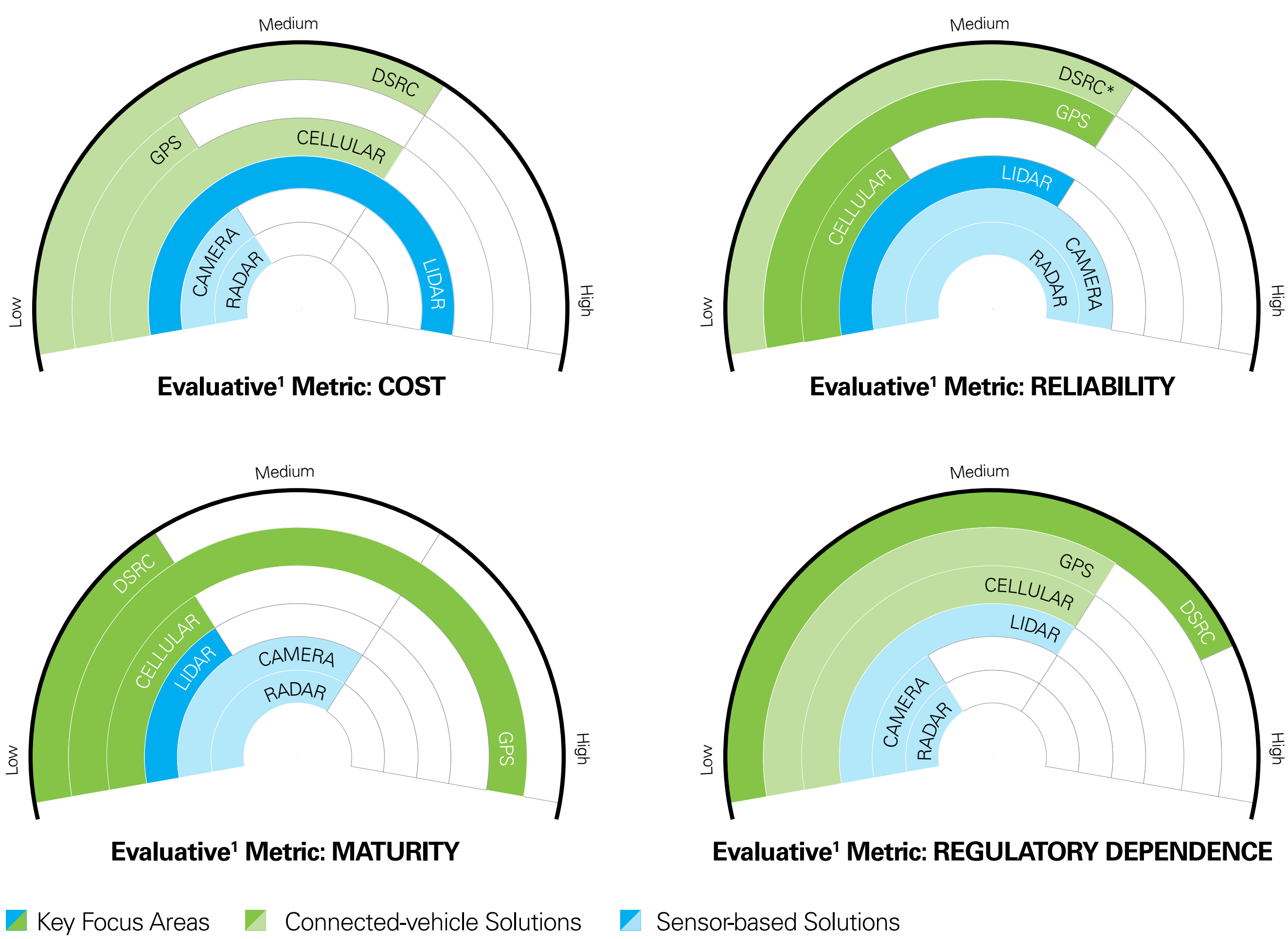
a) **Critical Mass:** Because V2V communication requires other similarly equipped vehicles for sending and receiving signals, the technology will not achieve its potential until the capability is ubiquitous. That may require mandates and will certainly require cost-effective solutions and the ability to retrofit existing vehicles. (For more on this topic, please see Section 3: Adoption.)

b) **Infrastructure Modifications:** V2I communication for active safety will require infrastructure equipped with DSRC-compliant transceivers, and the cost of building that infrastructure may present barriers. An intermediate solution might focus only on crash avoidance at high-volume or other critical intersections. Another solution could use cellular technology and its existing infrastructure for longer-range communication and DSRC for shorter ranges. Heri Rakouth, PhD and manager of Technology Exploration at Delphi, notes, "Advances in cellular technology could be a longer-term solution to the infrastructure investment cost that is associated with DSRC."[17] However some inherent shortcomings exist with cellular technology for use in active safety systems: it suffers from latency issues (it is too slow) and has bandwidth constraints, both of which reduce its viability for safety-critical applications.

c) **Dependency on Sensors:** Although connected vehicle solutions can communicate with the external environment, sensor-based solutions will need to co-exist in order to cover situations that involve obstacles—obstructions in the road or pedestrians, for example—that would not be connected and communicating with the network.

Figure 4 (below) provides a framework for evaluating the pros and cons of the underlying technologies in connected- and sensor-based solutions. The ratings (low-medium-high) indicated in bright colors show areas where further development is needed before the technologies can be used in mass-market convergence-related applications.

Figure 4: Framework for evaluating technologies



[1] Evaluation is based on viability for safety critical automotive applications   * Safety pilot ongoing

The Benefits to Convergence

The convergence of communication- and sensor-based technologies could deliver better safety, mobility, and self-driving capability than either approach could deliver on its own. As Pri Mudalige, staff researcher for General Motors' Global R&D, puts it, "V2V technology…may simplify the all-sensor-based automotive advanced driver-assist systems, enhance their performance, and make them more cost effective."[18] Indeed, our list of top benefits to convergence corresponds with Mudalige's and includes:

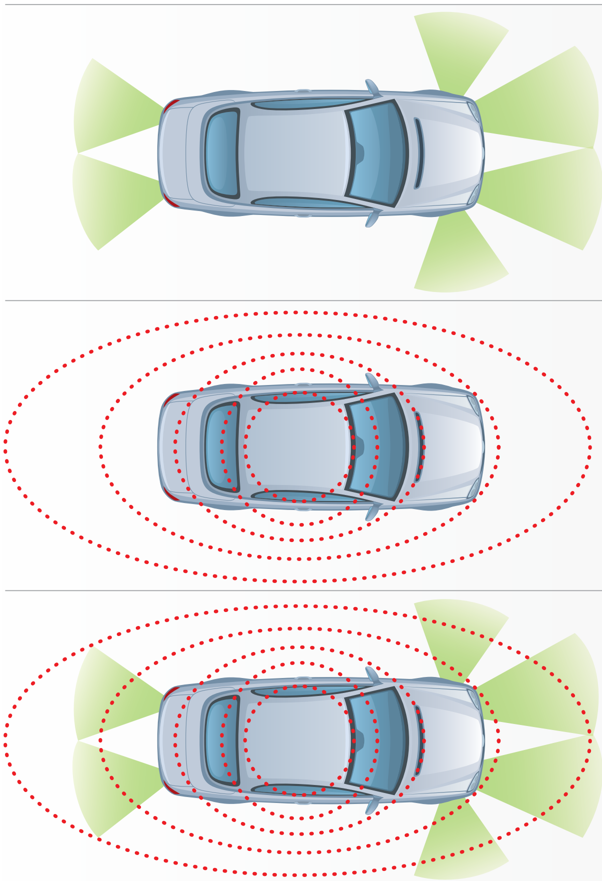
a) **Timing and Cost:** Convergence would help reduce the cost and complexity of stand-alone solutions. Adding DSRC would eliminate the need for the more expensive sensors and bring down the cost of the overall package.

b) **Proxy for Human Senses:** Convergence would increase the inputs that are available for decision making and reduce the need for more sophisticated artificial intelligence. The combination of sensors and connected-vehicle solutions would allow self-driving vehicles to collect the requisite information to make real-time "decisions" and respond to the myriad on-road scenarios drivers face every day. Whereas sensors can see what is directly within their frame of vision, V2V communication adds the potential for trajectory prediction, as vehicles communicate their intentions to each other, lessening the reliance on artificial intelligence.

c) **Functionality Redundancy:** There is no room for error with safety-critical functionality. The technology has to work 100 percent of the time; the combination of connected vehicle technologies and sensor solutions would provide a necessary level of redundancy.

d) **Infrastructure Investment:** Connected vehicle solutions require large-scale infrastructure investments. Convergence could help mitigate some of this requisite investment by covering some use cases using sensors.

Figure 5: Benefits of convergence



Sensor-Based Solution Only

- Cannot sufficiently mimic human senses
- Not cost-effective for mass market adoption
- Lack of adequate 360º mapping of environment in urban grids

Connected Vehicle Solution Only

- DSRC does not currently work with pedestrians, bicyclists, etc.
- DSRC-based V2I might require significant infrastructure investment
- V2V requires high market penetration to deliver value reliably

Converged Solution

- Convergence will facilitate adequate mimicking of human senses
- Convergence will reduce need for an expensive mix of sensors and reduce the need for blanket V2I investment
- Convergence will provide the necessary level of functional redundancy to ensure that the technology will work 100 percent of the time

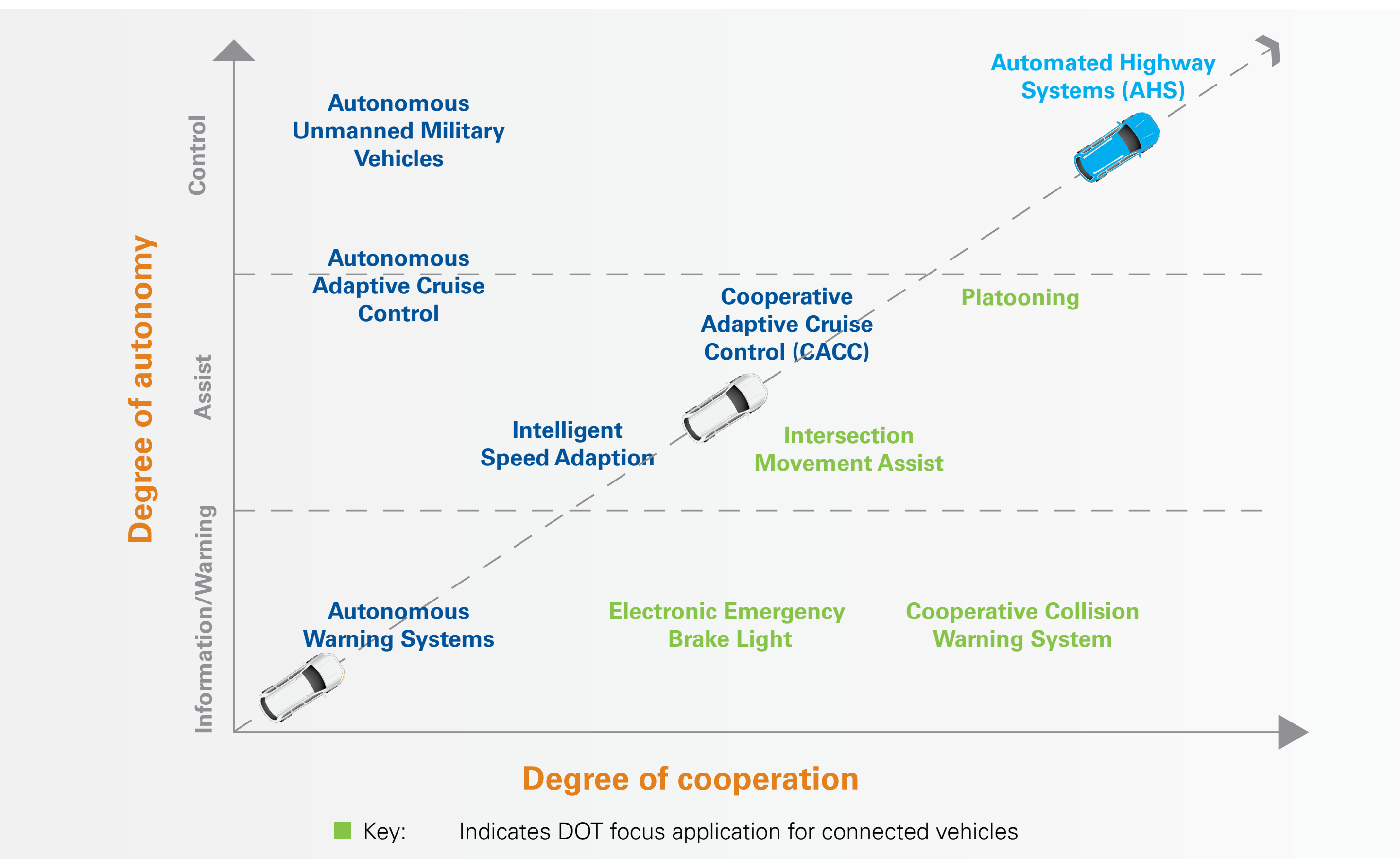
[18] KPMG Interview, 5/17/2012.

The Path to Convergence

There are still significant hurdles on the path to convergence, among them:

- **Improved Positioning Technology:** GPS offers some promise, but the technology, which pinpoints location within +/- 10 meters, isn't accurate enough to be used for safety-critical applications. GPS error-correction technologies such as RTK (real-time kinematics) are expected to be introduced in the future as the demand for accurate positioning increases and cost curves permit mass-market introduction. (For a detailed look at the pros and cons of the technologies, please refer to the Appendix).
- **High-Resolution Mapping:** Today's digital maps lack the necessary detail to support self-driving applications, which need to "see" the environment in as much detail as the human eye. If a firm is successful in resolving the accuracy issue, it would help alleviate some infrastructure burden of a DSRC-only solution.
- **Reliable and Intuitive Human Machine Interface (HMI):** The interface between driver and machine remains a complex problem. Drivers must know when and how to hand off control and take it back. That handoff must happen seamlessly, instantaneously, and safely—and drivers must be thoroughly comfortable with the process in any vehicle they use.
- **Standardization:** The regime for connected vehicles is fairly mature based on the SAE J2735 and IEEE 1609 standards, but additional standards will be needed to ensure full interoperability. A mandate, if it occurs, should provide momentum to develop them, but a question remains: What gets standardized, and what remains part of the branded experience controlled by manufacturers?

Figure 6: Shows self-driving applications plotted along two dimensions: the degree of autonomy and the degree of cooperation.



Adoption

Assuming the technologies mature, convergence occurs, and connected, self-driving vehicles hit the market, will consumers buy them? Who will be the early adopters, willing to buy into the value proposition of self-driving vehicles on day one, before the V2V network has achieved sufficient density to be useful?

Like many of the industry leaders, academics, and policy makers interviewed, we believe the age of the self-driving vehicle is coming. But getting there will require that many pieces of a large puzzle fit together. When and how that will happen remain open questions.

But imagine this: It's 2022, and autonomous vehicle technology is fully developed and priced within reach of most vehicle owners. Interest is high; the technology appeals to the usual technophiles, but many people are still on the fence. Now take a densely populated urban area like Southern California, where car ownership is high and commutes are often agonizing. The California Department of Transportation has been weighing its options to deal with the rising cost of congestion. The costs for building and repairing transportation infrastructure are also high, and now self-driving vehicles offer real promise. The DOT has thoroughly tested the new technology and even designed special autonomous vehicle permits, and decides to pilot a special HOV lane for self-driving cars. Perhaps it even provides tax rebates or other financial inducements for vehicle owners who buy the self-drive package—either on a new car or in the aftermarket—assuming it will make back the investment in usage fees.

Now you start to see those cars whiz by with their self-drive E-ZPasses®. You start to read stories about commute times cut drastically. Your colleague starts bragging about the e-mails she answered on the way to work, the books she's read, and movies she's watched on her way home. Now what? Do you take the leap?

In this section we present some thoughts on how widespread adoption might occur, what enablers and obstacles might arise, and how the stakeholders within the automotive ecosphere—including manufacturers, regulators, city planners, policy makers, and consumers—might work together to speed or inhibit progress. The analysis that follows focuses on four major requirements: consumer acceptance, achieving critical mass (to enable the "network effect"), the legal and regulatory framework, and incentives for investors.

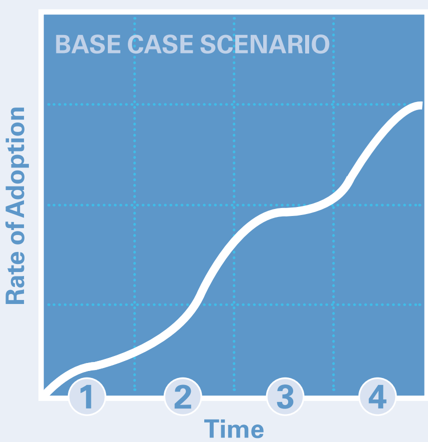
Three Possible Adoption Scenarios

We believe adoption will likely proceed in four stages, and depending on how the pieces of the puzzle come together, the time lines for adoption could vary. "Focused and phased introduction is a realistic path for mass deployment,"[19] stated Hideki Hada, Toyota. On the next page we describe a baseline adoption scenario, an aggressive one, and a conservative one.

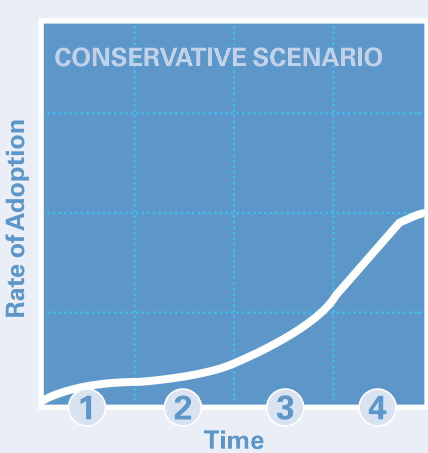
> "Focused and phased introduction is a realistic path for mass deployment."
>
> *– Hideki Hada, General Manager, Integrated Vehicle System Dept., Toyota*

[19] KPMG Interview, 5/16/2012.

1	2	3	4
• Early applications "sell" the promise of self-driving • Consumers embrace tangible benefits • NHTSA issues NRI followed by immediate V2V mandate that includes aftermarket component • Technology breakthroughs lead to even greater value for V2X solutions	• Adoption levels out as aftermarket retrofit is gradually completed • Adoption density reaches critical mass • Adoption and speed of change eventually level off	• No change	• No change



1	2	3	4
• Early applications "sell" the promise of self-driving vehicles. • Consumers excited by tangible benefits • NHTSA issues NRI	• Assist systems provide greater value proposition to consumers • Early adopters flock to new offerings • NHTSA issues V2V mandate but without aftermarket component	• Adopton plateaus due to lack of V2X functionality in aftermarket	• Private enterprise introduces aftermarket solutions • Aftermarket retrofit reaches required density for 'control' apps • Adoption eventually levels off (not necessarily at 100 percent participation)



1	2	3	4
• Initial adoption slow due to lack of consumer enthusiasm for early assist and information systems • NHTSA issues NRI unfavorable because DSRC not seen as viable for V2V	• Unfavorable NRI causes adoption to plateau due to lack of consumer interest in available sensor-based solutions	• Slow rise in adoption as sensor technology improves	• Adoption levels never reach critical mass for self-driving due to lack of V2X capability

Pieces of the Puzzle

The adoption of most new technologies proceeds along an S-curve, and we believe the path to self-driving vehicles will follow a similar trajectory.[20] It will be the confluence of multiple, interdependent activities and forces, including regulatory action, business cycles, technological advancements, and market dynamics, that will ultimately determine the trajectory and speed of market adoption. (See opposite page for our take on three possible adoption scenarios.)

As we noted in the previous section, several sensor-based automated driving applications, such as Adaptive Cruise Control and Park Assist, are in use today, and the automotive industry and technology firms are already working on more sophisticated solutions. While the available technology does not yet enable self-driving, it is moving in that direction. Most of the underlying sensor-based technologies exist, although not all of them are robust enough to be considered automotive grade. They will require further testing and validation and will be subject to the automotive industry's long development and sourcing cycles.

Nonetheless, we believe that sensor and connected-vehicle technologies will continue to develop and converge, leading to an eventual inflection point beyond which it is likely that the driver will increasingly be taken out of the loop.

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[20] As C.S. Smith described it in his book, *A Search for Structure,* The "S" curve…can be used to apply to the nucleation and growth of anything, really any "thing" that has recognizable identity and properties depending on the coherence of its parts. It reflects the underlying structural conflicts and balance between local and larger order and the movement of interfaces in response to new conditions of components, communication, cooperation, and conflict." (http://inside.mines.edu/~meberhar/new1/classes/down_loads/smith.pdf), 7/20/2012.

Figure 7 Pieces of the Adoption Puzzle

Laying the Groundwork: Engaging Consumers

Even if the current technological limitations did not exist, it would be necessary and even preferable to introduce self-driving capabilities gradually. Doing so would still provide benefits to vehicle operators and the transportation network, and provide time for consumers to learn about and begin to trust the technology.

Building Trust: There is no margin for error with safety-critical technologies. They must work perfectly every time; life and death hang in the balance. Consumers will not relinquish control until they are certain their vehicles and the mobile environment are 100 percent safe and reliable. But John Augustine, managing director of USDOT, is optimistic. "When people can see what the car can see, they are convinced," he said at the 2012 Driverless Car Summit.[21] The ramifications of an early autonomous or connected-vehicle traffic crash could be calamitous. Bad publicity is a significant risk for the deployment of innovative automotive technology, even if the technology itself is not the cause.

When Antilock Braking Systems (ABS) were first introduced, negative publicity and poor consumer education delayed mass-market adoption. Similarly, when Electronic Stability Control (ESC) systems were rolled out, consumers did not fully understand how to make use of the technology. On the road, however, these systems delivered a clear, quantifiable reduction in fatalities. Once consumers understood how these systems worked, widespread adoption of ABS and more effective use of ESC followed.

Appealing to the Right Demographics: Industry executives, such as Michael Stankard, who heads Aon's automotive practice, believe certain segments of the population will be less likely to embrace autonomous driving. "Car enthusiasts will not be receptive to this trend,"[22] he said. As we noted previously, baby boomers, especially, who equate their cars with personal freedom and identity, may be reluctant to give up the wheel. But as boomers mature beyond driving age, subsequent generations may come to view the vehicle as more of a commodity, meant to convey them from point A to point B, while they stay connected. The "Digital Natives" and "Gen Now" generations are likely to be the most receptive to self-driving vehicles and become the early adopters because their identity is less likely to be attached to the "driving experience."

Selling the Value Proposition: To adopt the new technologies and embrace fully self-driving vehicles, consumers will need to see real value for each new feature they buy. The industry's ability to deliver an attractive value proposition, customized for different segments of the market, will drive consumers' willingness to pay and, therefore, will be critical to widespread adoption. Younger generations—those within the Digital Natives and Gen Now cohorts—will likely be the most receptive to self-driving, but they also comprise the market segment with the least purchasing power. Therefore, the industry will need to price these packages accordingly.

One potentially attractive pricing scenario would be to have a baseline set of self-driving features that would be standard in every vehicle, and then include a menu of options that could be priced as "self-driving on the go" (similar to premium trim options). Such a tiered pricing model could speed adoption by providing affordable options for a broader range of customers. Baseline features could potentially be spelled out in a government mandate.

Facilitating a Learning Curve: Autonomous vehicle technology will revolutionize the driving experience, and consumers will need time to learn how to use and manage the new features. (A new car is not like a new smart phone; one can't reboot in the middle of a highway.) They will need to feel comfortable with the functionality and the interface with the vehicle, and even then, they will likely have to overcome a psychological hurdle before they cede control and "let the car drive." So it will be imperative to proceed incrementally and guide consumers along a manageable learning curve. The guided learning curve might take the form of new driver education requirements and perhaps specific permits to operate different levels of self-driving vehicles.

[21] Association for Unmanned Vehicle Systems (AUVSI) Driverless Car Summit 2012, Detroit, 6/13/2012.

[22] KPMG Interview, 5/15/2012.

> "When people can see what the car can see, they are convinced."
>
> *– John Augustine, Managing Director, USDOT RITA*

Enabling the Network Effect

Achieving Critical Mass: To work well, connected vehicle technology requires a large network of vehicles equipped with similar, or at least interoperable, communication systems. With high degrees of vehicle autonomy comes the need for higher degrees of cooperation and, hence, higher levels of adoption density to deliver the technology's full value and potential. Density is critical for V2V safety applications and for automated driving. Some "monitored automation" applications have "cooperative" features, which require minimal levels of adoption density to deliver on their value proposition.

Enabling the Aftermarket: "A viable aftermarket solution is a key to adoption,[23]" says Doug Patton, DENSO's senior vice president of Engineering. Without a viable aftermarket solution to retrofit vehicles already on the road, it will take a longer time to achieve the necessary critical mass. While a significant number of aftermarket vehicles will need to have fully enabled devices for V2X communication, a portion of them will only need to have comparatively "dumb" devices that transmit their location.

Localized Adoption: Convergence-based applications could also be implemented and adopted within densely populated urban areas. This approach might obviate the need for broader infrastructure investment and create inducements for other cities and individual consumers to adopt the technology. This is especially feasible in high-density areas such as the borough of Manhattan, where drivers could reap the benefits of V2I communication without the need to retrofit all of New York City.

Bringing Costs Down: According to research conducted by J.D. Power and Associates,[24] 20 percent of consumers surveyed said that they would definitely/probably be willing to pay as much as $3,000 for autonomous driving applications. However, today's more advanced sensors, such as LIDAR, cost tens of thousands of dollars. As convergence of the two technologies occurs, fewer sensors would be needed, perhaps bringing the total cost down to $1,000 to $1,500 per vehicle, as economies of scale are achieved. When the pricing is right, the rate of adoption will likely increase, enabling users to realize greater value from V2V communication and creating a reinforcing effect. As more people adopt the new technologies, greater economies of scale will bring costs down, attracting still more consumers.

[23] KPMG Interview, 5/4/2012.
[24] J.D. Power and Associates, 2012 U.S. Automotive Emerging Technologies Study.

Developing a Legal and Regulatory Framework

States and Local Laws Legislation, or lack thereof, will impact the speed and trajectory of adoption. To some extent, states such as Nevada are ahead of the curve, having already passed legislation that permits licensing and operation of autonomous vehicle licenses. These actions help focus greater attention on the emergence of self-driving vehicles and create environments where further testing and validation of the technologies can occur. However, private enterprise will still need to play a role in developing products and concepts that facilitate consumer pull. If this happens, it could motivate regulatory agencies to issue necessary regulations. As the director of the Nevada DOT put it, "Make a [self-driving] product that the consumer wants, and we will adapt and follow." And as more states establish policies, federal regulators may be compelled to act to ensure a uniform and cohesive approach.

A Federal Mandate: Automotive suppliers and vehicle manufacturers believe a government mandate requiring that vehicles be equipped with V2V safety technology (just as seatbelts and airbags are now mandated) will be instrumental in motivating the automotive value chain to invest in developing convergence-related technologies. Any such mandate or series of mandates will also need to encompass criteria that will drive development across the industry.

In fact, USDOT has already launched a Connected Vehicle Safety Pilot Program, and NHTSA will use data from the pilot as important input for determining if a Notice of Regulatory Intent (NRI) regarding V2V safety will be announced in 2013. NHTSA's regulatory approach could evolve along one or more of several possible paths: mandatory deployment of the technology, voluntary installation of wireless devices in new vehicles, or additional research and development.

An affirmative NRI in 2013 is likely to be succeeded by the release of specifications in 2014 or 2015. Assuming a four-year vehicle development cycle, the first vehicles with built-in V2V and V2I capability could launch in 2019, perhaps sooner if manufacturers opt to pursue DSRC with or without a mandate.

The advantage of a mandate is that it would spur development across the industry and expedite adoption of convergence solutions. Figure 8, on page 22, shows a potential time line for introduction of V2X-based applications, assuming a favorable decision by NHTSA in 2013.

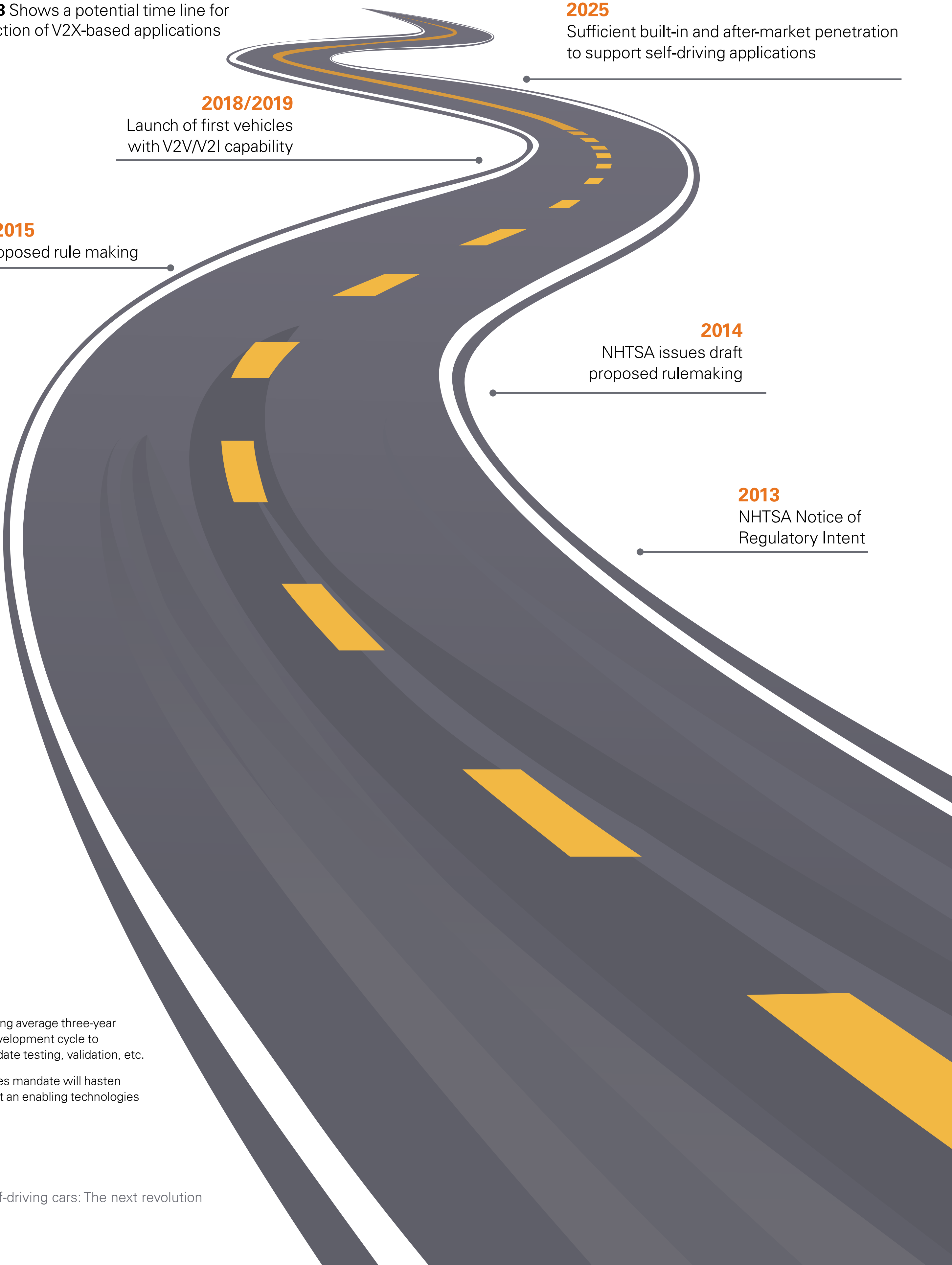
Incentives: If NHTSA does not issue a full mandate for V2V safety, it's possible that the agency might instead offer incentives to automakers who introduce convergence-based solutions and to consumers who are willing to buy them. Incentives would be less powerful than a full mandate, but would, nonetheless, have broad effects on the industry, because they would likely enable first-mover advantages for manufacturers that are further ahead in the development life cycle of V2V technologies and self-driving solutions.

A Legal Framework: If the driver, by design, is no longer in control, what happens if the vehicle crashes? The "driver" could well be an innocent bystander or might at least bear lesser liability than drivers do today. A legal framework will be necessary to deal with the potentially complex liability issues that may come with self-driving cars.

Insurance underwriting will be another thorny issue. Interviews with insurance risk firms indicate that the entire underwriting process will need to be revamped, and a greater portion of the liability could transfer to manufacturers and infrastructure providers (federal and state). These legal concerns, and the question of who "owns" the risk, will need to be addressed for convergence solutions to gain mass-market adoption. Litigation-related issues that come with widespread use of autonomous vehicles will be a challenge.

The advantage of a mandate is that it would spur development across the industry and expedite adoption of convergence solutions.

Figure 8 Shows a potential time line for introduction of V2X-based applications



Note:
(*) Assuming average three-year vehicle development cycle to accommodate testing, validation, etc.

(*) Assumes mandate will hasten investment an enabling technologies

Spurring the Necessary Investment

But relying on government spending is a risk. Given a sluggish economy and widening state and federal budget deficits, the appetite for infrastructure investment is likely to be low. Interviews with industry participants indicate that a purely DSRC-based system might require a multibillion-dollar investment on a national level.

These costs could be mitigated by leveraging some of the existing cellular infrastructure. Doing so would be possible only if a combination of DSRC and cellular (or an alternative technology) is proven viable for short- and long-range communication, respectively. The likely outcome is somewhere in between, with DSRC infrastructure present at important intersections and other critical nodes within the transportation system.

If slow economic growth continues, it would likely curtail capital spending, especially by automotive companies, which struggled during the recent recession. It is unlikely that traditional automotive companies would be willing to spend heavily on technologies for which the ROI time line is unclear. On the other hand, companies that fail to invest could find themselves falling behind and losing market share as the self-driving trend gains traction.

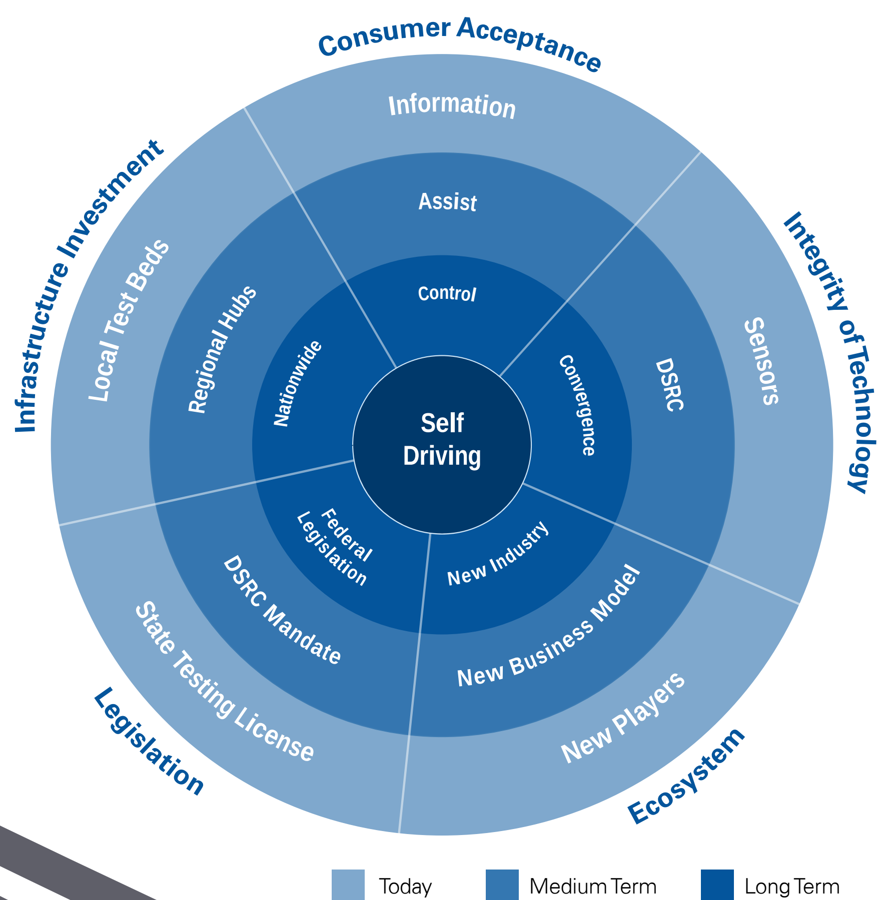
Political Will: Regulations and planning at the federal level are subject to elections and changes in the political climate. Because 2012 is an election year, a change in governing party—or even a change in leadership at the helm of USDOT—could affect funding, prioritization, and timing of a connected vehicle mandate. A lack of government support could be a significant obstacle to adoption.

Conclusions

We believe convergence of sensor-based and connected-vehicle technologies will happen and will have a positive effect on the adoption of both systems. We think drivers will take the leap. Convergence will bring enhanced mobility and safety and reduced environmental impacts. It may also have far-reaching implications for the traditional automotive value chain and beyond.

Automotive and technology companies are already investing in connected and autonomous technologies and applications. While there is no clear leader, companies are trying to figure out how to compete and collaborate at the same time. We believe that over the longer term, the evolution of these advancements will cause a rebalancing of the automotive value chain, with nontraditional firms playing a more significant role. We explore these implications in the next section.

Figure 9 Shows the various facets and forces that must come together to enable self-driving.



Implications for investment

In the new world of self-driving (autonomous) cars, who will design and manufacture automobiles? Who will design the consumer experience? Who will own the aspirational brands? Will the automotive brands still matter? If so, how will they adapt to maintain competitive advantage? Who will lead in this evolving ecosystem?

These questions and others abound, as various participants in the automotive ecosystem grapple with the impact of these potentially disruptive new technologies. Intel, for example, recently launched a $100 million Connected Car Fund because, says Mark Lydon, director at Intel Capital, "Intel is looking to apply its expertise in consumer electronics and systems intelligence to the development of smarter vehicle technologies that seamlessly blend IT, CE, and next generation ADAS while maintaining optimal safety. The Connected Car Fund was created to further this vision and spur greater innovation, integration, and collaboration across the automotive technology ecosystem."[25]

What's clear is that the convergence of sensor-based safety systems and connected vehicle technology will have far-reaching implications as the technology matures and becomes pervasive. Below, we have listed a number of major implications that, in our view, represent significant paradigm changes for the vehicle transportation ecosystem as a whole. Some will offer enormous economic and social benefits, while others will present significant challenges for society:

Crash Elimination

Reduced Need for New Infrastructure

Data Challenges

New Models for Vehicle Ownership

Travel Time Dependability

Productivity Improvements

Improved Energy Efficiency

New Business Models & Scenarios

Crash Elimination

Eventually, convergence will lead to vehicles that can drive themselves and operate autonomously.

These vehicles will not be autonomous in the sense of being unconnected—rather, they will be able to drive themselves precisely because they *are* connected to the outside world via sensors and V2X communications. Ultimately, this will lead to vehicles that cannot crash—or at least cannot crash under normal operation. That's what Bosch, for example is working on. Frank S. Sgambati, director of Marketing for Chassis Systems Control at Robert Bosch LLC explains, "Bosch is developing next-generation driver assistance systems as it pursues a vision of collision-free driving."[26] System failure may remain a possibility, but convergence also implies a multitude of redundant systems that can substitute for one another and yield safe operation even when failures occur. This crashless future would eliminate the injuries and property damage associated with vehicle crashes and save more than 30,000 lives a year.

The implications are profound. Historically, vehicle safety—driver and passenger safety especially—has focused on crash worthiness. This shift means that at some point, self-driving vehicles will no longer require significant amounts of structural steel, roll cages, or air bags, among other safety features. Vehicles could therefore be much lighter. With crashless vehicles, not only can weight be reduced, but cabins can also be redesigned to support activities other than driving and crash survival. Possibilities include a rolling office or a reconfigurable space to suit occupants' changing needs. A crashless world would have profound implications for vehicle design and development, manufacturing cost and methodology (methods and costs), tooling, and a host of other characteristics of today's vehicle ecosystem.

Clearly, not everyone will be happy with these changes. Steelmakers, for example, would see a fall in demand for their product, while electronics suppliers could see increased demand for theirs. In addition, in a crashless world, automotive development cycles will be shorter because of testing requirements that will be less onerous. This will help to address life cycle mismatches between the auto industry and faster-paced industries such as consumer electronics.

The ramifications extend well beyond the automotive industry. Vehicle repair and maintenance shops could lose business, although they might find new opportunities for aftermarket personalization of vehicles. Emergency rooms and hospitals, too, would lose the more than two million crash victims sent annually to U.S. emergency rooms and the resulting 240,000 annual hospitalizations. Few, however, would lament these declines.

Already, the insurance industry is evolving through the introduction of insurance "telematics" (often described as "pay as you go and drive" insurance). But a crashless world could have a much larger effect. At the very least, it would change underwriting models, which are based on driver behavior, and it's possible it could even end the need for car insurance.

Not only will self-driving vehicles be crashless they also will adhere to traffic rules and regulations, although those rules and regulations may be quite different than the ones in effect today. This could very well revolutionize traffic management. State and local governments, for example, would lose the revenue from traffic fines, but their payrolls might also shrink as demand for highway patrol officers plummets. Governments might still seek to replace the lost revenue—perhaps with infrastructure usage fees?

Ultimately, the size, shape, and design of the vehicle will be different and will open up huge new business opportunities for a host of new and existing players—from software and electronics companies to design and manufacturing firms.

[25] KPMG Interview, 6/12/2012.

[26] KPMG Interview, 5/30/2012.

Reduced Need for New Infrastructure

Convergence will transform not only future vehicles, but also the road and highway systems that support them. Today's roads are designed for human drivers—who are too often inexperienced, distracted, or impaired. Thus, today's roadways and supporting infrastructure must accommodate for the imprecise and often-unpredictable movement patterns of human-driven vehicles with extra-wide lanes, guardrails, stop signs, wide shoulders, rumble strips and other features not required for self-driving, crashless vehicles. Without those accommodations, the United States could significantly reduce the more than $75 billion it spends annually on roads, highways, bridges, and other infrastructure.[27]

An essential implication for an autonomous vehicle infrastructure is that, because efficiency will improve so dramatically, traffic capacity will increase exponentially without building additional lanes or roadways. Research indicates that platooning of vehicles could increase highway lane capacity by up to 500 percent.[28] It may even be possible to convert existing vehicle infrastructure to bicycle or pedestrian uses. Autonomous transportation infrastructure could bring an end to the congested streets and extra-wide highways of large urban areas. It could also bring the end to battles over the need for (and cost of) high-speed trains. Self-driving vehicles with the ability to "platoon"—perhaps in special express lanes—might provide a more flexible and less costly alternative.

The *Highway Capacity Manual* rates the capacity of at-grade intersections to be only about half the capacity of the intersecting routes.[29] To the extent that traffic control signals are needed, they will no longer be designed to direct human operators; thus many signals and signs will be unnecessary. The vehicle itself will "know" how to avoid conflicts with other vehicles. Simulations of intelligently controlled intersections indicate that such a system could perform 200–300 times better than current traffic signals.[30]

The convergence of sensor-based safety systems and connected vehicle technology could also assist transportation agencies with asset management and reduce maintenance costs. Vehicles could report road or weather conditions back to transportation agencies, which could then rapidly address issues such as road deterioration or icy conditions. Additionally, autonomous vehicle traffic could automatically be rerouted around problem areas, if necessary, while maintenance crews address the problem.

Parking, too, will be affected. Vehicle sharing would keep vehicles in more constant use, serving more people and reducing demand for parking infrastructure. Vehicles, now built via just-in-time systems, could now reach travelers using similar logic.

Even a 10 percent reduction in need for infrastructure investment—a conservative estimate relative to such a dramatic change in needs—would result in savings of $7.5 billion per year, or $75 billion per decade compared to current infrastructure expenditures.

Data Challenges

An enormous amount of data will become available for alternative usage, which is likely to present challenges and opportunities pertaining to data security, privacy concerns, and data analytics and aggregation.

Data Security: Numerous security threats will arise once personal mobility is dominated by self-driving vehicles. Unauthorized parties, hackers, or even terrorists could capture data, alter records, instigate attacks on systems, compromise driver privacy by tracking individual vehicles, or identify residences. They could provide bogus information to drivers, masquerade as a different vehicle, or use denial-of-service attacks to bring down the network. The nefarious possibilities are mind-boggling—the stuff of sci-fi thrillers. But system security will undoubtedly become a paramount issue for transportation systems with the successful deployment of integrated sensor-based and cooperative vehicles.

Security systems protecting against such threats could include characteristics such as data sanitization (e.g., removal of identifying information) and data suppression (e.g., reducing sampling frequency). They could aggregate data (possibly within the vehicle rather than having the vehicle transmit large quantities of raw data). They could use vehicle authentication, encryption, tamper-proof hardware, real-time constraints, user-defined privacy policies (allowing data handling preferences for each user), and defense-in-depth (meaning each layer of hardware and software would provide its own security functions).

New threats to personal privacy: Even now, with pervasive connectivity in and outside of our vehicles, we are finding it increasingly difficult to preserve our privacy. As the use of autonomous and connected vehicle solutions expands, maintaining individual privacy within the transportation system may become even more arduous. Although the increased use of sensing, tracking, and real-time behavior evaluation creates new privacy issues as well as ethics and policy dilemmas, the benefits to be derived from vehicle sensor and communication technologies make them an appealing pursuit for most stakeholders.

Privacy concerns must be resolved to enable the deployment of integrated sensor-based and cooperative vehicle technologies. A balance between privacy protection interests and other affected interests is essential to resolve conflicts between the stakeholders who will make decisions about how information is collected, archived, and distributed. Potential stakeholder concerns are numerous: disclosure of vehicle data could reveal trade secrets; public personalities, such as politicians and celebrities, could be connected to potentially embarrassing locations or routes; and ordinary citizens could find themselves spammed or stalked as the data enables a variety of harmful applications such as commercial misuse, public corruption, and identity theft. And what's to prevent nefarious governments from using the expanded surveillance capabilities to spy on their citizens?

Data Analytics and Aggregation: It is possible that individual privacy is threatened less by the collection of public location information than by the aggregation of information, combining location and route data with other personal information. Current laws may not be equipped to adequately address new technologies and the growing data industry. Large-scale data mining and analytics techniques have been highlighted in newspaper headlines of late, stirring much concern over the power of aggregation and analytics. Consumer and privacy advocates are already calling for more transparency among data brokers and requesting that these firms publicly reveal information on the data they collect, how they collect it, who has access to it, and how it is used. In early 2012, the Federal Trade Commission issued a report urging greater transparency from data brokers.

Though many view large-scale data aggregation as intrusive, manipulative, and an invasion of privacy, it has its benefits as well. Location and route information collected from vehicles allows for numerous types of location-based services (LBS) that may be personalized for travelers. The Pew Research Center reports that, as of 2012, three-quarters of smartphone users use location-based services, up from just over half of smartphone users in 2011. As consumers and businesses become more comfortable with new technology, the field of location-based services is set to continue expanding.

Beyond direct traveler services, acquisition and use of data could be beneficial for businesses, government agencies, universities, economic developers, nonprofit groups, and other organizations. Data could be used by state departments of transportation or other road managers to analyze road use patterns and plan maintenance and improvements. Licensing agreements could allow organizations access to vehicle and travel route data under controlled conditions and for legitimate purposes. Sharing could be done through the data collecting agency itself, or may involve a third party that would gather data, remove any individually identifiable information, and make it available to interested organizations. Such work is already being done with certain data sets with organizations.

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[27] Includes federal, state, and local expenditures.

[28] "*Platooning With IVC-Enabled Autonomous Vehicles: Strategies to Mitigate Communication Delays, Improve Safety and Traffic Flow*". IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, VOL. 13, NO. 1, MARCH 2012. Pedro Fernandes, Member, IEEE, and Urbano Nunes, Senior Member, IEEE.

[29] Transportation Research Board, *Highway Capacity Manual*, 5th Edition. 2010.

[30] "Multiagent Traffic Management: A Reservation-Based Intersection Control Mechanism". In *The Third International Joint Conference on Autonomous Agents and Multiagent Systems* (AAMAS 04) pp. 530-537, New York, New York, USA, July 2004. Kurt Dresner and Peter Stone, University of Texas at Austin Department of Computer Sciences.

New Models for Vehicle Ownership

Self-driving vehicles could contribute to a significant redefinition of vehicle ownership and expand opportunities for vehicle sharing (imagine Zipcar on steroids). If vehicles can drive themselves, they can be summoned when needed and returned to other duty when the trip is over. Thus, travelers would no longer need to own their own vehicles and could instead purchase mobility services on demand.

Even when vehicle usage is at its peak—near 5:00 p.m. in the U.S.—fewer than 12 percent of all personal vehicles are on the road, which means, of course, that 88 percent are not in use. (Not all of those vehicles would be available for sharing at any given time; the composition of the 12 percent changes as trips begin and end, and vehicles would need time to travel from the end of one trip to the beginning of the next.) Self-driving vehicles could be used more efficiently throughout the day instead of being parked most of the day and night. This would require new models for vehicle insurance and maintenance but would also provide multiple new business opportunities.

At the same time, vehicle sharing would cause significant challenges for traditional manufacturers and suppliers, as the ratio of vehicles per person would inevitably decline. If vehicle sharing occurs on a global basis, there can be little doubt that annual worldwide demand for vehicles could decline, perhaps by a large percentage. The Center for Automotive Research forecasts that U.S. vehicle sales will return to more than 15 million units in 2014, and that sales will remain between 15 and 16 million through 2022. If, for example, convergence resulted in only a 20 percent reduction in demand for new vehicles—far less than 88 percent—that forecast could fall to about 13 million units with the introduction of self-driving vehicles and the associated new ownership models.

But many other variables will affect global demand for vehicles. Pricing is a significant variable that could dramatically change the demand curve. If prices for a basic autonomous vehicle fell below $10,000, for example, ownership would be within reach for a much broader segment of the world's population. And as vehicle ownership becomes possible for previously excluded demographic groups—younger and older drivers, those with physical limitations, and those with fewer resources—the resulting increase in demand could help offset some of the aforementioned decreases.

Travel Time Dependability

Anticipated travel time is the most useful information to support trip decisions and assess the operational status of a transportation network, and convergence provides the opportunity to eliminate, or at least substantially reduce, uncertainty in travel times. Nonrecurrent congestion can account for as much as 30 percent of the delay faced by drivers.[31] In addition, with unpredictable traffic patterns, traffic congestion can occur at any time of day. In large urban areas such as Los Angeles, "rush hour" congestion regularly lasts more than six hours, and approximately 40 percent of total traffic delay occurs in off-peak hours when travelers and freight companies expect relatively free-flow conditions.[32]

With the surface transportation network composed of self-driving vehicles linked electronically and via communications, the intelligent transportation system of the future will be able to provide each vehicle with a reliable and predictable path from origin to destination. This will virtually eliminate the need to allocate extra time for trips to avoid nonrecurrent congestion and traffic incidents, thus allowing for more productive time and more efficient freight movement, as well. Furthermore, industries dependent on just-in-time delivery will be able to reduce inventories even further, knowing that needed components and products will arrive when needed.

Productivity Improvements

Vehicles that can drive themselves, combined with highly improved travel time dependability, offer travelers the opportunity to regain time formerly lost to driving as productive time. With traffic congestion costing Americans 4.8 billion hours of travel delay each year, amounting to a cost of more than $100 billion annually in delay and fuel, $23 billion of the delay cost can be attributed to the effects of congestion on truck operations.

An automated transportation system could not only eliminate most urban congestion, but it would also allow travelers to make productive use of travel time. In 2010, an estimated 86.3 percent of all workers 16 years of age and older commuted to work in a car, truck, or van, and 88.8 percent of those drove alone, while the remaining 11.2 percent traveled in a carpool. Thus, conservatively, more than 90 percent of workers 16 years or older drove a car, truck, or van to work. A driver loses productivity while commuting, because attention must be given to driving. The average commute time in the United States is about 25 minutes. Thus, on average, approximately 80 percent of the U.S. work force loses 50 minutes of potential productivity every workday.

With convergence, all or part of this time is recoverable. Self-driving vehicles may be customized to serve the needs of the traveler, for example as mobile offices, sleep pods, or entertainment centers. Through connected services, former drivers will now be fully connected to the outside world while in transit and capable, at no loss of safety or risk of violation, of video conferencing, document production, and spending time with family and friends, either in person or via future incarnations of Facebook.

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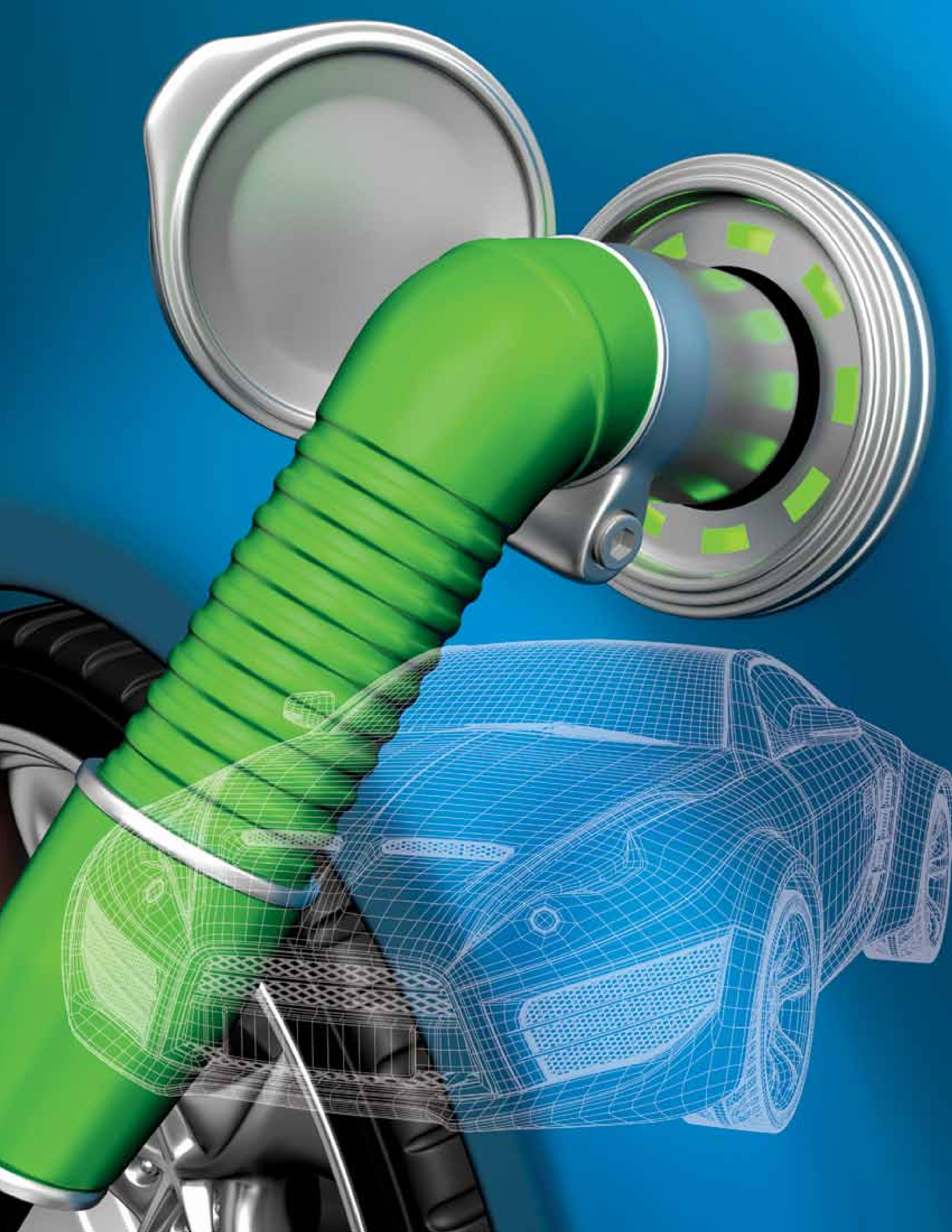

Improved Energy Efficiency

Would fuel prices plummet? Would CAFE (Corporate Average Fuel Economy) standards disappear? Consider how much more energy-efficient transportation would be in the post-convergence world. A transportation system composed of self-driving vehicles would decrease energy consumption in at least three primary ways: more efficient driving; lighter, more fuel-efficient vehicles; and efficient infrastructure. The energy policy and geopolitical implications could be profound.

In an autonomous vehicle transportation system, vehicles will navigate far more efficiently than current human operators do. The inefficiency of human-driven vehicles leads to considerable congestion at high traffic volumes and frequent traffic jams. In its 2011 Urban Mobility Report, the Texas Transportation Institute estimated that congestion costs Americans 4.8 billion hours of time, 1.9 billion gallons of wasted fuel (equivalent to two months' operation of the Alaska Pipeline), and $101 billion in combined delay and fuel costs. That's $713 per year for each commuter.

Even the most fuel-conscious human drivers could not match the fuel efficiency of autonomous cars communicating instantaneously and continuously within a connected and controlled infrastructure. Platooning alone, which would reduce the effective drag coefficient on following vehicles, could reduce highway fuel use by up to 20 percent (just as "drafting" behind the lead allows cyclists to reduce their exertion).[33] Nonrecurrent traffic congestion would be a thing of the past; stop signs and intersection queuing could also disappear.

Vehicles could also be significantly lighter and more energy efficient than their human-operated counterparts as they no longer need all the heavy safety features, such as reinforced steel bodies, crumple zones, and airbags. (A 20 percent reduction in weight corresponds to a 20 percent increase in efficiency.)

And we could even turn off a few lights. Today's roadways and supporting infrastructure are designed for human drivers—who need visual input to navigate. Thus, multiple electric traffic lights operate 24/7 365 days a year at every controlled intersection across the U.S. (Even in times of low traffic volumes, the signals must at least flash.) Across the nation, our streets, intersections, and highways are brightly lit all night for the benefit of human drivers. An autonomous vehicle, capable of "seeing" with infrared, radar, or other means, would have no need for such excessive lighting and signals. We could design our night lighting for safety and security, rather than vehicles. Converting the transportation infrastructure for autonomous vehicles could eliminate the need for much of the night lighting across the nation, reducing light pollution and energy use.

Potential New Business Models

In today's consumer-driven technology world, smart phone and tablet makers turn out new models every year (at least) to feed their tech-hungry consumers with the "latest and greatest." Will the same phenomenon begin to occur in the driverless era? We think so. Consumers will expect the latest gadgets in their driverless cars—and that means a new landscape and new business pressures for current players in the automotive ecosystem. As Larry Burns puts it, "Incumbent players rarely do well when industries disrupt. [34]" There are many industries involved in this complex ecosystem of self-driving, each with a varying pace of speed and innovation. Convergence of technologies may lead to convergence of industries in which ecosystem participants will need to compete and collaborate at the same time. There will be more pressure than ever to innovate or get left on the scrap heap of outdated technologies. The varying capabilities, willingness, and foresight of the various ecosystem participants will ultimately answer many of the questions posed by the coming convergence. Who will play the leading role in this ecosystem when self-driving becomes a reality? Who will create value, and who will claim it in the self-driving ecosystem?

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[31] Skabardonis, A., P. Varaiya, and K. F. Petty. "Measuring recurrent and nonrecurrent traffic congestion." *Transportation Research Record.* 1856, 118-124, 2003.

[32] Texas Transportation Institute (TTI). *Urban Mobility Report.* Sept 2011. <http://tti.tamu.edu/documents/mobility-report-2011-wappx.pdf>, 7/12/2012.

[33] Twenty percent is an accepted estimate based on field tests by PATH (California) and in the European SARTRE project (Volvo, Ricardo, etc.). Most of the sources are project web sites. Vaughan, Michael. *The Globe and Mail* [Toronto, Ont] 08 June 2012: D.6.

[34] Comment made during presentation NADA/IHS Automotive Forum, NYC, April 3 2012.

Congestion costs Americans 4.8 billion hours of time and 1.9 billion gallons of wasted fuel.

Who will make and sell cars in the future?

Imagine a new automotive ecosphere in which manufacturing is no longer a core competency and consumer demand for the newest technology is as avid as demand for the latest, greatest video console or smart phone. Who will make and sell cars? Who will get left behind? What kinds of strategic alliances, joint ventures, or mergers will reshape the competitive landscape? Will new consumer products companies enter the market? In pondering these questions, we've identified four potential new business models.

> "Incumbent players rarely do well when industries disrupt."
>
> *– Larry Burns, Co-Author of Reinventing the Automobile: Personal Urban Mobility for the 21st Century*

The Branded Integrated Life-Style Model

It's a sleekly designed experience, riding in this self-driving car. As elegantly designed as the sleekest smart phone. You use an app on your phone to summon your car when you need it or to program a daily pick-up. It's as simple as setting the alarm on your phone. Your windshield doubles as a screen, synching seamlessly with your other connected devices. As you ride along, you swipe through applications and web sites, checking your progress and the local weather on a digital dashboard, uploading photos to your favorite web site or watching a video. When you arrive at your destination, the screens you've opened are synched and waiting for you on whatever device you pick up next.

In this model, perhaps a company with no traditional presence in the auto industry that is already an integral part of the consumer's life outside the vehicle could become a key participant in the ecosystem. Since self-driving vehicles will no longer need the same level of rigorous testing and validation, and manufacturing could potentially be outsourced, their emphasis would be on consumer research, product development, and sale of integrated lifestyle experiences.

The Branded Lifestyle Value Proposition: Design, Technology, Software, Consumer experience

The Open System Model

It's all about the data and how to use these data to customize the consumer value proposition. The market for big data is growing exponentially. Market intelligence provider IDC predicts that by 2015 the "Big Data" market will be $16.9 billion, up from $3.2 billion in 2010.[35] A major player in the data market might not want to manufacture vehicles, but could well design a vehicle operating system. With more than a billion cars serving up trillions of data points about consumer behavior, traffic patterns, and topography, an operating system (OS) developer could afford to give away the OS but accrue significant value from the data they could aggregate. Who would manufacture the vehicle? The OS provider could partner with any of the world's vehicle manufacturers—and not just the traditional automotive manufacturers. Partnerships could be established with one or more new players who might compete in the branded technology arena.

The Open System Value Proposition: Utility, Technology, Customization

The Mobility On Demand Model

Zipcar was the pioneer in the shared-vehicle field, but other players are breaking into the market. Whereas current mobility on demand providers must make vehicles easily accessible for customers in urban areas, their vehicle maintenance and parking fees are high. With self-driving vehicles, proximity to end-users would no longer be necessary. Vehicles could be dispatched by taxi and car service companies.

Giant retailers with a core competence in managing complex distribution channels or fleet providers with the capability to manage the complexity of renting and allocation of fleets could enter the fray and accrue significant value in the new ecosystem. New entrants in the market might compete at either end of the spectrum—with generic, low-cost utilitarian transportation on demand at one end (the low-cost airline model) and super-luxury mobile executive suites and sleeping pods at the other (the first class or private jet experience). Success will be determined by efficiency, reliability, flexibility, vehicle maintenance, customer service, ease of human-vehicle interface, and integration with existing consumer devices—and all the other psychographic factors that determine consumer behaviors and brand preferences.

The Mobility on Demand Value Proposition: Flexibility, Reliability, Convenience, Cost

The OEM Model

Traditional automotive manufacturers have decades of experience in designing and manufacturing vehicles, and shaping an emotional connection with consumers. But will they move fast enough to maintain their brand dominance? Smart automotive manufacturers should be planning now, thinking about how to restructure their organizations and what potential strategic investments they should be making. History has not been kind to those who get stuck protecting the status quo in the face of disruptive change. In fact, collaboration is already taking place across the ecosystem as companies strive to stay relevant. The joint project between Intel and DENSO[36] to develop in-vehicle communication and information systems exemplifies the new cross-industry synergistic relationships.

Vertical integration is an option for companies looking to bring a critical skill or technology in house. Some vehicle manufacturers have established venture capital subsidiaries to invest in promising new technologies as a means of bridging any skill or technology gaps. Doing so may provide a competitive advantage in this rapidly evolving ecosystem.

The OEM Value Proposition: Design, Technology, HMI, Supply Chain Management

[35] IDC Press release (March 7, 2012), http://www.idc.com/getdoc.jsp?containerId=prUS23355112, 7/10/2012.

[36] http://newsroom.intel.com/community/intel_newsroom/blog/2012/03/01/chip-shot-intel-and-denso-collaborate-on-automotive-research.

Appendices

Pros and Cons of the Technologies in Development

The table below shows the potentially applicable technologies, their strengths and limitations, and the key players developing them.

Technology	What It Does	Limitations & Opportunities	Key Players
LIDAR	Light Detection And Ranging. An optical remote sensing technology that measures distance to a target or other properties of the target by illuminating it with light.	Noise removal. Interpolation to fixed point spacings. Triangulation issues.	Siemens, Hella, Google
GPS	The Global Positioning System is a space-based satellite navigation system that provides location and time information anywhere on or near the earth.	The accuracy of a GPS receiver is about +/- 10 meters, not practical for locating an object the size of an automobile, which is about 3 meters long.	Garmin, TomTom, Parrot, Apple, Google, Government
DGPS	Differential Global Positioning System is an enhancement to GPS that improves location accuracy from +/- 10 meters to about 10 cm.	The DGPS correction signal loses approximately 1 meter of accuracy for every 150 km. Shadowing from buildings, underpasses, and foliage causes temporary losses of signal.	Government
RTK	Real Time Kinematic satellite navigation is based on the use of carrier phase measurements of the GPS, GLONASS, and/or Galileo signals where a single reference station provides the real-time corrections.	The base station rebroadcasts the phase of the carrier that it measured; the mobile units compare their own phase measurements with the ones received from the base station.	N/A
Digital Maps	Digital mapping (also called digital cartography) is the process by which a collection of data is compiled and formatted into a virtual image.	Only some parts of the world have been mapped (mainly urban areas), and there is a need for a critical mass of mappers to enter and cross-validate data in order to achieve a satisfactory degree of accuracy.	Google, TomTom, Microsoft, Navteq, Apple

Glossary

Glossary of Terms	
3G	Third Generation of Mobile Telecommunications
4G	Fourth Generation of Mobile Telecommunications
AAA	American Automobile Association
ABS	Antilock Braking System
ADAS	Advanced Driver Assist Systems
AHS	Automated Highway Systems
CACC	Cooperative Adaptive Cruise Control
CAFE	Corporate Average Fuel Economy
CAMP	Crash Avoidance Metrics Partnership
CES	Consumer Electronics Show
DGPS	Differential Global Positioning System
DSRC	Dedicated Short Range Communication
ESC	Electronic Stability Control
GDP	Gross Domestic Product
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GPS	Global Positioning System
HMI	Human Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
LBS	Location-Based Service
LIDAR	Light Detection and Ranging
LTE	Long-Term Evolution
MIT	Masachussetts Institute of Technology
NHTSA	National Highway Traffic Safety Administration
NRI	Notice of Regulatory Intent
OEM	Original Equipment Manufacturer
OS	Operating System
ROI	Return on Investment
RTK	Real-Time Kinematics
SAE	Society of Automotive Engineers
USDOT	United States Department of Transportation
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to External environment
VII-C	Vehicle Infrastructure Integration Coalition

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