I see. I think. I drive. (I learn).

How Deep Learning is revolutionizing the way we interact with our cars

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A MESSAGE FROM GARY SILBERG

DEEP LEARNING: DRIVING TOWARDS FULL AUTONOMY

Your brain, even your 6:00 a.m. brain, is amazing: On too few hours of sleep, after a mind-numbing 52-minute commute, you arrive at work having accomplished some incredible things you do not even realize. You saw 235 road signs, 12 bicycles, 12,430 trees, 1,376 cars, 4 police cars with their lights flashing, and 16 people texting while driving. You accelerated; you stopped; you turned; you merged; you swerved. You changed radio stations, drank a cup of coffee, and made two hands-free phone calls. And yet none of this phased you. In fact, you might not remember the commute.

Now imagine you—or some genius you hired—wrote a computer program that would drive your car for you on that exact same trip. Think about that for a moment: How many millions if not billions of lines of code would be required to figure out all the different permutations to make this "simple" commute successful?

How do you program a car to stop at a red light? To allow it to turn right after red? Except in New York where it is always illegal? Or where it is specifically forbidden? What if there is a pedestrian in the crossing? What if someone breaks the law and runs the red light in front of you? What if a bicycle comes speeding past you in the wrong direction?

Now multiply something as supposedly simple as that by a million or likely more, for all the actions and permutations necessary for that car to drive you. Impossible, right?

Not anymore. Thanks to deep learning, what once seemed like fantasy is swiftly becoming reality. An advanced form of artificial intelligence, deep learning is accelerating to the point of transforming the development of self-driving cars. It is steering an exciting new course for the automotive industry. Instead of humans programming every one of those actions and permutations, a machine builds on the data of its experience. It's as if it learns on its own.

Deep learning is not only powerful and transformative but essential for automakers. It has asserted itself as a critical technology, speeding up the clockspeed of innovation. And yet the number of experts able to create deep learning is few. They possess a level of expertise that make them beyond special.

Four years ago, KPMG boldly asserted that self-driving cars are the next revolution[1]. Since then, we have charted the technological advances and changing consumer perspectives on autonomous vehicles,[2] analyzed the evolution of the automotive ecosystem in response,[3] and advised you on the accelerating pace of innovation required to compete in it.[4]

Now we want to analyze deep learning's role in transforming the automotive and transportation industries. To do so, we interviewed mathematicians, heads of R&D, computer scientists, automotive executives, and founders of self-driving start-ups. All of our research has brought us to this conclusion: Deep learning will be the driving force that propels fully autonomous vehicles into reality. And it will impact virtually every corner of the industry.

There are risks. There are threats. There are unknowns.

Only time will tell how the future unfolds. However, one thing is for sure. Whether you are an automaker, automotive supplier, technology firm, or any other player in the automotive value chain, opportunity is up for grabs. So how will you seize it? How will you navigate uncertainty? How will you respond to disruption in the market?

In the following pages, we will explore what deep learning is, how it solves self-driving challenges, and what it will mean for your business as deep learning unlocks full autonomy.

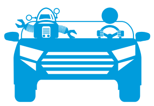
Gary Silberg
Partner and National Automotive Leader

[1] Self-Driving Cars: The Next Revolution (KPMG, 2012)
[2] Self-Driving Cars: Are We Ready? (KPMG, 2013)
[3] Me, My Car, My Life (KPMG, 2014)
[4] The Clockspeed Dilemma (KPMG, 2015)

KEY INSIGHTS: HUGE OPPORTUNITIES

Deep learning is driving significant change in the development of autonomous cars and for the automotive and transportation industries. These are thrilling, even profound developments with far-reaching implications, and they are ones that companies in and around the automotive ecosystem must understand if they are to adapt and to survive.

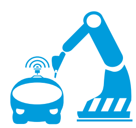
BY 2030, A NEW MOBILITY SERVICES SEGMENT WORTH WELL OVER $1 TRILLION DOLLARS WILL EMERGE FOR PRODUCTS AND SERVICES RELATED TO AUTONOMY, MOBILITY, AND CONNECTIVITY. THE OPPORTUNITY IS MASSIVE!



From man to machine, deep learning is revolutionizing how we interact with our cars. Deep learning is swiftly transferring driving operation from man to machine. Already, semi-autonomous vehicles manage low-risk situations. And deep learning algorithms will be critical to achieving fully autonomous cars, able to navigate any circumstance.

Mobility services will be a major new market and therefore a critical battleground. By 2030, a new mobility services segment worth well over $1 trillion dollars will emerge for products and services related to autonomy, mobility, and connectivity. The opportunity to shape and participate in this new and evolving ecosystem is massive.

Vehicle operation and ownership is changing. In *"The Clockspeed Dilemma,"* we predicted that the combination of mobility and autonomy will lead to personal miles soaring and ownership models changing. With deep learning as the catalyst, that transformation is accelerating. Car ownership is shifting from individually owned vehicles to shared driving experiences, increasing consumer focus on mobility and transportation on demand. We are moving from a product to a service model. The enormous economic and social effects of that shift affect carmakers but also auto repair chains, dealers, and insurers.



Most car companies will not simply be automakers anymore. As deep learning accelerates autonomy, carmakers will make choices whether to remain pure automakers or to become mobility service providers, or both. The strategies automakers select will influence how much of the transport experience they participate in, what profit pools they access, and ultimately whether they thrive or survive as independent businesses.

Investment focus is changing. Advances in mobility, connectivity, and autonomy and the related services are encouraging more dollars directed toward acquisitions, joint ventures, and partnerships.

Miles are like gold! Deep learning will set off a race for accumulating miles, but not all miles are created equal. It is the eventful new situations, behaviors, environments, and, most importantly, "corner cases"—rare events which occur so infrequently it is nearly impossible to collect real-world data for self-driving algorithms to train on—that create the richest datasets. Out of them come the learnings needed to build full autonomy.

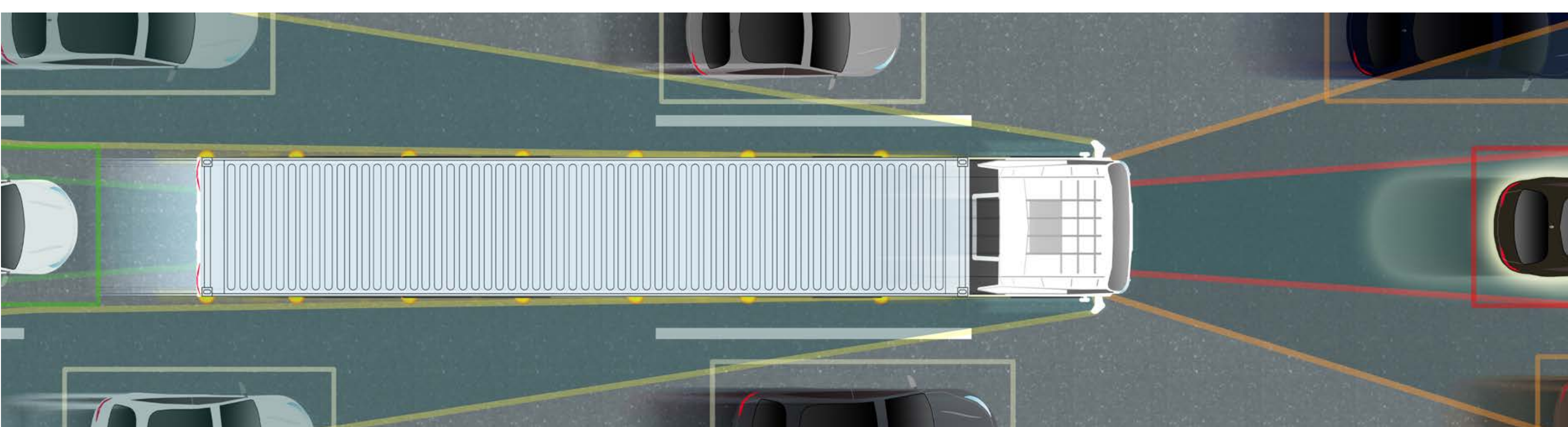
Talent is the new arms race. There are precious few people capable of building deep learning systems. Automotive players are already scrambling to find them.

The nervous system will become the center of vehicle design. It is a new era in automotive product development and manufacturing - one that emphasizes the car's nervous system - which includes the computer "brain", sensors, controls for braking and driving, driver interaction, data storage, and over the air updates with increasingly smart neural nets over time - even more than the powertrain. This is an enormous shift in organizational structure and operating model for most car manufacturers.

Power of the fleet will eclipse the importance of the individual car. The interaction of the individual car with the fleet and ecosystem in which it drives will be essential to deep learning and autonomy. Connectivity will ensure constant interaction with the network: It is essential for localization mapping, operational mapping, routing, vehicle integrity, and the data on those precious miles, from which the entire fleet learns.

Highly secure, fleet-wide software architectures will be a new basis of competition. The emergence of the software platform as a powerful way to control, manage, and upgrade the car will become critical for competition. And the need for such a sophisticated system that is highly secure, independent of differences in model, and can be upgraded on all car models at the same time will create advantage in the marketplace.

Ideation and innovation will change. As carmakers develop new capabilities as experience and service providers, deep learning will be central to their efforts to innovate and to test those innovations. The change in perspective deep learning provides may change the way we think about ideation.



WHAT IS DEEP LEARNING?

While deep learning may be less known in the automotive sector, it has been around for more than 30 years and has already had significant impact on the world around us. Surprisingly, deep learning owes its success to a combination of biology, mathematics, and computer gaming. It all started in 1959 with two Nobel laureates figuring out how neural networks interact between cells in the human eye. Inspired by this, the first functional deep learning networks appeared already in 1965 to try to mimic biology.

From a layman's standpoint, deep learning is a high performance, dynamic way of computerized decision-making that can learn features, objects, and patterns automatically and more accurately with the more data you give it. A deep learning system identifies and classifies patterns utilizing a set of analytical layers. The first layer does a relatively primitive task, such as identifying the edge of an image. It then sends the output to the next layer, which does a slightly more complex task, such as identifying the corner of the image. This process continues through each successive layer until every feature is identified. In the final, deepest layer, the system should reliably and quickly recognize the pattern. For example, the layers of the algorithm could determine: 1) The object is round; 2) The object is red; 3) The object is shaped like an apple; 4) The object is a red delicious apple. According to Dr. Raquel Urtasun, associate professor of Computer Science at the University of Toronto, "In deep learning, the layers in the beginning are calculating very simple things. As the computer goes farther and farther into the layers it combines what it sees to more complicated concepts. At the end it gets the output. The fact that it can learn by examples at each layer is the key thing."

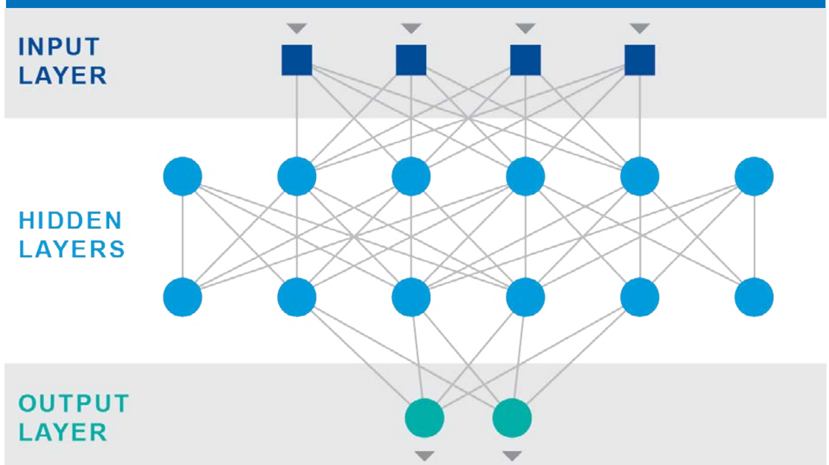
Deep learning systems are "trained" by repeatedly seeing more and more input data, or training examples, and gradually optimizing their ability to make an accurate prediction. As the "wrongness" of their predictions is minimized, they become smarter and smarter until they can make highly accurate predictions. In this way, the system learns to recognize patterns in masses of unstructured raw digital data. The result is a system that can handle unexpected situations and quickly suggest the best possible option. If it does not know what to do, it can be "trained" with additional data inputs how to handle the situation better and make a different decision or recommendation in the future.

The term "deep learning" was first used in 1986 but, while the technology worked, there was not enough data or processing power readily available for deep learning systems to be used effectively. It would take the system far too long to arrive at its predictions, and the accuracy of its predictions was too low to be useful. Enter the computer gamers to save the day—demanding faster and faster computers and more powerful graphics processing units (GPUs) that, it turns out, are perfect for the kind of number crunching and matrix/vector math involved in deep learning.

Since then, there has been an explosion in investment in deep learning, fueling rapid advancements in the capabilities and applications of the technology. When Apple's Siri or Microsoft's Cortana understand and respond to your question, that is due to deep learning. Not only do Siri and Cortana accurately process natural language, but they seem to understand intent, as they are able to interpret commands that contain slang, shorthand or accents.[5] When your Google search almost instantly turns up the exact Web result you need, that is also due to deep learning.[6] And when Amazon recommends you the perfect product, you can thank deep learning. Amazon's deep learning system analyzes how purchases relate to other purchases and uses those insights to make predictions about what you might be interested in buying based on your past shopping behavior.[7]

Deep learning is absolutely critical for solving one of the major computer science challenges of autonomous driving: managing the unpredictable. Early autonomous vehicles relied on manually-coded, deterministic algorithms, but such systems simply could not handle all the scenarios that a vehicle might encounter on your "simple" drive to the office. Not only were the many rules of driving immensely difficult to express algorithmically, but even the most precise rules could not account for the millions of potential exceptions to those rules.

"Deep Learning has the potential to impact every corner of the automotive industry and beyond."
Gary Silberg, National Automotive Leader, KPMG

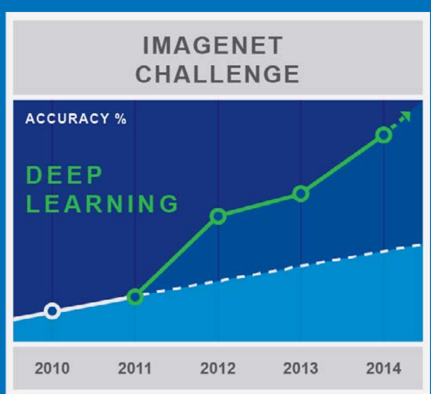


[5] The Brain is Here and It's Already Inside Your Phone (Backchannel, August 24, 2016)
[6] AI is changing the technology behind Google search (Wired, February 4, 2016)
[7] Amazon's Giving Away the AI Behind It's Product Recommendations (Wired, May 16, 2016)

THE RESEARCH THAT REVIVED DEEP LEARNING

The breakthroughs in deep learning we are seeing in the automotive industry today can be traced back to—of all things—the development of a computer program that could recognize cats in screen grabs from YouTube videos. Deep learning got a major boost when a Google Brain team designed a massive neural network that could detect objects in millions of unlabeled images (of cats, in this case) without human help.[8]

But what really won over the computer vision scientists who are now advancing driverless technology was University of Toronto machine learning expert Geoffrey Hinton's victory in an ImageNet competition, which tests computer programs on how well they can label new images after being trained on a million labeled images. The first program to use deep learning, Hinton's entry won by a landslide. The deep neural network cut in half the difference between the image identification error rate of the best algorithms to date and that of an average human.



Before the competition, the computer vision community was largely using prior knowledge to build the software systems behind autonomous driving features. After it, "the computer vision community flipped to use deep learning," says Prof. Raquel Urtasun, associate professor of computer science at the University of Toronto.

As computer vision innovators began to show performance gains in identifying not just cats, but cars, pedestrians, signs and lanes, the automotive industry followed suit and started adopting deep learning. So did other industries. Deep learning is now used for speech recognition, natural language processing, and many other computer science challenges.

"We can do image classification and detection much better than ever before with deep learning," says Urtasun.[9]

Enter deep learning. Deep learning is a critical enabler of the self-driving vision because it helps software engineers build a vehicle that can essentially think on its feet—or wheels—without human intervention.

Deep learning systems for vehicles operate at the fleet or original equipment manufacturer (OEM) level where they can collect and analyze data from billions of miles traveled by individual vehicles. The system is initially "trained" in the lab or datacenter and test fleet with rules-of-the-road, tens of thousands of hours of video and observation of a few million miles with human test drivers. Once a safe, reliable neural net is developed, it is loaded into the car. The benefit, however, is the collective wisdom of all the driven miles that have come before it, rather than the inexperience of a newly licensed driver. Each time a car in the fleet encounters something new—an unmapped construction zone, a new driving behavior, an action by another car or a pedestrian, or an animal not anticipated in its driving program—it uploads that new experience to the fleet's deep learning system. The deep learning system captures and analyzes hundreds of millions and

[8] Computer Science: The Learning Machines (Nature, Jan. 8, 2014)
[9] How a Toronto professor's research revolutionized artificial intelligence (TheStar.com, April 17, 2015)

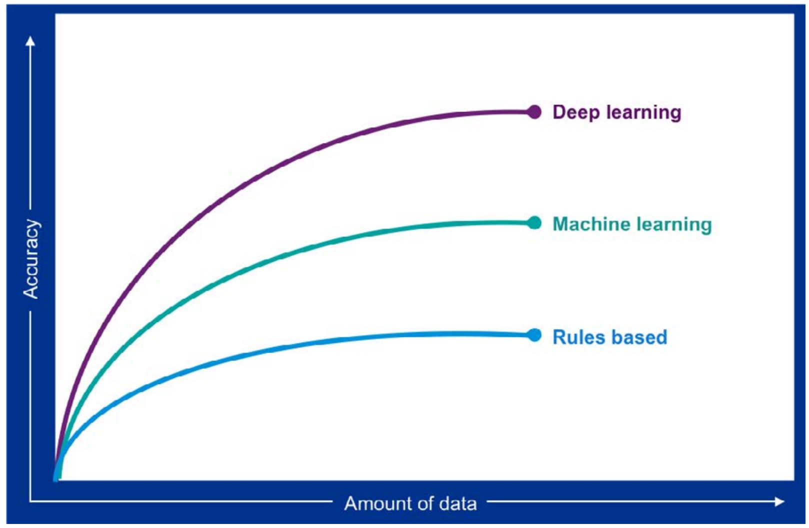
ultimately billions of miles and as it learns, tests, and validates the new neural net, updates to the driving program are released back to all the cars in the fleet.

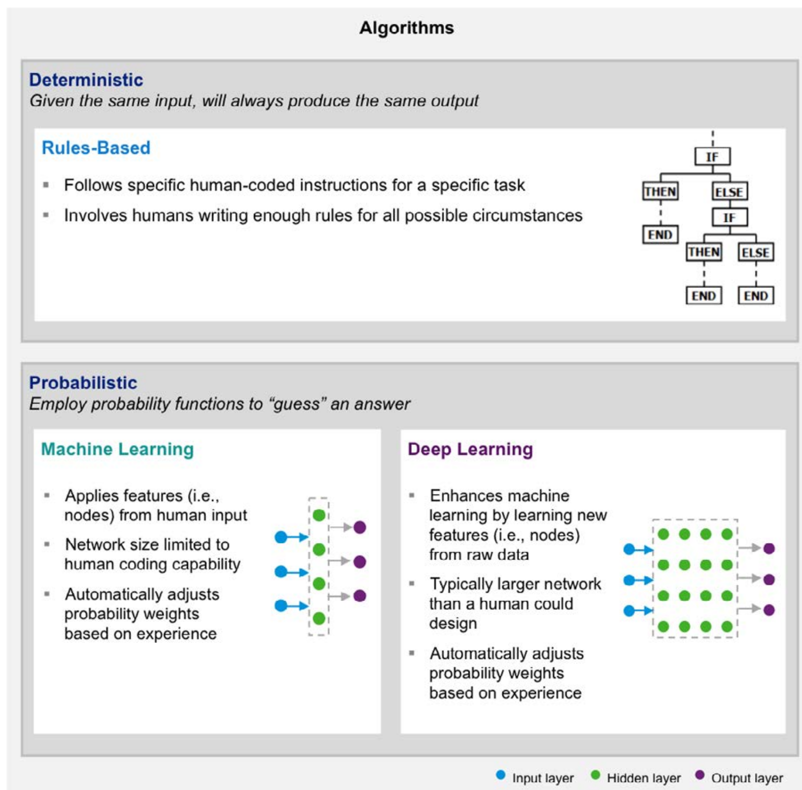
Although there has been significant progress in deep learning over the last few years, there are a number of limitations to what it can do and hurdles that need to be overcome before it can unleash full autonomy.

From a technological standpoint, advances are needed to improve how well deep learning systems manage unpredictable situations. Engineers will also need to gain greater transparency into how autonomous vehicles make decisions so they can improve upon incorrect decisions.

From an industry standpoint, tech players will need to ensure their deep learning solutions meet auto industry standards for safety and reliability. At the same time, automakers will also need to change their evaluation and testing processes to ensure they are accumulating miles in a way that captures enough information to inform anticipated situations, and find ways to capture unanticipated situations and stand up processes to review, analyze and retire corner cases as they occur.

Deep learning takes advantage of large data sets to learn and improve over time





DEEP LEARNING: CHOOSING THE RIGHT ROUTE

Let us take a scientific look at the two prevailing approaches of deep learning applied to autonomous driving to uncover some pros and cons.

SEMANTIC ABSTRACTION

Semantic abstraction uses a modular approach to break down the problem of autonomous driving into its various components. One component may detect vehicles. Another detects lanes. Still another detects what lies at the boundaries of the lane—a curb, a guardrail, or a row of cars, for example. Using prior knowledge and domain expertise, software engineers train each individual component for its specialized role by labeling, or annotating, data images to identify their real-world meaning.

When each component has mastered its assigned task, data has to be transferable between the components so they can all work together to decide how to control the vehicle. So, once the vehicle detection component knows where the vehicles are, the lane detection component knows where the lanes are, and the lane boundary component knows where the curbs are, they combine that understanding with tons of other inputs about the driving environment collected by still other components. Then the master computer can decide what trajectory to take and what speed to go to maneuver the car safely while avoiding obstacles.

PROS

Lower tolerance for mistakes: Before the network is downloaded onto an active autonomous vehicle, the algorithms responsible for every single separate component of driving can be explicitly trained until each has very high accuracy rates in performing its individual task.

Can pinpoint where errors occurred: When failures occur—when the car makes the wrong decision—software engineers are able to more easily identify where it may have occurred in order to address it.

More capable of managing the unpredictable: The system has been fed prior knowledge of layers of labeled data that helps it adapt to an unusual situation, like a child chasing a ball into the street. It has seen thousands of people. It can tell a child is a person. It can generalize what a person is likely to do. And it knows how to control the vehicle to avoid a person.

CONS

Requires intensive prework and complex programming: Before the system is up and running, the engineering team first has to use its own domain expertise to design the network and code algorithms for every component of driving. Then, the team has to train each individual component by meticulously labeling the dataset, an extremely intensive and time-consuming process.

Often processes label more data than necessary: The amount of data represented may be overkill with unnecessary redundancies, because not all data in a scene will be relevant to driving decisions.

END-TO-END LEARNING

End-to-end learning is a more disruptive deep learning technique, in which the act of learning to drive is done automatically through training examples of real human driving data. Rather than breaking down driving into its various parts and training components for each function, the system operates by working holistically through large data sets, rather than relying on the existence of specific features to be detected.

"Car manufacturers will have to consciously create 'surplus' capacity in vehicle's sensing, computing and communication systems to meet the inevitable demands of future over-the-air updates to their driving programs. That is a profound change in the traditional program management model."

Tom Mayor,
National Strategy Leader,
Industrial Manufacturing,
KPMG

PROS

When fed big data, it can perform classification accurately without always requiring explicit labeling and annotation of scene data: With end-to-end learning, the network does not have to be explicitly told what a vehicle or a lane looks like. It takes big data set inputs and classifies features, objects, and situations as it experiences them. That means engineers do not need to pre-define and pre-program all of the various components that combine to enable the act of driving, nor do they need to spend countless man hours identifying and labeling objects in visual data sets.

The more data available for different types and situations, the more robust the resulting capability: As carmakers capture more and more data about the environment, objects, driving situations, and types of corner cases, end-to-end learning can be trained to achieve an end result very quickly and accurately. For example, NVIDIA, a leader in visual computing which offers specialized platforms for the automotive market and other fields, piloted an end-to-end learning system that flawlessly cruised the Garden State Parkway in New Jersey that had been trained on only 72 hours of driving data. Imagine how well trained these systems will be for driving when given 20 billion miles of information.[10]

Optimizes processing steps simultaneously: The internal algorithms self-optimize with the goal of maximizing overall system performance, rather than optimizing each human-selected component of driving, such as detecting lanes. This can lead to a better-performing system that solves the problem with the least possible processing steps, therefore requiring smaller networks.

CONS

Requires large data sets to support the learning process: In cases where there is not significant amounts of data collected, for example, in some corner cases, end-to-end systems will need to be augmented with human assistance and other algorithms utilizing other methods to achieve a solution.

Difficult to train and tune properly: Training an end-to-end system requires time to train and tune different behaviors and applications and often requires modification of different net architectures. This is highly dependent on the level of expertise of the engineers and scientists conducting the algorithm development. For example, whether to utilize a basic neural network structure, or a captioning network, or a convolutional network.

Time will tell which of these architectures will prevail or adapt in solving the problem of vehicle autonomy. As technology rapidly advances, that time is likely coming soon.

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[10] End to End Learning for Self-Driving Cars (NVIDIA Corporation, April 25, 2016)

I SEE. I THINK. I DRIVE. (I LEARN).

Underlying the efforts to develop autonomous cars is the need for the vehicle to "see," "think," "drive," and, when necessary, "learn" and improve. Already, semi-autonomous vehicles manage low-risk situations. And it is through this last "learning" step where deep learning will be critical to achieving fully autonomous cars, able to navigate any circumstance—particularly those with the most complex missions and set of interactions to navigate.

"The process of innovation will depend upon and therefore reflect the critical importance of deep learning." Todd Dubner, Principal, KPMG Strategy

I see—How vehicles sense the environment.

"Seeing" relies on real-time data collection from sensors on the car, like cameras, LIDAR (light imaging, detection, and ranging), ultrasonic and radar; and detailed mapping, routing, and other environmental information streamed from the cloud, like road conditions and traffic. And as connectivity increases, cars will be able to connect with other cars, smartphones, nearby infrastructure, or really anything in the continuously growing Internet of Connected Things to share information.

I think—How vehicles fuse information collected and determine a course of action.

"Thinking" is the complex process of fusing information collected from sensors and other sources to determine what is useful and accurate, and then making a decision about the appropriate action to take. Imagine, in a hundredth of a millisecond, understanding what is being seen, determining what has changed, interpreting other new information, and comparing all of the possible alternatives to make a decision. According to Dr. Alain Kornhauser, faculty chair of Princeton Autonomous Vehicle Engineering, the real challenge is dealing with not only what is happening now, but also being able to extrapolate what will be happening in the immediate future. Over time, deep learning might be used to help with this extrapolation.

I drive—How vehicles move and send signals.

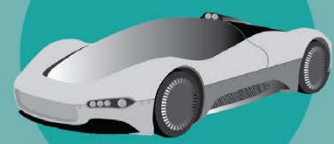
"Driving" is the execution of its decisions by sending signals to steer, accelerate, and brake the vehicle. The car responds to the system's choices about what steering angle, throttle position, or braking force to apply to safely navigate its current environment, and the car provides continual feedback to the driving system on the results—wheelslip, suspension travel, acceleration, yaw rate, and speed.

I learn—How the collective fleet of vehicles learn from experience.

"Learning" is the essential and differentiated way that deep learning creates a feedback loop to capture new experiences and events to analyze and improve the collective intelligence of the fleet. With every new experience, event, and corner case, deep learning increases its knowledge base and decision-making ability, which is then tested and pushed out to the vehicles to improve future decision making and performance.

I SEE

Most autonomous vehicle technology, deep learning and other, will employ a combination of three types of data collection for operations, though relying on each to different extents



SENSORS

Real-time data collection on the vehicle's surroundings, including road conditions, obstacles, etc. most often using a combination of the following:

- **Optical:** Camera technology capturing color, contrast, etc.
- **LIDAR:** Uses light pulses to map surroundings with high resolution
- **Radar:** Uses radio waves to map vehicle surroundings
- **Ultrasonic:** Uses high frequency sound for close range detection

Companies such as Mobileye, following the "sense and understand" approach, rely primarily on sensor data to orient the vehicle while driving

STORED & CLOUD DATA

Detailed map and driving experience data is streamed to vehicles in transit to augment sensor data, allowing the following:

- Vehicle routing
- Traffic updates
- Traffic signs & road conditions
- Algorithm updates based on driving experience

Companies like Google use a "store and align" approach, leveraging detailed maps to orient the vehicle and using sensor data less extensively

DATA FROM CONNECTED DEVICES

Data feeds from nearby objects used to improve autonomous algorithm performance, passenger experience, convenience, etc.

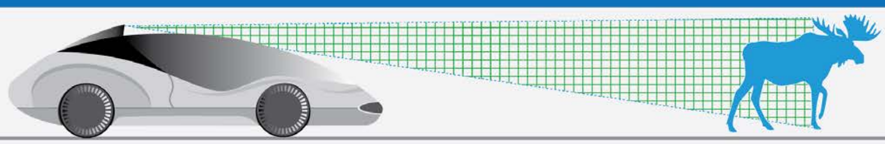
- Vehicle to vehicle
- Infrastructure to vehicle
- Device to vehicle

While current autonomous vehicle (AV) technologies make minimal use of this data, emerging markets for the Internet of Things and in-vehicle advertising may drive its growth

I THINK

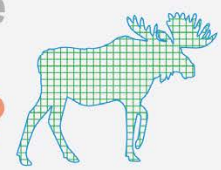
The complex process of fusing information collected from sensors and other sources to determine what is useful and accurate

1 Sensor data is fed into the deep learning algorithm



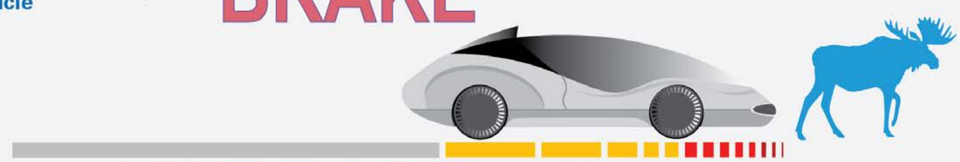
2 Objects, movements, etc. are identified based on the recognition of certain input characteristics to determine the vehicle's situation

Color · Location · Size · Distance · Is it a stoplight? · Shape · Velocity · Is it moving? · Is it a person? · Is it green? · Injury likely? · Collision course? · Legally can proceed? · Speed appropriate?



3 The vehicle situation then defines the most appropriate action for the vehicle

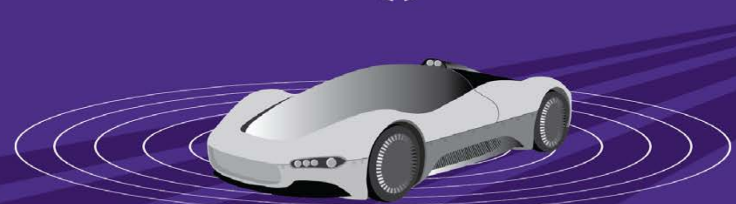
Accelerate · Maintain speed · **BRAKE** · Turn right · Turn left



I DRIVE

Once the vehicle algorithm comes to a decision on the most appropriate course of action, the car executes the decisions

While moving, the vehicle is constantly "seeing" and "thinking" to reevaluate and confirm its course of action



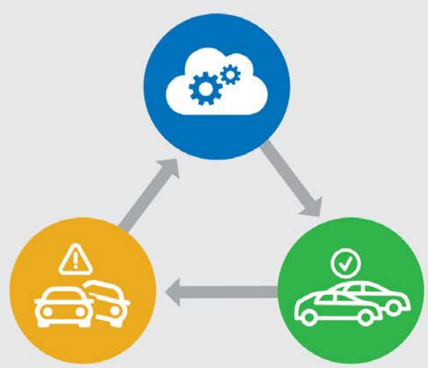
Before being commercially released, deep learning neural networks will be developed and trained from a combination of human driving data, from professional drivers, as well as millions of miles of simulated scenarios. As it is unlikely that traditional driving will reveal sufficient corner cases, simulated hazards will enable the creation of robust deep neural networks

I LEARN

The experience data is used to train and improve deep learning driving algorithms

Acquiring miles across diverse situations provides cars with many opportunities to learn from experience data and share this experience with other cars

Cloud data, datacenter, and algorithm repository



Sensor data, telematics, decision process, vehicle actions, and outcomes are constantly captured and pushed to the cloud

Newly improved driving algorithms are pushed out to autonomous vehicles on a continuous basis, allowing for constant performance improvements

A BRAVE NEW AUTOMOTIVE WORLD

We believe deep learning will have profound impacts on the automotive industry in three ways:

First, deep learning is enabling the rapid development of autonomous vehicles. As we discussed in our white paper, *"The Clockspeed Dilemma,"* this will open mobility to a host of currently underserved populations, shift vehicle ownership models, and drive massive growth in miles traveled.

Second, crashes will decline dramatically with ever-vigilant deep-learning based algorithms replacing or backing up easily distracted and error-prone human drivers. Thousands of lives will be saved in the U.S. and over 1 million globally, collision part revenues and profits will collapse, and the insurance market will be reshaped as insured risks simultaneously shrink and transfer from driver to driving algorithm. Add-on improvements in urban land use, labor productivity, and sustainability will further reduce externalities associated with today's personal-vehicle ecosystem.

Third, automakers will want to build a host of new capabilities to take advantage of the new environment. Innovation and product development will want to evolve to increase focus on design of the on-board "nervous system" of sensors, GPU-based supercomputer, actuators, and connectivity. A new skill community will focus on "above the car" fleet learning, connectivity, and cybersecurity. New in-use data streams will deliver consumer insights to feed drive/ride-experience innovations. Executive teams and boards will reassess the business portfolio to access new profit pools—possibly including entering mobility services, vehicle fleet management, and insurance or on-board systems-platform businesses.

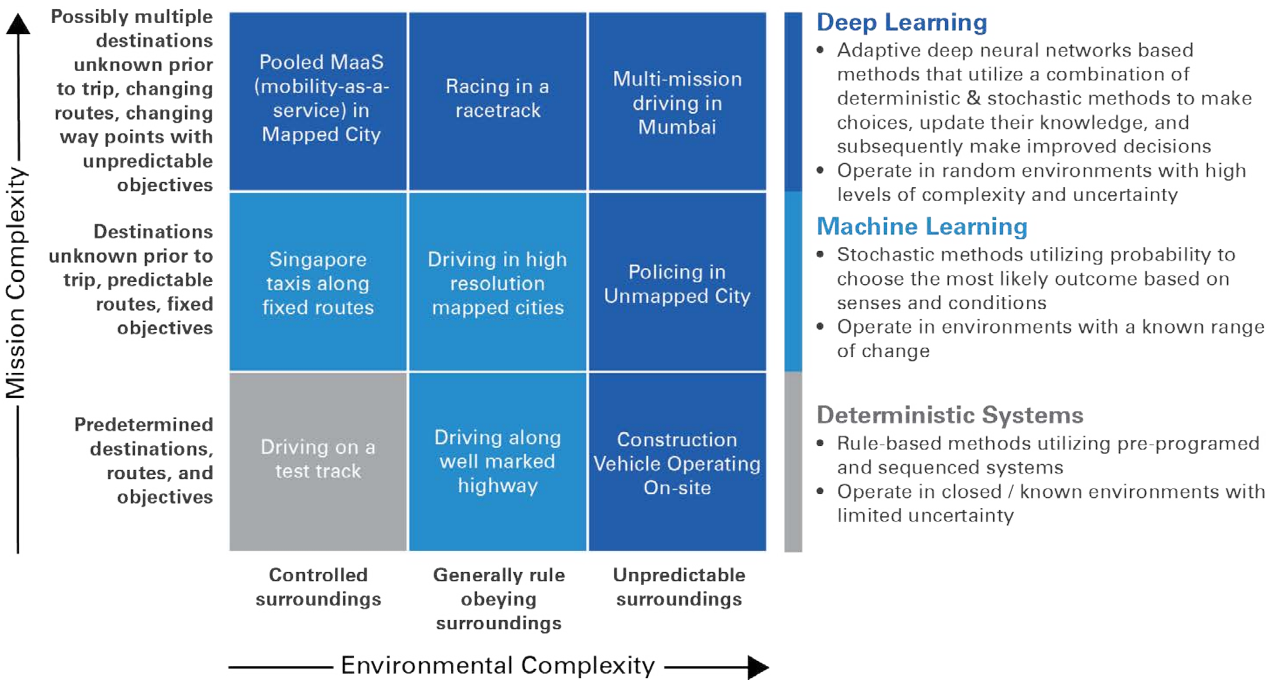
"The race has already started to retrofit cars currently on the road with additional sensors and to create platforms for aggregating and sharing information from all connected cars in real-time. The winners will either control unique data with many use cases, and/or control the sharing platform with the largest scale for each target segments". - Per Edin, Principal, KPMG Strategy

The direct impacts of deep learning will revolutionize the nature of doing business for automakers. So much so that unless those in the automotive space react wisely to the effect of deep learning, they may be out of business.

DEEP LEARNING DELIVERING THE PROMISE OF AUTONOMY

Deep learning-enabled autonomy is nearly upon us. Tesla has announced they are bringing a deep learning-enabled vehicle to market now.[11] It will be continuously improved through software updates to ultimately achieve full autonomy. Other new players are already on the road, serving customers in Pittsburgh and Singapore.[12,13] Most major automakers are developing production autonomous vehicles with committed on-sale dates in the 2020 or 2021 model year.[14] Initially those vehicles will be geo-fenced—restricted to "simpler" environments, such as very well-mapped urban areas or "lower-distraction" highway and suburban environments, depending on the individual automaker's design choices and market strategies. But a few years after that, deep learning will likely enable free-ranging fully autonomous vehicles to take us wherever we choose to be driven.

MISSION VS. ENVIRONMENTAL COMPLEXITY



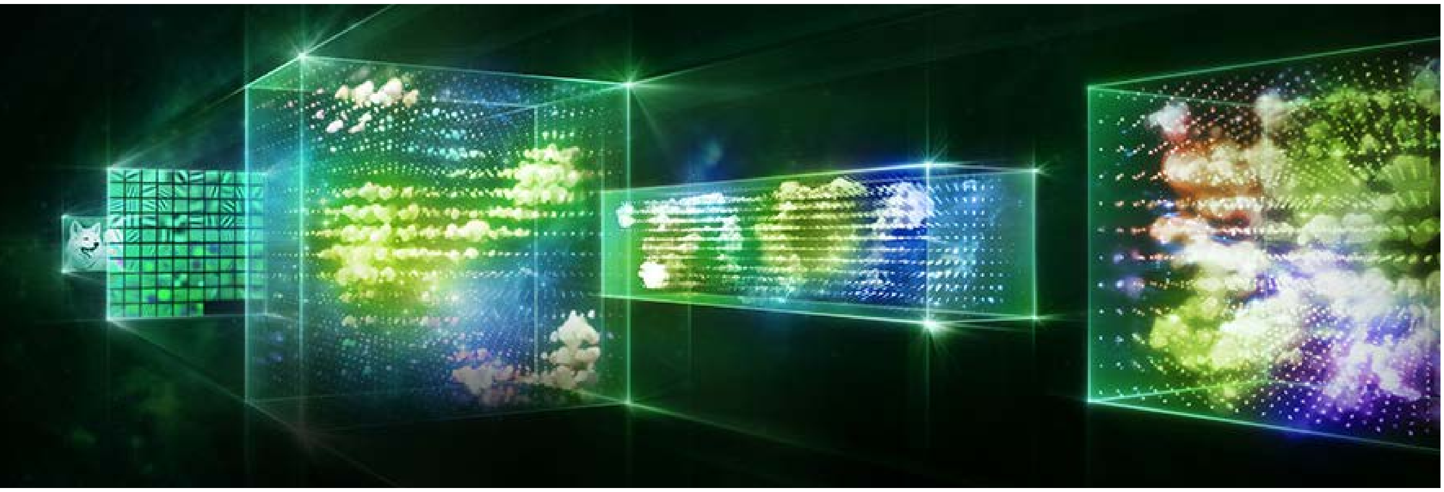
Source: KPMG research

[11] https://blogs.nvidia.com/blog/2016/10/20/tesla-motors-self-driving/
[12] Pittsburgh, your Self-Driving Uber is arriving now (Uber, Sept. 14, 2016)
[13] World's First Self-Driving Taxis Debut in Singapore (Bloomberg, Aug. 25, 2016)
[14] The complete timeline to self-driving cars (ReCode, May 26, 2016)

THE SIGNS OF AUTONOMY ARE ALREADY AROUND US

Because of deep learning, the Audi A7 already has a camera-based technology that recognizes traffic signs, like speed limits, by their shapes and characters.[15] Because of deep learning algorithms, Tesla Autopilot enables drivers to stay within lane markers, and change lanes, without having to turn the steering wheel.[16] Deep learning has catalyzed the development of high-resolution mapping in Google's prototype self-driving car. It can navigate safely through four cities, including metro Phoenix, because deep learning accelerated the capture and analysis of data as the Google Car drove their streets.[17]

As deep learning accelerates the adoption of autonomy, the effects of autonomy we predicted in *"The Clockspeed Dilemma"* will appear sooner, and because they are sooner, they will disrupt the automotive ecosystem more swiftly and more forcefully than we expected only a year ago. The automotive and transportation industries should bear in mind five particular effects of accelerated autonomy.



Visualization of a deep neural network, courtesy of NVIDIA

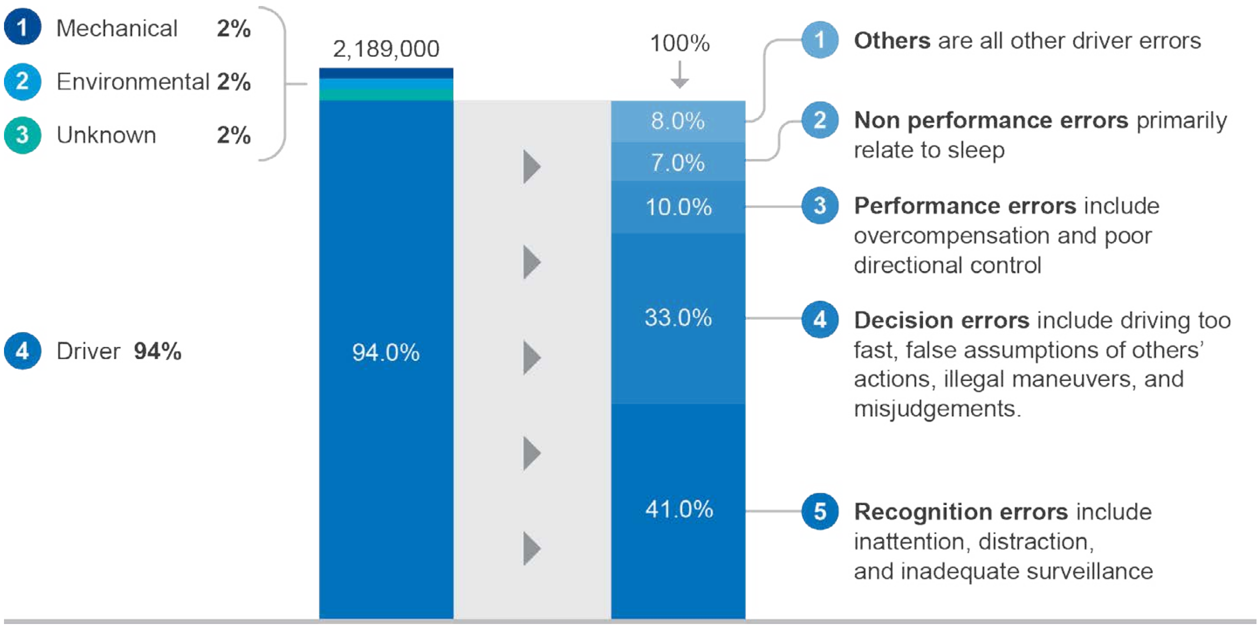
SAFETY, MOBILITY, THE ECONOMY, SOCIETY AND THE ENVIRONMENT

SAFER ROADS.

As we speed still faster toward autonomy, the greatest effect will be the reduced number of accidents. Gone will be driver error, which are mostly related to the time it takes for drivers to react to danger. The National Highway Traffic Safety Administration (NHTSA) reports driver error to be the cause of 94 percent of accidents—at a potential economic savings of $300 billion. Still more important will be the reduction, or near elimination, of fatal accidents. In the United States alone, autonomous vehicles could save a huge number of lives. There were 35,200 traffic

[15] How does road sign recognition work? (https://www.carwow.co.uk)
[16] Tesla Model S Adds 'Speed Assist,' Lane-Departure Warning (Green Car Reports, Oct. 4, 2014)
[17] www.google.com/selfdrivingcar/

94% OF ACCIDENTS ARE CAUSED BY DRIVERS



Source: NHTSA, KPMG research

fatalities in 2015, a 7.7 percent spike from the year prior, largely due to behavioral factors such as driving drunk, distracted, drowsy, or unbuckled.[18]

Deep learning will not only accelerate this improvement in safety but make this safety more apparent and more attractive for consumers. When drivers choose to take over the wheel of a self-driving car, deep learning will nonetheless promote safety. According to Dr. Panagiotis Tsiotras, professor of Aerospace Engineering at Georgia Tech, deep learning face and voice analytics will soon be able to detect when a human driver is impaired. That has already led some forward-thinking automakers to begin development of "active" vehicle safety systems, capable of returning a car to autonomous mode when its driver poses a danger. The system would have levels of autonomy and intervention; it could be completely manual or completely autonomous based on the driver's current state.[19]

MOBILITY FOR ALL.

Two years ago, in our white paper *"Me, My Car, My Life,"* we detailed the powerful effect of mobility that autonomous vehicles will produce. A year ago, in *"The Clockspeed Dilemma,"* we explored its appeal for transporting children, the elderly, and the disabled, quantifying that appeal in a remarkable increase in vehicle miles traveled. We are seeing mobility advance

[18] Traffic fatalities up sharply in 2015 (www.NHTSA.gov, Aug. 29, 2016)
[19] Interview with Panagiotis Tsiotras, professor of aerospace engineering at Georgia Tech

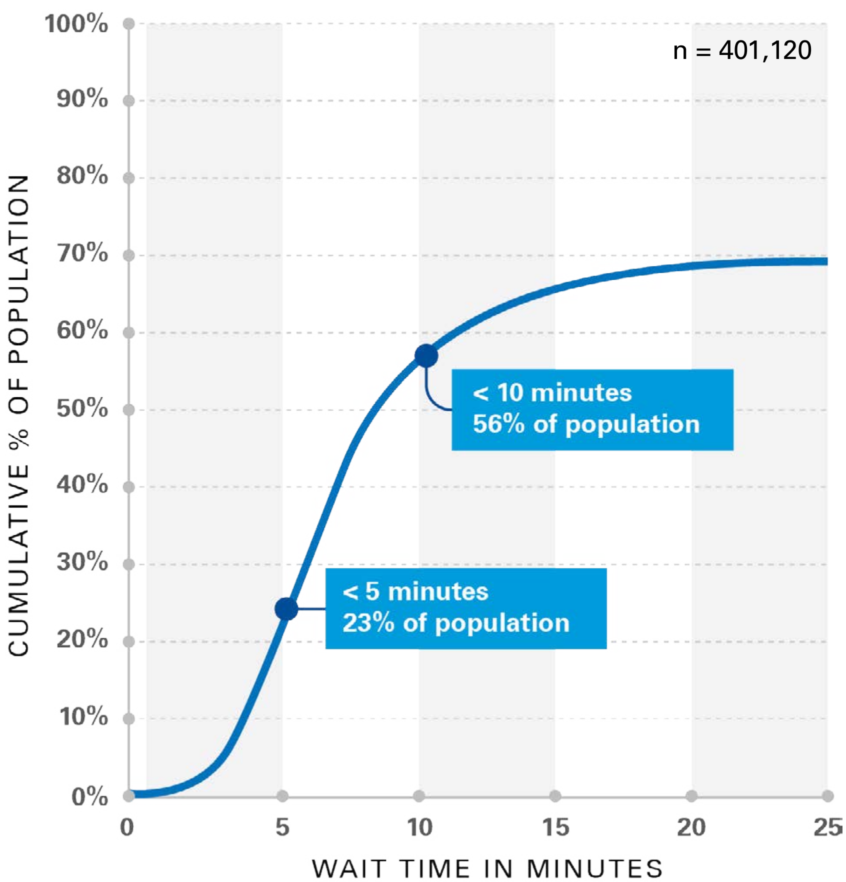
even more quickly than we anticipated, with more than 67 percent of the U.S. population able to access an Uber in less than 10 minutes and most global urban centers seeing wait times of less than 3 minutes.

With the accelerating effects of deep learning on autonomy, mobility will emerge in the automotive ecosystem with astonishing speed. Mobility will quickly appear less as a trend and more as the norm: The car will soon be more of a service rather than just a product to be owned.

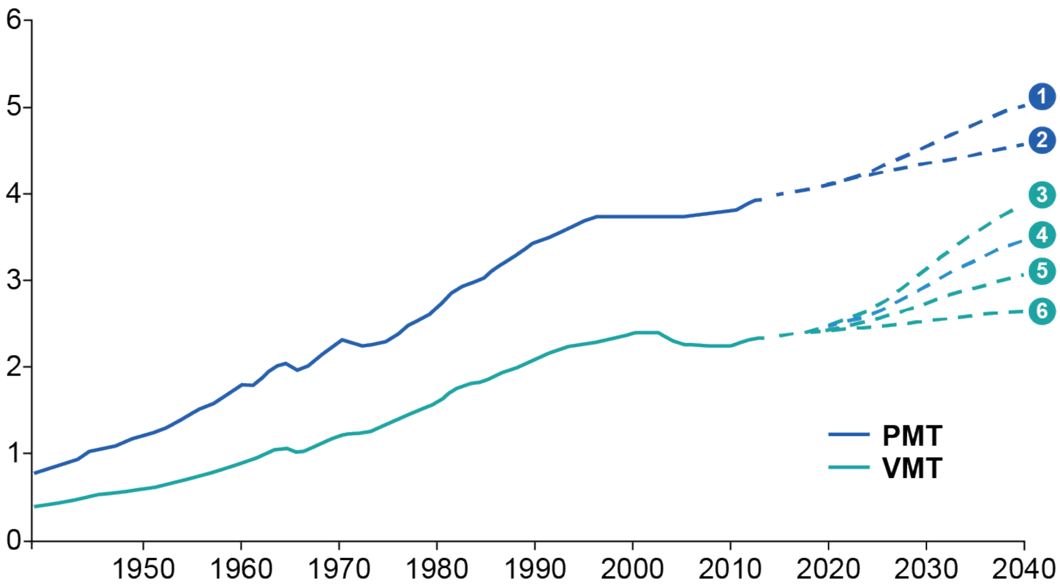
Our consumer research and analyses of network density and service-level relationships suggest mobility may rapidly become a dominant travel mode in most urban and suburban areas—anywhere the population density is more than 300—500 people per square kilometer. Meanwhile, mobility will increasingly equate with autonomous mobility. Consumers will no longer need to rely on a human driver for an on-demand ride. To no surprise, it is in autonomous mobility where car companies will compete most fiercely to establish themselves as leaders in autonomy.

In fewer than five years, in large and small cities alike, MaaS (mobility-as-a-service) covers 70 percent of the U.S. population.

CUMULATIVE % OF U.S. POPULATION BY UBER WAIT TIME



1950 - 2040 VEHICLE AND PERSONAL MILES FOR PERSONAL TRAVEL
(TRILLION MILES)



1. PMT grows due to increased mobility at all ages
2. PMT grows with the population
3. AV AOR is 40% lower than manually driven cars
4. AV AOR is 20% lower than manually driven cars
5. AV AOR is the same as manually driven cars
6. AV AOR is 20% higher than manually driven cars

While AV AOR is expected to decrease due to "deadhead" miles (miles traveled without passengers), carpooling and ridesharing trends may put upward pressure on AOR

AOR is defined as Average Occupancy Rate of a vehicle. | PMT: Personal Miles Traveled | VMT: Vehicle Miles Traveled

Source: KPMG research

ECONOMIC AND SOCIAL IMPACTS OF AUTONOMOUS MOBILITY.

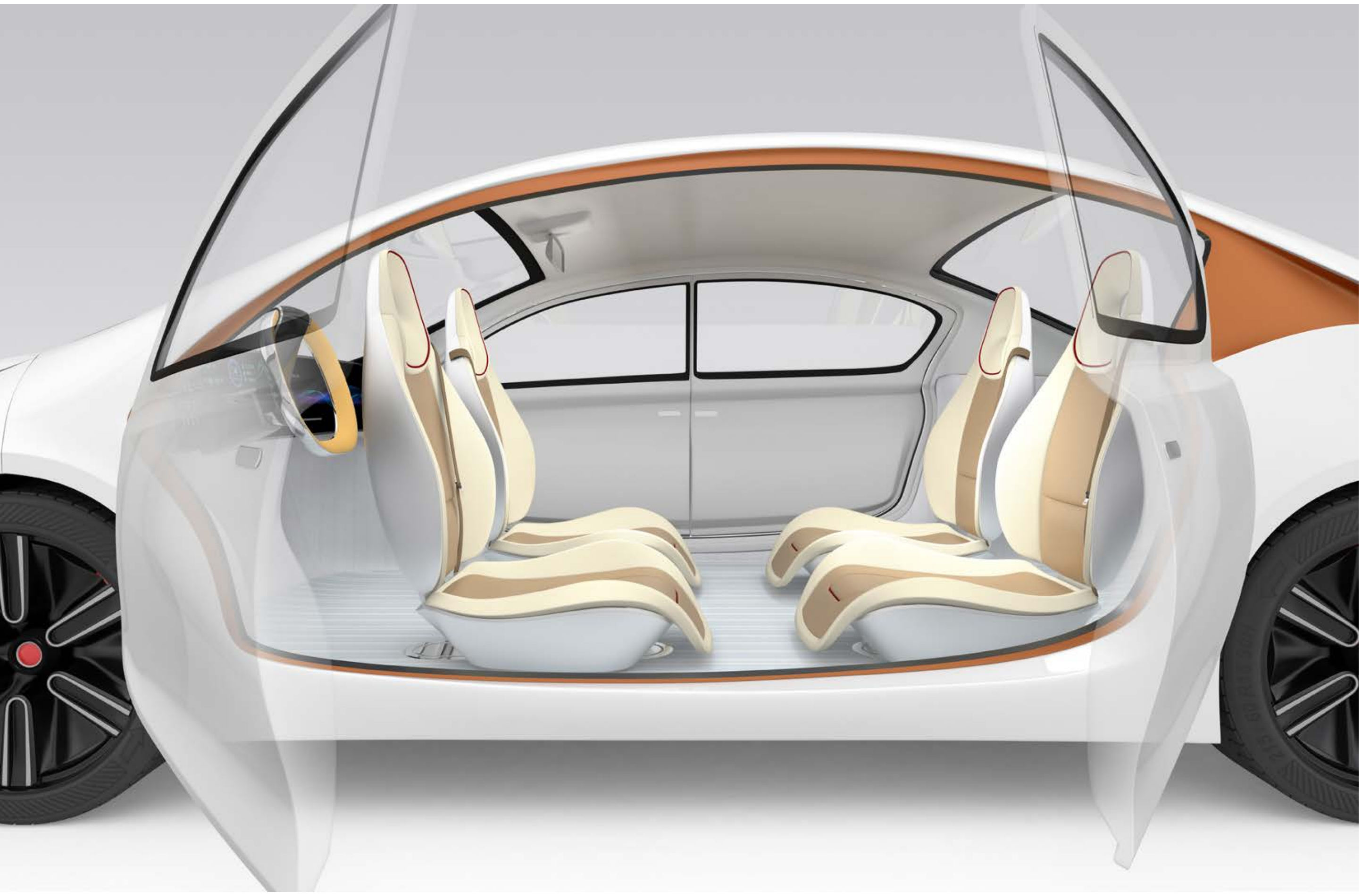
As autonomous mobility speeds its way into consumers' lives, it will have powerful economic and social effects.

Autonomous mobility-on-demand. Autonomous mobility services will offer substantial savings to consumers over buying their own cars. In fact some predict that the reduced cost and added convenience of on-demand driving—a car brought to you when and where you need it—will all but replace car ownership, especially in urban settings. At the very least, autonomous mobility services will affect the types of cars sold, the pricing, and the profitability of cars.

The democratizing of transportation. The decreased labor costs of mobility-on-demand mean the cost of a ride will reduce, making mobility available to people in a wider range of incomes and classes.

This could in turn lead to widespread, explosively fast adoption of mobility, with profound economic benefits for consumers but unclear consequences for the automotive industry.

Enabling happier, more productive lives. Without the demands of concentrating on the road, riders will enjoy more productive and less stressful use of their time: working, following the news, or engaging other people. Autonomous car interiors may become personalized, whether that means beds for overnight road trips, stocked bars for entertainment travel, or desks for commuting to work. When autonomous vehicles become available at scale, the car will transform still further from a mode of transportation to a new-age entertainment hub. Analysts predict that hub will immerse consumers in communication and entertainment technology an average of five or more hours per week.[20] They predict infotainment systems will add $65 billion of operating profits to the overall industry value chain from 2016 to 2025.[21]



[20] Tech Crunch, Sept. 15, 2016 The End of the Automotive Supply Chain, Alex Moazed
[21] World Economic Forum, 2016

LONG-HAUL TRUCKING: THE GOOD LIFE

"A trucker's life is tough and lonely." Joe used to hear that all the time. Not anymore.

After a good night's sleep and a homemade breakfast, he had arrived at his commercial trucking job at 9:00 a.m. to find a trailer already hooked up to his rig and three self-driving trucks lined up behind it, ready to go.

Self-driving truck #3 has extra capacity, so it drives to the address and loads up, aided by a delivery drone.

Joe leads the platoon onto the highway, following the route dispatch sent to his center console. He parks in Springfield while two of the self-driving trucks disperse. One delivers a load of fresh vegetables to the supermarket; another delivers two-by-fours to the hardware store. As Joe waits in his cabin, dispatch gives him the location of a load of medical supplies ready for pick-up half a mile away. Self-driving truck #3 has extra capacity, so it drives to the address and loads up, aided by a delivery drone.

Fifteen minutes later, the platoon is back on the road, having made more deliveries than Joe could have made on his own in an entire, lonely, grueling day. Headquarters is happy, and so is Joe. At this rate, he will be home before dusk to play with his kids before dinner. He is looking forward to a game of catch. He has had so much more energy since the company was able to shift the overnight hauls to autonomous rigs, and his cholesterol is down too.

A trucker's life? Nothing like today!

Deep learning can help analyze traffic patterns and light sequence to automatically optimize traffic flow in urban centers. Or can be used to optimize route planning and shipping logistics and more!

OTHER ECONOMIC IMPACTS AND ENVIRONMENTAL IMPROVEMENTS.

Beyond the economic and social effects of mobility, the acceleration of autonomy will have more general economic and environmental effects.

Labor productivity. Once autonomous vehicles scale, economists predict a $99 billion annual increase in productivity for drivers newly freed to use their time as passengers.[22]

Reduction of capital and resources trapped in the car parc (number of vehicles in operation). A future world of autonomous mobility will require fewer cars per mile traveled. Self-driving cars used for mobility services will drive many more miles than personally owned vehicles and have the potential to replace four individually owned cars. As we transition to autonomous mobility, hundreds of billions of dollars of capital and billions of tons of steel, aluminum, rubber, and plastic will be released for new uses in the global economy.

[22] The Massive Economic Benefits of Self-Driving Cars (Forbes, Nov. 8, 2014)

Relief of congested urban infrastructure.
In our highest-density cities, dynamic shuttle or "pool" offerings may become a preferred (or even mandated) form of mobility—increasing vehicle occupancy rates from today's U.S. average 1.67 people per vehicle to as high as eight or nine in high-volume commuter vans. In addition to that potential consolidation of vehicle requirements in a mobility-dominated world, our most congested cities could expand existing lanes of travel by restricting or eliminating on-street parking of personally owned vehicles. Finally, as increased vehicle-to-vehicle and vehicle-to-infrastructure connectivity starts to emerge, we may see methods emerge to better route autonomous vehicles and improve traffic flows. Says Dr. Kornhauser, "Current road rules are structured to try and obtain human behavior that keeps all of us safe. For example, why is 50 mph on a certain road safe? Does a stop sign need to have a full stop? Equivalent road rules needs to be written for computers that drive the cars."

Improved urban land use. Since experts estimate that parking difficulties account for 30—60 percent of downtown traffic, on-demand driverless transportation will greatly reduce congestion.[23] It will also decrease the need for individual parking spaces, freeing up valuable downtown real estate in the process, and relocating garages to less costly areas. Since the self-driving car will drop off passengers and use telematics data to find the most convenient location to park, it will reduce stress on passengers and save them time.[24]

[23] No Parking Here (Mother Jones, Jan. 2016)
[24] Cruising for Parking (University of California, Los Angeles, 2006)

DEMOCRATIZING MOBILITY

When Eva was a girl, every morning—rain, sleet or snow included—her mother would rise before dawn to take three buses from the Kansas City housing projects to the downtown hotel where she worked as a maid. They owned a car once, but it had cost every cent of their savings to keep it running.

Seeing the huge toll the simple act of transportation took on her mother's health and happiness, Eva's mayoral campaign pledge was to improve mobility for low-income residents. Now, during her first term, it's already happening. And it is all thanks to Eva's initiative to geo-fence the city and enable autonomous vehicles to navigate the roadways.

Equipped with ultra-high resolution maps of virtually every stationary object in every square mile of the city, self-driving cars now deliver hardworking people from their doorsteps to work ten times faster than the bus routes allowed—and for less than the cost of a bus commute. No longer are people freezing at bus stops, missing out on their lives commuting, or going into debt to pay for the uncertain costs of car ownership.

This is Eva's crowning achievement. Where Kansas City once felt divided, it now feels connected—almost like a family. Her mother would be proud.

DEEP LEARNING VS. THE HUMAN RACECAR DRIVER

Meet Lloyd. Ph.D. in computer science focusing on deep learning, Lloyd is the world's greatest racecar driver. Or he could be. He looks a lot different than Mario Andretti and Dale Earnhardt, but that is because he practices his craft from a high-tech computer lab surrounding powerful processing equipment.

You see, in the next wave of auto racing, the humans "behind the wheel" may be the software engineers who program autonomous vehicles to speed around the track faster than any human.

Take Audi's engineers. They taught "Robby the Autonomous Racecar" to drive in the fastest, most efficient manner possible, maintaining perfect lines through each turn while remaining stable. In a true test of man versus machine, Robby beat an amateur driver with ease in a lap around Sonoma Raceway.[25]

How long will it be until autonomous vehicles start crushing track records set by human drivers? We will probably find out soon. Roborace, the world's first driverless electric car competition, kicked off in October during the 2016–2017 Formula E season.[26] On the race track will be 10 teams competing with identical high-speed electric race cars. Everything about these cars will be the same from the electric motors to the GPU-based supercomputer, except for the paint, the software, and the deep neural networks trained by the teams.

> **"Deep learning and autonomy don't have to be boring."**
> - Jono Anderson, Principal, Strategy, KPMG

[25] A Human Driver vs. Robby the Autonomous Racecar, Popular Science, Dec. 2, 2015
[26] roborace.com

DEEP LEARNING'S DIRECT, TRANSFORMATIVE EFFECT: **SIX ESSENTIAL TAKEAWAYS**

The market changes deep learning enables will demand fundamental rethinking of the business models of automakers. They create new markets, redefine the primary pathways for innovation among car makers, bring huge value to information accumulated via driven miles, and multiply the importance of computing to car making and the importance of data integration to transportation.

1 MASSIVE NEW OPPORTUNITIES ARE AROUND BUT CHANGE IS REQUIRED FOR AUTOMAKERS

Historically, automotive OEMs chose to focus their business in the design, manufacturing, distribution, and financing of new automobiles. They had little direct contact with consumers and ceded many business opportunities such as dealer sales and services, aftermarket maintenance, or insurance to others. Automakers can no longer afford to leave such opportunities on the table. They must become hardware, software, and experience providers in some combination that fits their individual assets, capabilities, and competitive positioning. If they do not, they will be left behind and potentially be out of business.

As new information and big-data based segments are enabled by mobility, connectivity, and autonomy, we expect existing profit pools to shift and new profit pools to emerge. It gives automakers an opportunity to change the way they interact with their customers and new opportunities to re-enter and to develop new business areas. Automakers will of course have fierce competition for these new profit pools. Tech giants and disruptive tech start-ups are here to stay and will continue to challenge traditional OEMs in many of these segments. The ability to own the "secret sauce"—the deep learning databases, algorithms, software, and revenue streams—will play a large part in determining the future balance of power.

With the acceleration of autonomy deep learning enables, we will likely see a shift in the car ownership model, with greater value found in ride sharing services and less in direct sales of personal cars.

27

"Deep learning is revolutionizing practically every industry, from healthcare to finance to transportation. In particular, the development timeline of self-driving cars is dramatically accelerating thanks to the role GPUs and deep learning are playing as they replace traditional programming and computer vision. Remarkably, by using deep learning, we can teach cars how to drive with superhuman levels of perception and performance, and thereby significantly decrease the number of accidents, injuries and fatalities."

- Danny Shapiro, Senior Director of Automotive, NVIDIA

That shift creates an opportunity for automakers to unlock new profit pools and recapture direct access to the consumer. As we indicated in *"The Clockspeed Dilemma"* and now affirm, our proprietary models of PMT and VMT in the United States, China, and other countries predict that personal miles will soar. Those changes offer the automotive industry a chance to alter its relationship with customers throughout their transportation experience. To do so, traditional players will need to develop mobility and customer experience strategies, to offer and to benefit from these type of services. This opportunity requires the willingness of traditional automakers to expand the scope of their business; it means capitalizing on advancing technology and innovative thinking to expand beyond manufacturing and sales of vehicles to moving people and goods from place to place.

Forward-thinking companies have already begun this kind of transformation. General Motors (GM) spent $1 billion on its acquisition of the autonomous vehicle start-up Cruise Automation[27] and invested $500 million in the ridesharing company Lyft. Volvo has partnered with Uber to develop self-driving cars.[28] Ford has begun a raft of efforts, a sampling of which include its Smart Mobility initiative; a telematics service, SYNC Connect; and FordPass platform.[29] As Don Butler, head of Ford's Connected Vehicle and Services, comments, "The future is going to be different, and we are embracing that difference."[30]

In every segment, automotive companies need to reassess their competitive strength against others and to determine if they should do it themselves, partner, or outsource entirely those parts of the value chain.

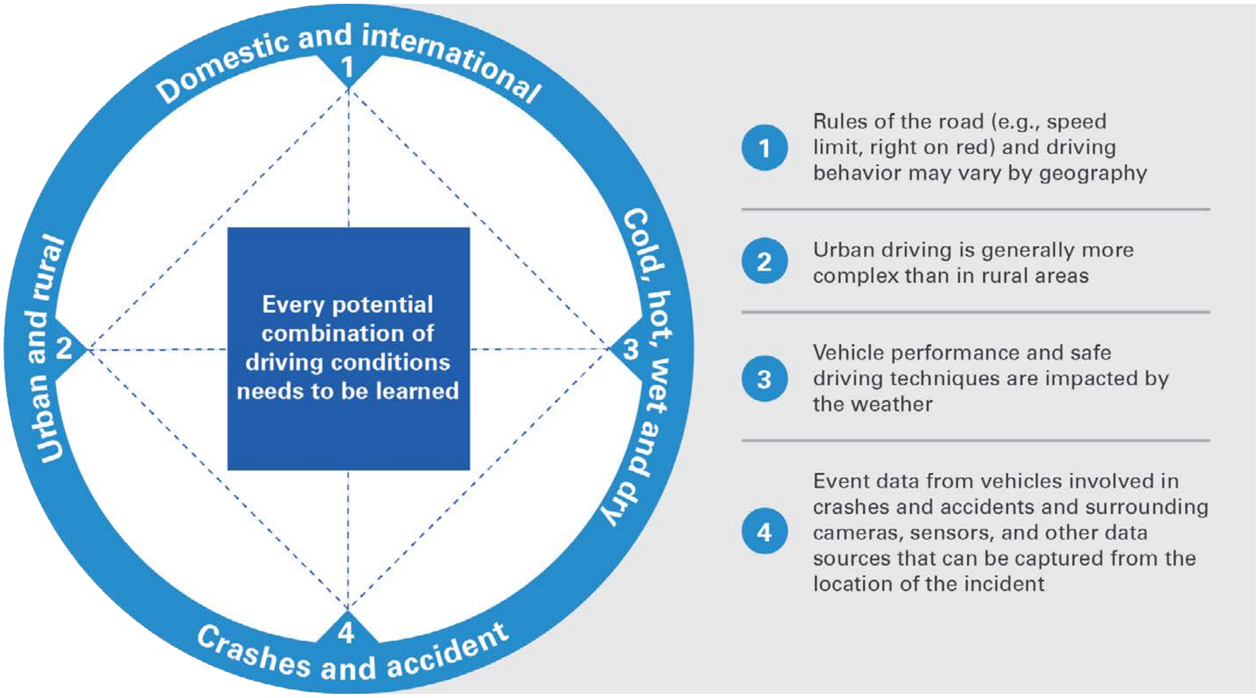
[27] GM Buying Self-Driving Tech Startup for More Than $1 Billion (Fortune, March 11, 2016)
[28] Volvo Partners with Uber on Self-Driving Cars (Fortune, Aug. 18, 2016)
[29] "FordPass Points to a Future beyond Selling Cars", by Sam Abuelsamid, Navigant Research, June 21, 2016
[30] "FordPass Points to a Future beyond Selling Cars", by Sam Abuelsamid, Navigant Research, June 21, 2016

2 WITH DEEP LEARNING, MILES ARE LIKE GOLD

To improve how autonomous vehicles perform, each mile of "eventful driving" is valuable. The input training data gathered from different traffic, different speeds, different environments, different dangers encountered, and all other distinguishing phenomena while driving is critical for the ability of deep learning to build autonomous capacity.

To effectively train autonomous vehicles, miles should be acquired across various conditions and geographies.

From the variety of this data—with their different incidents, accidents, and conditions—deep learning educates an autonomous vehicle to drive more safely and smoothly than humans. The variety in those kinds of miles is therefore essential for rendering an autonomous vehicle a capable, experienced driver. Dr. Kornhauser says it comes down to which miles are driven. For example, how many miles have you driven in environments where the car has had less than two seconds to react? And given the enormous, seemingly infinite variety of driving miles on the planet, their



accumulation and the ability to capture the data of those miles becomes extremely valuable for the development of self-driving cars.

Deep learning unlocks the value proposition for vehicle and simulated miles, and sparks a competition for them. Their acquisition and the efficient means for capturing and building knowledge from them will be critical to the progress of autonomy. Leaders in the race for miles will have an advantage in developing deep learning technology for mass deployment since they are imperative for continued learning. This makes the ability to generate miles and "fleet experience" a critical consideration in evaluating whether to develop autonomy in-house or with an external partner.

ACQUIRING DATA FROM MILES

Telematic data, from the GPS and on-board diagnostic systems, pinpoint where a car is, how fast and in what direction it is moving, and how it is performing internally.

Scene data from the car's sensors capture 3D/4D geometry around the vehicle and "paint a picture" of its surroundings.

Behavioral data—also collected through the car's sensors—assess the likely actions of moving objects that might interact with the car, such as other vehicles, people, and animals.

DRIVING DATA STRATEGIES BY TYPE OF COMPANY

Large OEMs: Large OEMs like GM, Ford and Toyota, likely have an advantage in collecting miles in stealth mode due to their market share of vehicles and the billions of miles they drive each year. This, of course, assumes sensors are installed on the vehicles currently on the road.

Small OEMs: Small OEMs, like Tesla, are still competing in the race for miles using stealth mode, by acting first to deploy sensors on their vehicles.

Tech players: Tech players like Apple, Google, Baidu, Uber and other new entrants, without market share, are at the greatest disadvantage in gathering stealth miles. Their success may depend on:

- First mover advantage in acquiring autonomous miles from their own fleets
- Early penetration of autonomous vehicles in fleets, possibly through mobility services, greatly expanding the number of vehicles they have on the road
- Focusing on offering autonomy in restricted geographies, thereby reducing the number and types of miles required to offer an autonomous vehicle service
- Achieving scale, either through significant growth in car penetration share in a certain region, or through partnerships. Mobileye has collected data from customer OEMs' vehicles that leverage its camera technology

"The importance of deep learning cannot be understated and we think it is critical to our future."

- Dr. Ken Washington, Vice President, Research and Advanced Engineering, Ford Motor Company

3

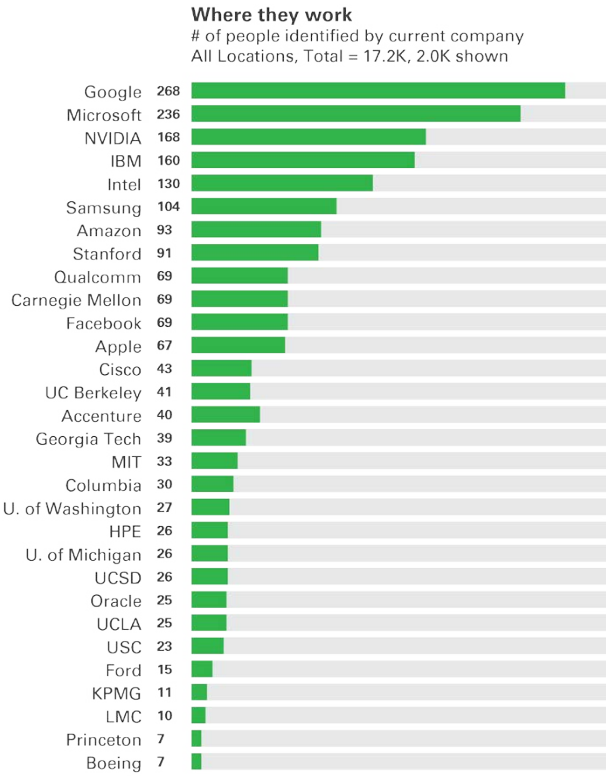
OEMS AND TECH COMPANIES WILL FACE OFF IN A WAR FOR SPECIALIZED TALENT

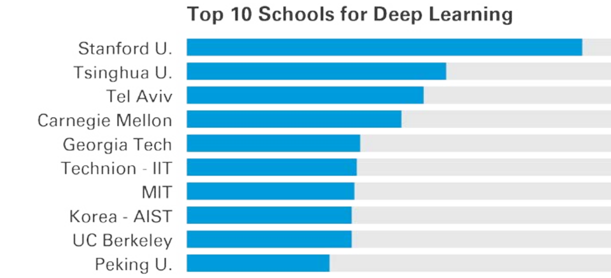
This is truly a critical juncture in the history of the auto industry. Traditional automakers always owned the “secret sauce” of the vehicle. But with deep learning, somebody else has it.

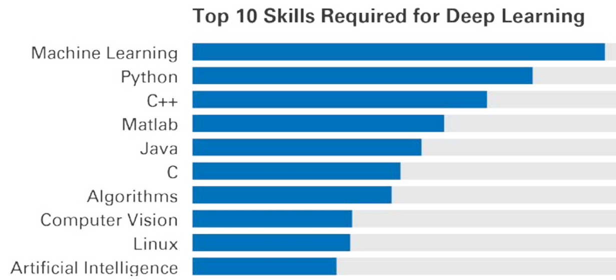
For car companies to control the algorithms driving the vehicle, they will need the people who design them. However, deep learning specialists are not flocking to the auto industry. People with deep learning expertise are in short supply, and tech companies have the clear advantage. KPMG research in June 2016 revealed that the pool of deep learning specialists is limited and very few companies have reached critical scale, e.g., only 28 companies or universities had 10 or more specialists and that six technology companies employed 54% of them, i.e., Google, Microsoft, NVIDIA, IBM, Intel, and Samsung. This makes it difficult for traditional automakers to compete.

Unfortunately, universities cannot crank out deep learning graduates fast enough. Start-up company Udacity, however, just started a self-driving nanodegree program and in just 2 weeks received 12,000 applications for 500 slots.

SPECIALIZED TALENT FOR DEEP LEARNING







Currently, deep learning talent is highly concentrated within a few large tech firms and schools

Source: Search conducted using Linkedin.com on June 1, 2016 for individuals self-identifying themselves with the skill "deep learning" and capturing where they work, what they are skilled at, and where they went to school.

The incoming pool of talent graduating from Stanford, Carnegie Mellon, Georgia Tech, and other leading institutions cannot meet the estimated demand of the autonomous driving market of 100,000 new jobs by 2025.[31]

Some automakers are scrambling to scoop up whatever deep learning talent they can get, whether through recruiting or acquisitions. In 2015, Uber made headlines for hiring away more than three dozen of Carnegie Mellon's 150 artificial intelligence researchers, most of whom were working on self-driving cars.[32] Later, Ford made news when it acquired SAIPS, a little-known Israeli tech company specializing in computer vision and deep learning.[33]

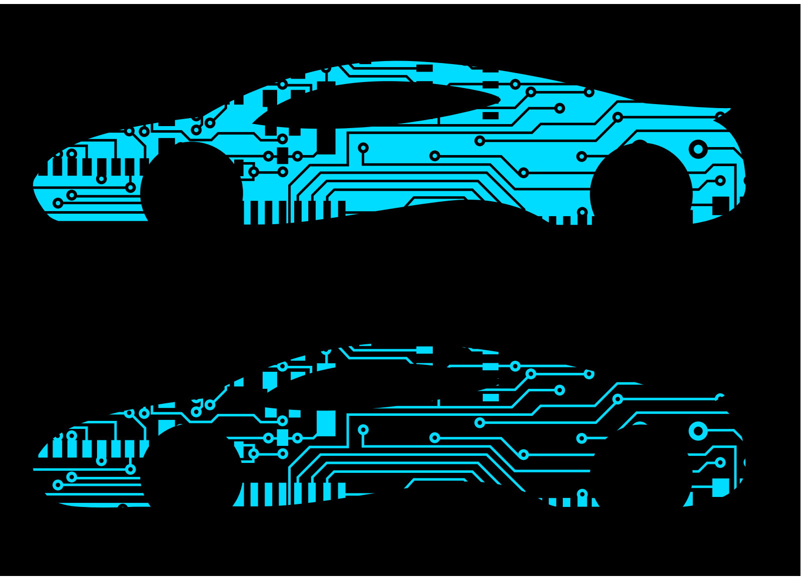
Others are combatting the talent war by helping to advance the field of deep learning. Playing off the intense demand for engineers with deep learning skills, Udacity, an online educator, is launching a 27-week, $2,400 course to earn a "self-driving car engineer nanodegree." Mercedes, NVIDIA, Chinese ride-sharing company Didi and autonomous trucking company Otto are partners in the program.[31]

[31] A $2400 course to make anyone a self-driving car engineer (Wired, Sept. 13, 2016)

[32] AI talent grab sparks excitement and concern (Nature, Aug. 26, 2016)

[33] Ford acquires SAIPS for self-driving machine learning and computer vision tech (TechCrunch, Aug. 16. 2016)

4 DEEP LEARNING WILL REQUIRE OEMS TO CONSIDER THE NERVOUS SYSTEM FIRST



Traditionally vehicle program development has put a primary emphasis on one or two of a select number of options—styling, packaging, powertrain, or chassis and suspension—in order to create an attractive, differentiated vehicle. Then it has relentlessly managed cost, weight, and fuel economy at start of production—relentlessly pruning any surplus gram or penny from the bill of materials. The latter will no longer be a competitive way of making cars now that deep learning is becoming an essential part of the autonomous vehicle. Instead, car manufacturers will have to consciously create "surplus" capacity in vehicles' sensing, computing, and communication systems to meet the inevitable demands of future over-the-air updates to their driving programs. That is a profound change in the traditional program management model of minimizing costs, weight, or any other form of "surplus" from the design.

Whether automakers proceed toward autonomy incrementally, as Tesla and Mercedes-Benz appear to be doing, or leapfrog straight to full autonomy in the style of Google, Nutonomy, and Ford, being competitive will require them to design cars for a future of ever-expanding nervous system demand, which deep learning systems will generate. According to Richard Wallace, a director at the Center for Automotive Research, software upgrades will be almost mandatory once vehicles progress to higher forms of autonomous driving. He references the New York Times: "The artificial intelligence underpinning self-driving will require constant upgrading to deal with novel situations."[34] They will need to expect repeated software upgrades for features and performance and updated safety requirements, to be delivered over the air.

It will be essential not to underestimate the amount of computing power or bandwidth that is going to be needed down the road.

[34] Your Car's New Software Is Ready. Update Now? (New York Times, Sept. 8, 2016)

Given how fast autonomous vehicles are advancing, automakers must consider what technologies cars may use 2 years, 5 years, or 10 years from now. The car's nervous system must be designed for the requirements of the last vehicle to be delivered, not sized for the initial needs at start of production.

That is not to say all of the nervous system hardware will be locked for the life of a vehicle program. Given the clockspeed of electronic components, there will undoubtedly come a point when hardware functionality will need to be upgraded to keep pace with the demands of the software.

The key to nervous system design will be to, where possible, anticipate the power, space, heat-dissipation and bandwidth requirements of future hardware to allow its incorporation without high-cost redesign of key platform components or modules.

As one automaker executive stated, "Ultimately, satisfied customers will want an ongoing relationship with us. As with an iPhone, at some point the hardware will no longer be upgradeable. It's part of the world we live in."[35]

[35] Your Car's New Software Is Ready. Update Now? (The New York Times, Sept. 8, 2016)

5 DEEP LEARNING WILL MAKE INTEGRATED AUTONOMOUS VEHICLE FLEETS A KEY COMPETITIVE DIFFERENTIATOR

Currently, the capabilities of an individual vehicle and driver are limited to that of the vehicle and driver alone. However, with deep learning, a vehicle will draw from the learnings of the whole fleet. No single car could experience enough to learn everything that it needs to know, but each car will benefit from the learning of the entire fleet and the world it passes through.

> **Ensuring adequate capacity to interact, to communicate, and to capture data is essential to the capacity of the fleet for deep learning.**

Integration therefore includes determining what miles are valuable, how they will be transmitted, and which data is stored on-board and which in the cloud. It includes how the car signs on and off of the network, gets recognized as a “real” car (so it can be integrated into the system), and how it validates and maintains that the integrity of the vehicle is not compromised. And integration includes how the fleet captures and receives real-time updates for localization mapping, operational mapping, routing, and other features essential to relating the individual car to its environment and to other cars on the road.

Accordingly, automakers will need to stand up integrated systems modeling, data management, communication management and cybersecurity capabilities akin to those of a cloud software, telecom, or systems company in order to effectively manage their deep learning fleet systems.

Of course, the integration of autonomous vehicles to each other and to an open network makes them vulnerable to data theft and other more ominous cyber threats. As such, the industry will need to aggressively manage cybersecurity and the threat to privacy. From hackers assuming remote control of autonomous vehicles, to infecting their algorithms with bugs, to exploiting programming loopholes to carry out thefts or terror attacks, a host of cyber-related scenarios will need to be worked out to ensure adequate security.

The shift towards integrated autonomous mobility fleets will also alter vehicle maintenance requirements, leading to the emergence of new "maintenance-as-a-service" or full-service lease businesses. Unlike individual owners who often focus on transaction price of an individual maintenance event and who are willing to leave a car for the day, mobility fleets will value reduction of full-life cycle cost-of-ownership. And, because every minute of downtime costs revenue, autonomous vehicle fleets will place a premium on uptime and dispatch reliability. They will eventually be serviced by sophisticated providers similar to those we see in the commercial truck or airline business today.

A CHECKLIST FOR DETERMINING INTEGRATION

Questions like these illustrate the complexity of integration as well as determine the drive management system integration car makers create.

OPERATIONS:

What information and how much is needed from the vehicle in case of a learning event?

When and how quickly should it upload this data?

How will it distinguish valuable from nonvaluable miles?

INTEGRATION WITH THE VEHICLE:

How will it monitor the integrity of the vehicle and its components?

How will it determine if all of the car's safety critical components are legitimate and working?

Is the system legitimate and its integrity intact?

How and when will it upgrade the software of the car?

How and when will it modify configuration?

What kind of interfaces will it use?

INTEGRATION WITH THE FLEET:

How much data resides on the vehicle and how much in the cloud?

How are vehicles going to interact with other vehicles within the same system to share information?

How will the fleet interact with the cloud layer?

How will it interact with the infrastructure of the city or other environment around it?

How will it test all of these pieces together in a harmonious way?

6 DEEP LEARNING WILL CHANGE HOW THE AUTO INDUSTRY IDENTIFIES AND EVALUATES INNOVATION

As carmakers develop core capabilities as experience and service providers, deep learning will be central to their efforts to innovate and to test those innovations. Instead of market surveys and other imprecise information, connected vehicle's nervous systems will provide an ability to continuously gather elegant, granular, fleetwide data with which to identify and evaluate new service and experience opportunities. Consider mobility experience, an area where steep competition requires auto industry players to assess carefully how to proceed.

Deep learning can be used to identify new, previously unseen patterns in consumer behavior and relationships, out of which companies might find new business opportunities.

Deep learning applied within the corporation can generate new perspectives and insights from which to rethink the capabilities a car maker has or might develop: how it builds autonomous vehicles, how it leverages its knowledge and experience, how it interacts with customers—and how, ultimately, it innovates at the right clockspeed to be competitive and successful. In short, the process of innovation will depend upon and therefore reflect the critical importance of deep learning.

The change in perspective deep learning provides may change the way we think about ideation. Identifying specific value creation hypotheses and the types of data to collect provides the primary starting point to structure a set of specific pilots designed to prove value propositions. In this way, we can create a continuous cycle of ideation and prototype, as well as pilot and scale great ideas and capabilities into the ecosystem.

THRIVING IN THE AUTONOMOUS FUTURE

Deep learning is accelerating autonomy and arriving faster than many realize. When it arrives, nothing will ever be the same. Will you be ready?

While uncertainties abound, so do opportunities—for automotive players that strategically embrace change. To steer your company on a winning path, you will need to reinvent where you compete, what products and services you sell, how you design cars, how you manage your fleet, and how you think about innovation, talent, and technology.

Solving each of the six essential takeaways requires a view of where the market is likely to evolve to, a broad understanding of technology strategy, thoughtfulness around organizational structure, a control system, engaging with potential candidates to include in your ecosystem through partnership, investment or acquisition, and a people and organizational change strategy that can win the talent and drive the innovation engine to support growth.

But developing a strategy to engage talent and drive innovation is only the first step. Many of the elements and capabilities required to compete in this new landscape will require new ways to engage with customers, like digital customer-facing front ends that tie seamlessly into an organization's back-end datasets, evolving product launch, manufacturing, intellectual property payment and other processes, and financial and managerial reporting systems and controls.

These are all things that KPMG is deeply experienced in helping inspire confidence in our clients and empower change.

To make it through the transformation journey that will be occurring in the next few years, you will probably need to circumvent roadblocks, take detours, and endure a long road ahead to thrive in the autonomous future. But your destination will be well worth the journey and KPMG can be your partner to help you along the way.

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ABOUT KPMG

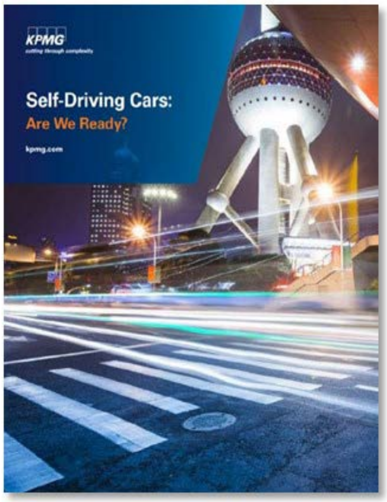
KPMG LLP's Automotive team understands the complexity currently flowing through the industry. We leverage our deep industry insight and our hands-on experience to help automotive companies shape a successful future while strengthening performance today. Using a cross-functional approach, KPMG's Automotive team helps empower the world's leading manufacturers, OEMs, and suppliers to achieve their goals. We put our breadth of experience and industry-specific knowledge to work for our clients, guiding them to make better decisions today to potentially create the greatest impact tomorrow.

In case you missed them, you can download our previous papers related to the future of the automotive industry.

SELF-DRIVING CARS: THE NEXT REVOLUTION

August 2012

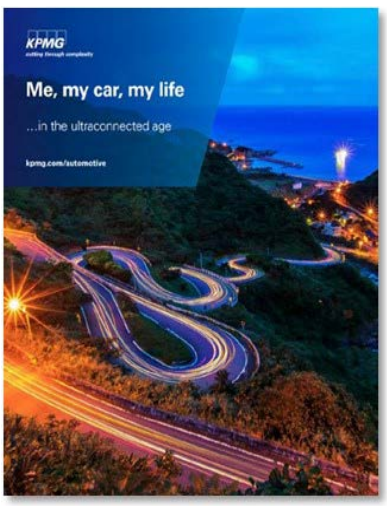
For the past hundred years, innovation within the automotive sector has brought major but mostly evolutionary technological advances. Now, the industry is on the cusp of revolutionary change with the advent of autonomous or "self-driving" vehicles. KPMG LLP and the Center for Automotive Research (CAR) joins forces in examining 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.



SELF-DRIVING CARS: ARE WE READY?

October 2013

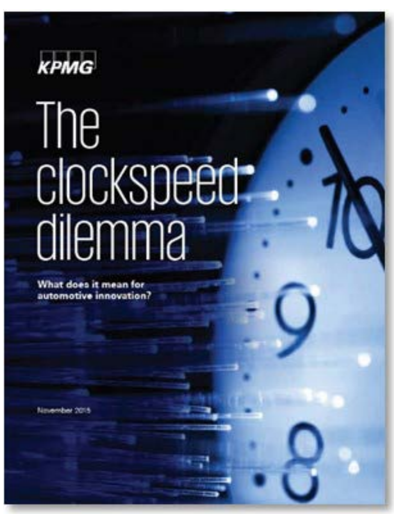
Gaze out at the automotive horizon and you can almost see a new era coming into focus: the age of self-driving cars. Ultimately, the shape of the automotive future will depend on consumers—their needs, preferences, fears—and their pocketbooks. Will they trust these new vehicles? What will future car buyers care about? If we build self-driving cars, will they come? KPMG seeks to answer these questions through the lens of real consumers who provide us with their unique perspective on the self-driving market.



ME, MY CAR, MY LIFE ... IN THE ULTRACONNECTED AGE

November 2014

Not since the first automotive revolution has there been such stunning innovation in the industry. The convergence of consumer and automotive technologies and the rise of mobility services are transforming the automotive industry and the way we live our lives. How will the automotive industry adapt to this new world? How is technology reshaping the automotive ecosystem—and how will these industries work together? What will customers of the future expect from this collaboration—and be willing to pay for?



THE CLOCKSPEED DILEMMA: WHAT DOES IT MEAN FOR AUTOMOTIVE INNOVATION?

November 2015

The convergence of consumer and automotive technologies, the rise of mobility services, and the development of autonomous vehicles are revolutionizing the automotive industry and the way we live our lives. There will be profound impacts on vehicle miles traveled, vehicle sales, car ownership models, energy demand, and infrastructure. KPMG examines how the automotive industry must innovate to thrive in this new and evolving ecosystem.