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Moving forward: Self-driving vehicles in China, Europe, Japan, Korea, and the United States

Darrell M. West

Darrell M. West is vice president and director of Governance Studies and the founding director of the Center for Technology Innovation at Brookings. His studies include technology policy, electronic government, and mass media.

EXECUTIVE SUMMARY

"The car is one of the largest mobile devices out there," Bridget Karlin of Intel.[1]

Vehicles equipped with sensors and cameras navigate the streets of Mountain View, California; Austin, Texas; Kirkland, Washington; Dearborn, Michigan; Pittsburgh, Pennsylvania; Beijing, China; Wuhu, China; Gothenburg, Sweden; Rotterdam, Netherlands; Suzu, Japan; Fujisawa, Japan; and Seoul, South Korea, among other places. Sophisticated on-board software integrates data from dozens of sources, analyzes this information in real-time, and automatically guides the car using high definition maps around possible dangers.

People are used to thinking about vehicles from a transportation standpoint, but increasingly they have become large mobile devices with tremendous processing power.[2] Experts estimate that "more than 100,000 data points" are generated by technology in a contemporary automobile.[3] Advances in artificial intelligence (software that applies advanced computing to problem-solving) and deep learning (software analytics that learn from past experience) allow on-board computers connected to cloud processing platforms to integrate data instantly and proceed to desired destinations. With the emergence of 5G networks and the Internet of Things, these trends will harbor a new era of vehicle development.

Between now and 2021, driverless cars will move into the marketplace and usher in a novel period.[4] The World Economic Forum estimates that the digital transformation of the automotive industry will generate $67 billion in value for that sector and $3.1 trillion in societal benefits.[5] That includes improvements from autonomous vehicles, connected travelers, and the transportation enterprise ecosystem as a whole.

This paper looks at different types of autonomous vehicles, shows their potential impact, and discusses the budgetary, policy, and regulatory issues raised by driverless cars and trucks. It argues that connected vehicles are likely to improve highway safety, alleviate traffic congestion, and reduce air pollution. However, to do that, designers must overcome obstacles such as poor infrastructure, bad weather, inadequate spectrum, hacking threats, and public acceptance.

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The technology to meet these barriers has advanced rapidly and is poised for commercial deployment. But to make progress, each country needs to address particular issues. There are budgetary, policy, legal, and regulatory concerns to resolve.

In China, for example, the key is to develop a national policy framework for autonomous vehicles. It has multiple ministries which are responsible for the supervision of automatic driving (some with overlapping jurisdictions) and there needs to be greater clarity regarding who regulates and how they regulate. In addition, the government needs to invest in highway infrastructure for autonomous vehicles, eliminate the current national prohibition on road testing, and reduce restrictions on road map development so that car makers and software designers can devise the most accurate navigational guides.

In Europe, the challenge is strengthening the artificial intelligence capability that is crucial to autonomous vehicles. One of the reasons why large technology firms such as Google in the United States and Baidu in China have moved into transportation is the opportunity to apply the processing insights and rapid learning capacity developed through search engine technology to a new sector. To be competitive in driverless vehicles, European auto manufacturers such as Audi, BMW (in collaboration with Intel), Volkswagen, Daimler, Mercedes-Benz, and Volvo need people with strong artificial intelligence skills and high performance computing aptitude because car manufacturing no longer is about physical design as much as it is about software development and real-time data analytics. The European Union also needs to make sure that its data protection rules don't place overly-strict limitations on the analysis of people's movement and location because that information is vital to high definition mapping for autonomous vehicles.

In Japan and Korea, governments and car manufacturers have been cautious about autonomous vehicles. Firms such as Toyota, Honda, Nissan, Kia, and Hyundai are investing major resources. They are keeping track of what is happening in other countries and undertaking pilot projects. Yet they have to decide whether autonomous vehicles represent a high priority for them. If so, they should invest resources in artificial intelligence, high definition mapping, and data analytics, which are key to the future of this sector. Failure to do so means they will be left behind as the industry embraces autonomous vehicles in the coming years.

In the United States, the major difficulty is overcoming the regulatory fragmentation caused by 50 states having differing preferences on licensing, car standards, regulation, and privacy protection. Right now, car manufacturers (such as Ford and General Motors) and software developers face conflicting rules and regulations in various states.[6] This complicates innovation because makers want to build cars and trucks for a national or international market. There also needs to be greater clarity in regard to legal liability and data protection, and legislation to penalize the malicious disruption of autonomous vehicles.

In each nation, government officials and business leaders have to resolve these matters because within a foreseeable period, the technology will have advanced to the point where intelligent vehicles will spread into key niches such as ride-sharing, taxis, delivery truck, industrial applications, and transport for senior citizens and the disabled. People and businesses will have driverless options for taking them safely to their destinations, and it is important for leaders to provide reasonable guidance on how to commercialize advanced technologies in transportation.

THE IMPORTANCE OF ARTIFICIAL INTELLIGENCE, HIGH DEFINITION MAPS, AND DEEP LEARNING TO AUTONOMOUS VEHICLES

Autonomous vehicles involve the application of advanced technological capabilities to cars, trucks, and buses. This includes automated vehicle guidance and braking, lane-changing systems, use of cameras and sensors for collision avoidance, artificial intelligence to analyze information in real-time, and high performance computing and deep learning systems to adapt to new circumstances through 3D high definition maps.

Light detection and ranging systems (known as LiDARs) and artificial intelligence are key to navigation and collision avoidance. The former are a combination of light and radar instruments mounted on the top of vehicles that use imaging in a 360-degree environment from a radar and light beams to measure the speed and distance of surrounding objects. Along with sensors placed along the front, sides, and back of vehicles, these instruments provide information that keeps fast-moving cars and trucks in their own lane, avoids other vehicles, applies brakes and steering when needed, and does so instantly so as to avoid accidents.

High definition (HD) maps also are crucial to autonomous driving. Baidu has HD maps for China that are accurate within centimeters.[7] HD maps are much more precise than GPS coordinates, as the latter are accurate only within five to ten meters (around 16 to 32 feet). The company uses 250 surveying cars to gather information on roadways for traditional navigation maps with 5 to 10 meter accuracy, and for high definition maps. Furthermore, all the surveying cars can be quickly upgraded to support data collection of high definition maps. As for the driverless car, Baidu uses the centimeter-level HD map, which include detailed information on traffic signs, lane markings (such as white or yellow lines, double or single lines, and solid or dashed lines), curbs, barriers, poles, overpasses, and underpasses, among other material. All of this information is geo-coded so that navigational systems can match features, objects, and road contours to precise positions for car guidance.

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Overall, the company has mapped around 6.7 million kilometers (or 4 million miles) of Chinese roads and highways for traditional navigation map. Its on-the-road navigational systems have an accuracy level of over 95 percent for road signs and lane markings.[8] Due to construction and other changes, highway maps need to be updated very regularly. Traditional maps are redrawn once every three months but autonomous vehicle maps have to be constantly updated to stay abreast of shifting road conditions.

Digital imaging technologies are extremely accurate. In facial recognition, for example, humans have an error rate of 0.8 of one percent, whereas computers with image recognition software have an error of only 0.23 of one percent.[9] And in terms of visibility (safe sight distance), humans can see only 50 meters (around 55 yards) down the road, compared to 200 meters (or 219 yards) for autonomous vehicles equipped with LiDAR laser beams and cameras.[10]

> On-board systems can learn from other vehicles on the road through machine-to-machine communications.

Since these cameras and sensors compile a huge amount of information and needs to process it instantly in order to avoid the vehicle in the next lane, autonomous vehicles require high performance computing, advanced algorithms, and deep learning systems to adapt to new scenarios. This means that software is the key, not the physical car or truck itself.[11] Advanced software enables cars to learn from the experiences of other vehicles on the road and adjust their guidance systems as weather, driving, or road conditions shift. On-board systems can learn from other vehicles on the road through machine-to-machine communications.

Without sophisticated artificial intelligence models and high definition maps to analyze information and the capacity to learn from changing circumstances, autonomous vehicles would be difficult to operate safely. They simply would not be able to handle the complex conditions that exist on roads and highways around the world.

Internet pioneer Marc Andreessen is famous for predicting that “software is eating the world.” By that, he means that businesses increasingly are using software to deliver digital products and online services. Rather than having brick and mortar industries offer what customers want, he thinks that “software programming tools and Internet-based services make it easy to launch new global software-powered start-ups in many industries – without the need to invest in new infrastructure and train new employees.”[12] The trucking and automotive sectors illustrate the beneficial possibilities of software-defined networks.

DIFFERENT TYPES OF AUTONOMOUS VEHICLES

There are two major types of autonomous vehicles: semiautonomous (levels one to three under the categories of the U.S. National Highway Traffic Safety Administration) and fully autonomous (level four). Each differs in the benefits it offers and the risks that it poses. Understanding their respective possibilities is crucial for considering the future of autonomous cars and trucks.[13]

SEMIAUTONOMOUS VEHICLES

Semiautonomous vehicles employ human control along with some automated features such as autopilot, cruise control, automated parking, emergency braking, backup warning signals, and lane-keeping technology. This allows cars to be operated autonomously but with the driver having the ability to override automated features. Cruise control, for example, is activated until the driver presses the brake, at which point that feature is turned off and the human takes full control of the car.

General Motors recently invested $1 billion through its acquisition of Cruise Automation, and hopes to pilot self-driving vehicles in the next year. Ford has announced plans to expand its Fusion Hybrid test cars and put 30 vehicles on the streets. In their trunks, it has “the equivalent of five decent laptops” that control the car.[14]

Tesla meanwhile has pioneered Autopilot and Autosteer features through a massive fleet of 70,000 vehicles that are on the road. Using Nvidia chips, its Autopilot system “can keep the car in a lane, adjust its speed to keep up with traffic and brake to avoid collisions.”[15]

It was a Tesla Model S sedan, however, that was involved in the first autonomous vehicle fatality in May, 2016 in Florida. Software associated with the automatic braking system confused the large white side of a semi-tractor truck with a bright sky, and therefore did not recognize the vehicle and did nothing to avoid a collision when the truck made a left turn near the car. The driver, Joshua Brown, did not override the semi-autonomous features and was killed when his car hit the truck, ran off the road, and hit a light pole at a high speed.[16]

This accident has subjected the company to government review for highway safety. The National Highway Traffic Safety Administration has asked the company to provide detailed information, such as “a list of all vehicles sold in the United States that are equipped with Autopilot system. It also asks how many miles have been driven with Autosteer activated, and how many times the automatic system warned drivers to put their hands back on the steering wheel.” In addition, the company has been asked to turn over information regarding “the number of incidents in which Tesla vehicles’ automatic emergency braking was activated” and “any information on consumer complaints or reports of crashes, or other incidents in which a vehicle’s accident prevention systems may not have worked properly.”[17] The company is working to comply with this data request.

Despite the accident, Tesla has one feature that is the envy of much of the automotive sector. That is the ability remotely to update the software on all its cars through home-based wi-fi connections without people having to take their cars into a dealership. With most conventional recalls, according to Diarmuid O’Connell of Tesla, only 70 percent of cars actually are repaired because owners don’t take the time to bring their car to a dealer. The other 30 percent remain out of compliance with the safety repair.[18] Other firms such as Ford, General Motors, BMW, Volvo, and Mercedes-Benz have developed a similar capacity.[19]

The virtue of semi-autonomous vehicles is that humans can override autonomous features when they believe there is an obstacle or when they perceive a novel set of circumstances that requires human judgment. As an illustration, if the human sees that the car is headed towards an accident because another driver has acted in an unanticipated manner such as occurs in cases of drunk driving, the person might make a better decision than a choice mandated by a computer algorithm.

The possible downside, though, is that humans are over-trusting of vehicular automation. People sometimes falsely conclude they can let the car’s self-driving features handle all the choices, and therefore risk an accident when other drivers act in ways not anticipated by computer models.

Fully-autonomous vehicles may turn out to be safer than semi-autonomous cars because they remove human error and bad judgment from vehicular operations altogether. For example, research undertaken at the Transportation Institute of Virginia Tech University “found that it took drivers of Level 3 cars an average of 17 seconds to respond to takeover requests [from the car]. In that period, a vehicle going 65 m.p.h. (or 105 kilometers per hour) would have traveled 1,621 feet (494 meters) – more than five football fields."[20]

Baidu engineers have found a similar result. Drivers take 1.2 seconds to see a road object and apply the brakes, much longer than the 0.2 seconds for on-board computers. This difference means that if the car is going 120 kilometers per hour (or 75 miles per hour), it will take a human 40 meters (or 44 yards) to stop the vehicle compared to 6.7 meters (or 7 yards) for the on-board computer.[21] In many accidents, that gap would be the difference between life and death for the passengers.

Since humans are lulled into a false sense of complacency by semi-autonomous vehicles, they may not be ready to take over the driving and may perform other activities that make the vehicle unsafe when confronted with conditions requiring judgment. That attention deficit has led some to conclude fully autonomous vehicles are likely to be safer than semi-autonomous ones because humans do not react quickly enough to avert dangerous circumstances. According to Chris Urmson, the former director of self-driving cars for Google, "human drivers can't always be trusted to dip in and out of the task of driving when the car is encouraging them to sit back and relax."[22]

FULLY AUTONOMOUS VEHICLES

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Fully autonomous vehicles are completely controlled by automated systems such as artificial intelligence, automated braking systems, machine learning, lane-changing technology, and deep learning. In some of these vehicles, steering wheels, gas pedals, and brakes are removed so that artificial intelligence systems make all the decisions. On-board computers deploy a full range of sensors, lasers, and cameras to implement decisions about movement, speed, and direction.

Baidu's AutoBrain-directed cars use artificial intelligence software and deep learning models for "training computers to work more like human drivers."[23] Its "automated driving maps record 3D road data and are accurate within a few centimeters for vehicle positioning. The object recognition and environment perception technology enables the car to detect and follow other vehicles with high accuracy, recognizing road lanes and accurately gauge distance and speed".[24]

Google meanwhile has logged over two million miles of on-the-road driving with its fleet of 60 autonomous vehicles.[25] Its monthly transparency data on accident reports shows only 17 minor accidents over seven years, none involving serious injury. In most of these situations, the accidents were caused by humans in other vehicles acting in unpredictable ways or rear-ending the autonomous vehicle.[26] The company has developed backup systems for braking, steering, and computing in case the main system fails and also has designed software so that its vehicles "stay out of other drivers' blind spots, nudge them away from lane-splitting motorcycles, and pause for 1.5 seconds after traffic lights turn green to avoid red light runners."[27]

Autonomous vehicles with these kinds of systems are the ultimate in software design. As Robin Li, Chief Executive Officer of Baidu, has suggested, "cars will be more like a computer on wheels."[28] Their computerized systems make life-altering decisions in real-time and navigate the vicissitudes of streets and highways. Through internal algorithms, they ingest a huge amount of data and use that to steer the car.

The benefit of this kind of autonomous system is there is no driver discretion, no human distractions due to texting or music, and no drunk driving. Cars will avoid collisions when objects appear in front of them or their algorithms indicate a danger based on sensor readings or camera imagery. There is no risk that drivers will become complacent or overly-confident regarding semi-autonomous automotive technology.

MARKET POTENTIAL AND EARLY ADOPTERS

The market for semi- and fully autonomous vehicles is expected to be quite large in the coming decades. For example, in China alone, it is estimated that by 2035 there will be around 8.6 million autonomous vehicles on the road, with about 3.4 million likely to be fully autonomous, while 5.2 million are semi-autonomous.[29] Industry officials believe that "the Chinese market for car sales, buses, taxis and related transportation services is potentially worth more than $1.5 trillion a year in revenue."[30]

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Boston Consulting Group anticipates that it will take 15 to 20 years for autonomous vehicles "to reach a global market-penetration rate of 25 percent."[31] Since autonomous vehicles are expected to hit the market by 2021, that would mean autonomous vehicles will comprise 25 percent of the global market between 2035 and 2040.

Autonomous vehicles are likely to spread in niche markets before they become popular in the broader consumer market. The initial cost of automated cars will be high, due to the addition of cameras, sensors, lasers, and artificial intelligence systems, therefore precluding adoption by the typical consumer. Rather, businesses and niche areas are positioned to be the early adopters. The most likely adopters include ride-sharing cars, buses, taxis, trucks, delivery vehicles, industrial applications, and transport for senior citizens and the disabled.

RIDE-SHARING CARS, BUSES, AND TAXIS

Ride-sharing companies are very interested in autonomous vehicles. They see advantages in terms of customer service and labor productivity. All of the major ride-sharing companies are exploring driverless cars.

The surge of car-sharing and taxi services such as Uber and Lyft in the United States, Daimler's Mytaxi and Hailo service, nuTonomy in Singapore, and Didi Chuxing in China demonstrate the viability of this transportation option.[32] Uber launched in 2010 and has a valuation of $68 billion. It operates in 90 American cities and in many other places around the world.[33] Along with Volvo, it has launched self-driving vehicles in Pittsburgh and slowly will replace at least some of its one million drivers.[34]

Lyft also has become a popular option. It has attracted $500 million in investment from General Motors, and is operating in many cities.[35] Didi meanwhile has a valuation of $35 billion and makes 14 million trips each day in 400 cities in China.[36] It is the largest ride-sharing service in the world, at least based on number of rides. As a sign of its long-term prospects, Apple recently took a $1 billion stake in this company. Recently, Didi grew even larger when Uber sold its China car-sharing operation to the firm.[37]

A study at the University of Texas at Austin investigated shared autonomous vehicle (SAV) operations. Their analysis found that "each SAV can replace around eleven conventional vehicles, but adds up to 10% more travel distance than comparable non-SAV trips".[38] That means that these services by and large will ease traffic congestion and environmental degradation. Shared vehicles will cut congestion by a considerable amount although the actual figure will be offset by some increase in miles travelled due to the convenience and popularity of ride-sharing options.

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Ride-sharing alternatives or taxis will reduce congestion because young people in many places have a preference for those options as opposed to purchasing their own vehicle. For example, a Roland Berger survey showed that "51 percent of Chinese car owners said they would prefer to use robot taxis rather than buy a new vehicle themselves, compared with 26 percent of Americans."[39] And in Japan, the company Robot Taxis says that "it hopes to develop a fleet of thousands of driverless vehicles in time for Tokyo [Olympics] 2020."[40]

Autonomous vehicles are likely to become a prominent option in mass transit systems. Baidu has plans to commercialize the self-driving vehicles in 3 years, which will begin with several trials in Chinese cities.[41] It has gained regulatory approval in several locales to run pre-determined routes and hopes to roll out these buses in the very near-future.[42] On August 31, 2016, the company received an Autonomous Vehicle Testing Permit from the California Department of Motor Vehicles that allows the company to test autonomous cars on public roads in California.

Some cities are considering a strategy of cordoning off certain city blocks exclusively for autonomous vehicles. Rather than mix human-operated cars and driverless vehicles, they are thinking about 30 to 40 block areas where autonomous taxis or ride-sharing vehicles provide all the transportation services. That would allow city planners to optimize those locales for automated vehicles. According to Jack Weast of Intel, this approach represents an effective way to move forward in the near future.[43]

DELIVERY VEHICLES AND INDUSTRIAL APPLICATIONS

Delivery vehicles and "platoon" trucks traveling together represent another area likely to see quick adoption of autonomous vehicles.[44] Purchases through online platform and e-commerce sites are rising rapidly, and this has been a boon to home delivery firms. People like to order things electronically (such as food, goods, and services) and then get delivery within hours. In China, online commerce totaled $590 billion in 2015, and much of it is based on the promise of same day delivery. That has been a boon to motorbike and truck delivering. The Chinese e-commerce numbers for 2015 represent a 33 percent rise over 2014.[45]

Trucks comprise 5.6 percent of vehicular miles in the United States, but 9.5 percent of the fatalities.[46] As such, they are a place where autonomous vehicles could add considerable value, both in terms of money and lives saved. Large trucks often cost over $150,000 so the introduction of cameras and sensors are quite cost effective compared to the case with automobiles, where the additional expense is based on a lower overall cost. In the United States, the firm Ottomotto is testing fully autonomous 18-wheel trucks, and its goal is to put them on the road in the near future.[47]

SENIOR CITIZENS AND THE DISABLED

Two parts of the consumer market that already see great applicability for autonomous vehicles are senior citizens and the disabled. Each face mobility restrictions based on physical limitations and/or visual acuity, and therefore see a number of benefits from intelligent cars.

The U.S. senior citizen population is expected to rise to over 80 million by 2050, or 20 percent of the overall population. At that point, there will be twice as many senior citizens as currently is the case, and one-third of these individuals will have mobility challenges.[48] The same situation is developing in China. By 2050, it is estimated that senior citizens will comprise 33 percent of the overall population.[49] In Japan, around 40 percent of its population will be 65 years or older by 2060.[50]

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The disabled market also is substantial. In the United States, for example, around 53 million adults have a disability, which is around 22 percent of the adult population. About 13 percent of adults have mobility problems and 4.6 percent have vision impairments.[51]

The vast size of these numbers for senior citizens and the disabled creates a ready-made market for autonomous vehicles. Both groups value independence, and self-driving vehicles give them mobility without dependence on friends and relatives. This is the reason that advocates for those communities are quite positive about the advent of autonomous vehicles.

BENEFITS OF AUTONOMOUS VEHICLES

Many benefits are expected of autonomous vehicles. These include improving highway safety, alleviating traffic congestion, and reducing air pollution. Research studies have found there are major gains likely in each of these areas.

IMPROVING HIGHWAY SAFETY

Highway deaths are a major problem around the world. In the United States, an estimated 35,000 people die in auto accidents each year, while in China, around 260,000 people die in vehicle accidents.[52] Japan experiences around 4,000 highway deaths each year.[53]

Worldwide, according to the World Health Organization, 1.24 million people die annually due to highway accidents.[54] It is estimated that traffic fatalities cost $260 billion each year and that accident injuries account for another $365 billion. This represents a total of $625 billion annually from highway fatalities and injuries.[55]

According to a RAND study, "39 percent of the crash fatalities in 2011 involved alcohol use by one of the drivers."[56] This is an area where autonomous vehicles almost certainly will produce major gains in terms of lives saved and injuries avoided.

In China, about 60 percent of accidents are related to cyclists, pedestrians, or motorbikes hitting or being hit by cars and trucks.[57] Around 94 percent of U.S. vehicular accidents involve human error, and therefore are potentially avoidable.[58]

A full deployment of autonomous safety features would lead to a 31 percent reduction in highway fatalities, or over 11,000 American lives a year.

A study by the U.S.-based Insurance Institute for Highway Safety found that a full deployment of autonomous safety features would lead to a 31 percent reduction in highway fatalities, or over 11,000 American lives a year.[59] That included features such as forward collision warnings, collision braking, lane departure warnings, and blind spot detection.

ALLEVIATING TRAFFIC CONGESTION

Traffic congestion is a problem in virtually every large metropolitan area. In the United States, for example, drivers spend an average of 40 hours stuck in traffic, at an annual cost of $121 billion.[60] For Moscow, Istanbul, Mexico City, or Rio de Janeiro, the wasted time is even higher. There, drivers can spend "more than 100 hours a year in congested traffic."[61]

There are "35 cities in China have more than one million cars on the road; 10 cities have more than two million. In the country's busiest urban areas, about 75% of all roads suffer rush-hour congestion." The number of private vehicles in China as a whole has risen to 126 million, which is up 15 percent over the preceding year.[62] The city of Beijing alone has 5.6 million vehicles in operation.[63]

Research by Donald Shoup has found that up to 30 percent of the traffic in metropolitan areas is due to drivers circling business districts in order to find a near-by parking space.[64] That represents a major source of traffic congestion, air pollution, and environmental degradation. Cars are thought to be responsible for "approximately 30% of the carbon dioxide (CO2) emissions behind climate change."[65]

In addition, it is estimated that anywhere from 23 to 45 percent of metropolitan traffic congestion occurs around traffic intersections.[66] Traffic lights and stop signs are inefficient because they are static devices that do not take traffic flows into account. Lights are pre-programmed to remain green or red for set intervals, regardless of how much traffic is coming from particular directions.

Once autonomous vehicles are phased in and represent a large part of the traffic, car-mounted sensors will be able to operate in conjunction with an Intelligent Traffic System to optimize intersection traffic flow. Time intervals for green or red lights will be dynamic and vary in real-time, depending on the amount traffic flowing along certain streets. That will ease congestion by improving the efficiency of vehicular flows.

REDUCING AIR POLLUTION

Automobiles are major contributors to poor quality air. According to a RAND study, "AV [autonomous vehicle] technology can improve fuel economy, improving it by 4-10 percent by accelerating and decelerating more smoothly than a human driver."[67] Since smog in industrial areas is linked to the number of vehicles, having more autonomous cars is likely to reduce air pollution. A 2016 research study estimated that "pollution levels inside cars at red lights or in traffic jams are up to 40 percent higher than when traffic is moving."[68]

A shared autonomous vehicle system also offers benefits in terms of emissions and energy. Researchers at the University of Texas at Austin examined pollutants such as sulfur dioxide, carbon monoxide, oxides of nitrogen, volatile organic compounds, greenhouse gas, and particulate matter with small diameters. Their findings show "beneficial energy use and emissions outcomes for all emissions species when shifting to a system of SAVs".[69]

The ride-sharing firm Uber has found that 50 percent of its trips in San Francisco and 30 percent in Los Angeles are pooled rides with multiple passengers. Globally, that number is 20 percent.[70] The more car-pooling there is, the greater the benefits for the environment and traffic congestion, both from traditional and autonomous cars. Moving away from the model of one person per vehicle would be a big benefit for air quality.

OBSTACLES TO ADOPTION AND UTILIZATION

There are several key challenges as intelligent cars emerge. This includes technical challenges arising from bad weather and digital hacking threats as well as obstacles that require institutional or societal action such as road infrastructure improvements, spectrum allocation, and public acceptance. Each of these matters poses problems for autonomous vehicles and their success in the market place.

BAD WEATHER

Bad weather represents an area where driverless cars do not perform very well. Heavy rain, large amounts of snow, or atmospheric smog obscure road signs and lane markings, and therefore raise the risk of driving accidents. It is difficult in these kinds of situations for autonomous vehicles to make good decisions. According to Rob Grant of Lyft, autonomous cars "don't behave well in certain weather conditions or poor road conditions."[71]

In addition, Duke Professor Mary Cummings emphasizes the problems of bad weather for autonomous vehicles. "Precipitation, fog, and dust create problems for lidar sensors, scattering or blocking the laser beams and interfering with the image detection capabilities of the camera. As a result, the vehicle is unable to sense the distance to other cars or to recognize stop signs, traffic lights, and pedestrians," she writes.[72]

DIGITAL HACKING

Security is an important consideration in this sector. There have been reports of vehicles hacked and systems disrupted. Autonomous cars depend on vehicle to vehicle (V2V) communications and vehicle to infrastructure (V2I) connections. It is crucial to maintain security in each of these pathways as well as in the personal electronic communications that passengers transmit via email, phone calls, texting, Internet surfing, and location data.[73]

Researchers Jonathan Petit and Steven Shladover outline a number of security threats to connected cars. This includes hacking, jamming, data theft, ghost vehicles, or malicious actions such as using bright lights to blind cameras, radar interference, or sensor manipulation. Any one of these activities could disrupt communications and create false readings for artificial intelligence algorithms. Their study identifies "GNSS (global navigation satellite systems) spoofing and injection of fake messages as the most dangerous attacks (i.e., most likely or most severe)."[74] Manipulating this type of information puts passengers are risk and potentially can lead to serious accidents.

Designers need to take vehicle security very seriously in order to avoid unnecessary risks.

Cybersecurity experts already have demonstrated a capacity remotely to hack a Jeep Cherokee. In a report published in *Wired* magazine, they tampered with the vehicle's steering, brakes, radio, windshield wipers, and climate controls, and showed that this vehicle was easy to disrupt through its Uconnect software. This example shows that designers need to take vehicle security very seriously in order to avoid unnecessary risks.

POOR HIGHWAY INFRASTRUCTURE

Infrastructure problems plague many countries. In India, for example, highways and roads represent major challenge. Nearly 38 percent of the country's roads are unpaved, compared to about 16 percent in China. For these reasons, the World Economic Forum ranks India 87th in infrastructure in the world, well below the number 6 ranking for Japan, 7 in Germany, 46 in China, 48 in Thailand, and 76 in Brazil.[75]

Poor highways pose challenges for autonomous vehicles. Cars need predictable surfaces and clearly defined traffic lanes. In a cross-country pilot drive, Delphi engineers found substantial variations in lane markings. According to Glen De Vos, "the automated vehicle encountered some roadways with wide white stripes, while others had narrow yellow markings. Some lane markings were new, others were faded, and some were marked with raised bumps."[76]

To the extent that roads are poorly marked or engineered, it is hard for either semi-autonomous or fully autonomous vehicles to traverse those routes. The risk of accidents goes up and there is a grave danger that computerized algorithms will lead to poor decisions. Unless addressed, this will limit the ability of autonomous vehicles to thrive. According to Cao He, an analyst at Minzu Securities in Beijing, "given the wide diversity of road conditions from one place to another, it is unlikely for any company to come up with a sizable industry operation within five years."[77]

Bridges represent special problems for autonomous vehicles. They "offer few environmental cues – there are no buildings for instance – making it hard for the car to figure out exactly where it is," according to Raffi Krikorian, director of engineering at Uber.[78]

INADEQUATE SPECTRUM

Inadequate spectrum is a major barrier in many countries. Finding dedicated frequency ranges is key to supporting autonomous vehicles. They need specific bands that perform well regardless of weather or traffic conditions. Autonomous vehicles and industrial applications need mid-range spectrum below 6 GHz due to the need to balance connection speed and radio link reliability. In a number of places, these frequencies are in high demand and it is difficult to guarantee the reliable service that autonomous vehicles require. A dropped phone call is annoying to consumers, but a lost connection for a driverless car could be deadly.

American manufacturers generally support a Dedicated Short Range Communication (DSRC) system. According to Sandy Lobenstein of Toyota, "DSRC is a two-way, short- to medium-range wireless communication protocol that allows vehicles to communicate with each other to detect and avoid hazards. DSRC-equipped vehicles broadcast precise information – such as their location, speed, and acceleration – several times per second over a range of a few hundred meters. Other vehicles outfitted with DSRC technology receive these 'messages' and use them to compute the trajectory of each neighboring vehicle, compare these with their own predicted path, and determine if any of the neighboring vehicles pose a collision threat."[79]

In 1999, the Federal Communications Commission set aside 75 MHz of spectrum in the 5.9 GHz band for DSRC, and that paved the way for testing and adoption of that crash avoidance technology. But industry leaders want to make sure there is sufficient spectrum for this and other aspects of connected cars. With the expected rollout of large numbers of autonomous vehicles, it is crucial to preserve available spectrum for industry development.

Inadequate spectrum is a major barrier in many countries. Finding dedicated frequency ranges is key to supporting autonomous vehicles.

PUBLIC ACCEPTANCE

Ultimately, the public must feel comfortable with autonomous vehicles for this market to develop. As with any emerging technologies, it takes a while for individuals to accept new models and different ways of navigating. Just as the shift from horses to cars and cars to mass transit was controversial, so too is the looming transition to autonomous vehicles.

According to an American public opinion survey undertaken at the University of Michigan, many people still prefer traditional approaches to vehicle operations. When asked about their preferences, 46 percent of Americans said they prefer no self-driving vehicles, followed by 39 percent who like partial self-driving [semi-autonomous] and 16 percent who support complete self-driving [fully autonomous] cars.[80]

There were interesting variations in attitudes by gender and age. Men (19 percent) were more likely to prefer full self-driving vehicles compared to women (12 percent). Young people aged 18 to 29 years old (19 percent) and those between 30 and 44 (22 percent) were the most likely to want self-driving vehicles, compared to those 60 and older (only 10 percent support self-driving) and those 45 to 59 (12 percent).

When asked about particular features, 95 percent say they want a steering wheel as well as gas and brake pedals, even in fully autonomous vehicles. Thirty-seven percent said they would be very concerned about riding in a full self-driving vehicle, 29 percent would be moderately concerned, 24 percent would be slightly concerned, and 10 percent expressed no concern about doing this.

Chinese drivers appear more open to vehicular experimentation. A World Economic Forum survey found that "75% of Chinese say they are willing to ride in a self-driving car."[81] This view was echoed in a separate survey undertaken by the Roland Berger consulting firm. It found that "96 percent of Chinese would consider an autonomous vehicle for almost all everyday driving, compared with 58 percent of Americans and Germans."[82] People in China do not have the same positive emotional relationship with driving and their own cars, and therefore are more amenable to self-driving cars.

ISSUES IN CHINA

China brings significant strengths to the area of autonomous vehicles. "Chinese carmakers started making cars 100 years after others and a lot of the core technology aren't in Chinese hands, such as engines," said Jin Wang, Senior Vice President, General Manager of Autonomous Driving Unit, Baidu. "With electric cars, with intelligent cars, the core technology shifts from the engine and gearbox to artificial intelligence and that's an area where China is very close to the U.S., giving China the chance to catch up and seize leadership."[83]

But the biggest challenge in China is the need to develop a national framework for autonomous vehicles. There are multiple ministries who are responsible for the supervision of automatic driving and designers require greater clarity regarding who regulates and how they regulate. In addition, the government needs to invest in highway infrastructure development for autonomous vehicles, eliminate the current national prohibition on road testing, reduce restrictions on road mapping so that car makers and software designers can learn from experimental trials, develop technical standards for autonomous vehicles, address legal liability in cases of accidents, and improve awareness of autonomous vehicles.

NEED FOR NATIONAL POLICY AND INVESTMENT

China has an advantage in that most of its regulatory processes related to autonomous vehicles operate at the national level. Its top-down approach has the benefit of simplifying the maze of regulatory rules and procedures that exist elsewhere in federal systems. It currently is developing draft regulations, and is soliciting industry and government comments before going to the State Council for final approval.

The biggest challenge in China is the need to develop a national framework for autonomous vehicles.

But there remains fragmentation over who will oversee regulation and development. Formal jurisdiction is split between the General Administration of Quality Supervision, Inspection and Quarantine (which handles product recalls), the Ministry of Industry and Information Technology (which makes industry policy), the Ministry of Transport (which makes plans for the transportation development), the Ministry of Public Security (which is in charge of vehicle registration, license management, and traffic safety supervision) , and the National Administration of Surveying, Mapping, and Geo-Information (which enforces rules on map data collection). Other agencies handle environmental protection, recycling, commerce, and finance. In all, nearly 10 ministries and departments have jurisdiction over some aspect of autonomous vehicles.

Getting these agencies to coordinate and work together is the task of current planners. Chinese policymakers must be careful regarding how they regulate autonomous vehicles. They need to balance innovation on the one hand with societal values designed to protect drivers, safeguard data, and protect security. What they decide sets the broader framework in which businesses operate.

In addition, the central government needs to invest in research and infrastructure development that aids autonomous vehicles. Having resources that make it clear this sector is a priority is important for the future of the industry. It is a way to signal to the world and the domestic sector that intelligent cars are important, and the country is committed to their development.

IMPROVE HIGHWAY INFRASTRUCTURE AND TRAFFIC MANAGEMENT

Improving roadways should be a high priority for autonomous vehicles. While the software development is the responsibility of the private sector, having good roads that are well-lit and display clear lane markings is very important. Both semi-autonomous and fully autonomous vehicles need roads that allow their cameras and sensors to operate effectively. If car cameras cannot read lane markings, 3D high definition maps are not as useful.

In addition, it would be helpful to install smart traffic lights that emit electronic signals to autonomous cars on whether the light is green, yellow, or red. LiDARs are very good at reading traditional traffic lights. But one circumstance where it is difficult for cameras is when the sun is low on the horizon directly behind a traffic light. In that situation, with the view somewhat restricted, autonomous vehicles would benefit from an electronic transmission from the signal telling them whether the car should proceed.

Putting money into intelligent traffic systems is another way the government can help the private sector. As noted earlier, current traffic signals are not efficient because they are static and do not incorporate any information on traffic flows. Having lights that are dynamic and shift their durations depending on the amount of traffic would ease congestion around intersections and reduce air pollution.

ALLOW ROAD TESTS AND ACCURATE MAP DEVELOPMENT

Current Chinese rules mandate that drivers must be in the vehicle and keep both hands on the steering wheel. That obviously complicates the introduction of autonomous vehicles and makes pilot projects unfeasible unless special exemptions are granted.[84] Fully autonomous vehicles cannot be tested under actual road conditions unless there is governmental flexibility in granting road test exemptions. It is hard to simulate actual highway driving through off-road sites.

Local Chinese governments can help by opening roads for car testing. The best way for autonomous vehicles to demonstrate they can deal with actual conditions is through road testing. That gives software designers more information with which to program their vehicles. In the long run, that will produce the safest cars. Having successful pilot projects will build greater confidence among the general public that autonomous vehicles are safe and reliable.

> Current Chinese rules mandate that drivers must be in the vehicle and keep both hands on the steering wheel.

It also is important to reduce restrictions on road map development. Accurate maps are vital to the future of autonomous vehicles. Existing technology can graph roads down to several centimeters in accuracy. But for reasons related to security, government regulations mandate that public maps cannot be more accurate than 50 meters (or

165 feet).[85] That rule makes it difficult to develop the accuracy required for 3D high definition maps for autonomous vehicles. Cars simply cannot operate safely with that degree of imprecision.

Companies need special licenses from the National Administration of Surveying, Mapping, and Geo-Information to collect data on road conditions and the height or weight limits of bridges. They are forbidden to collect any road data around military districts. That places an undue burden on industry innovators and makes it difficult to compile the information needed in this sector. Since most Western countries do not have these kinds of restrictions, it places Chinese businesses at a competitive disadvantage.

There are cumbersome rules on map data collection. Not only must a company have a license to collect navigational information, each of the individual engineers in the car needs a data collection license. The rules for granting licenses are quite strict and this complicates the development of high definition maps that are crucial for autonomous vehicles.

DEVELOP TECHNICAL STANDARDS

Technical standards are vital for autonomous vehicles. "If we can convince the government that every company, every car on the road must use this (single standard) … then there is a chance China can beat the rest of the world" in autonomous vehicles, noted Li Yusheng, the director of Chongqing Changan Automobile's autonomous driving program.[86] Standards help businesses know how to engineer their products and rely upon the best expertise.

Technical standards are needed in a number of areas. For example, standards would be helpful for high definition mapping. Guidelines could define measurement, analysis, and accuracy requirements. This would help clarify areas where government regulations currently are vague.

One feature where there is uncertainty is in wireless technology for cars. According to Li Yusheng, the head of the government panel, the country "may adopt cellular data technology – already used in many cars to access the Internet – for cars to communicate, rather than the dedicated short-range communications (DSRC) standard used in the U.S. and Europe."[87] It may rely upon either Long-Term Evolution wireless broadband or the newly-emerging 5G standard, thought to be ready for commercialization by 2020.

LEGAL LIABILITY

To develop fully, the autonomous vehicle sector must address issues of legal liability. Right now, insurance companies undertake elaborate risk assessment based on driver age, gender, experience, and the like. Since most accidents are the fault of humans, they focus on who is at fault and who should be held liable for accidents caused by speeding, drunk driving, going through spot signs, or hitting another vehicle.

It is less clear how to evaluate liability when there is no driver or the driver is relying upon automated controls. In China, policymakers are considering rules that shift legal liability away from drivers. Li Shufu, chairman of the automaker Geely, said that "China must revise its laws so the manufacturer, not the driver, is held responsible for accidents when a car is in self-drive mode."[88]

These decisions are important because Chinese roadways feature a range of people and vehicles. Junyi Zhang, of the Roland Berger firm, noted that "it is harder in China, where many roads have pedestrians, bicycles, low-speed vehicles and high-speed vehicles all mixed together. It is a very complicated environment, and many don't ride or drive to the same standard."[89]

PUBLIC AWARENESS

Industry and government should consider a public awareness campaign to inform people about the benefits of autonomous vehicles and their contributions to long-term job creation and economic development. The market in China for autonomous vehicles is quite large and the likely economic benefits are enormous. But government officials need to prioritize this area so as to reap the benefits of new technologies in the transportation area.

Such a campaign would help people understand what autonomous vehicles are, how they differ from traditional cars and trucks, and what the differences are between semi-autonomous and fully autonomous vehicles. Public engagement is important so that everyone understands the impact of intelligent cars and traffic systems on society, the economy, and national life itself.[90]

ISSUES IN EUROPE

In its "Declaration of Amsterdam," the European Union announced a blueprint for autonomous vehicles. In it, Dutch official Melanie Schultz van Haegen said "we want to pick up the pace because there are many gains to be made for mobility. Connected automated vehicles will make our roads safer, more sustainable and more efficient."[91]

To signify its commitment, the Netherlands sent six driverless truck convoys across the country on a semi-autonomous basis. These trucks drove in platoon-style and arrived without incident. The success of this pilot project generated considerable positive press for the initiative and has increased the momentum towards autonomous vehicles in Europe.

The European challenge is strengthening the artificial intelligence capability that is crucial to autonomous vehicles and making sure that its strict privacy rules do not preclude the development of high definition maps.

But the European challenge is strengthening the artificial intelligence capability that is crucial to autonomous vehicles and making sure that its strict privacy rules do not preclude the development of high definition maps. To be competitive in this sector, European auto manufacturers need experts with artificial intelligence skills and high performance computing aptitude because car manufacturing no longer is about physical design as much as it is about software development and real-time data analytics. The European Union also needs to ensure that its policies don't preclude artificial intelligence systems that are vital to autonomous vehicles.

STRENGTHEN ARTIFICIAL INTELLIGENCE AND HIGH DEFINITION MAPPING CAPABILITIES

European car companies are interested in autonomous vehicles. The Audi A4 has a Dynamic mode that has a number of semi-autonomous features and chips designed by Delphi, Mobileye, Bosch, and Qualcomm. It uses sensors and braking systems that automate parts of the driving process. Volvo has its IntelliSafe Assist and Pilot Assist system, while Mercedes-Benz uses a Distronic Plus with Steering Assist.[92] BMW has teamed up with Intel and Mobileye for its semi-autonomous vehicles.

But European nations do not have many strong indigenous technology companies and often rely on firms outside the region for Internet, mapping, chips, sensors, equipment, and services. Mobileye, for example, is an Israeli firm that builds cameras and sensors. The European Union should do more to develop home-grown talent in artificial intelligence, deep learning, big data analytics, and high definition mapping because those skills are vital for future automotive development.

RULES ON DATA COLLECTION AND PRIVACY PROTECTION

Data collection is an area where the European Union has taken a restrictive stance on data collection and analysis. For example, it has rules limiting the ability of companies such as Google from collecting data on road conditions and mapping street views. Because many of these countries worry that people's personal information in unencrypted wi-fi networks are swept up in overall data collection, the EU has fined Google on several occasions, demanded copies of its data, and placed limits on the material collected.[93] This has made it more difficult for firms operating there to develop the high definition maps required for autonomous vehicles. Without these maps, it is impossible for self-driving vehicles to navigate the roadways safely.

More ominously, recent European Union General Data Protection Regulations place severe restrictions on the use of artificial intelligence and machine learning. According to newly published guidelines, "regulations prohibit any automated decision that 'significantly affects' EU citizens. This includes techniques that evaluates a person's 'performance at work, economic situation, health, personal preferences, interests, reliability, behavior, location, or movements.'"[94] In addition, these new rules give citizens the right to review how digital services made specific algorithmic choices affecting people.

If interpreted stringently, these rules will make it difficult for European software designers to incorporate artificial intelligence and high definition mapping in autonomous vehicles. Central to navigation in these cars and trucks is tracking location and movements. Without high definition maps containing geo-coded data and the deep learning that makes use of this information, fully autonomous driving will stagnate in Europe. Through this and other data protection actions, the European Union is putting its domestic auto manufacturers at a significant disadvantage to the rest of the world.

SIMPLIFY REGULATION

Like other places, the European Union has a complex web of regulatory processes for autonomous vehicles. In Germany, for example, Google must notify the public before it collects Street View data on public streets. In addition, that nation limits the length of time the company can keep imaging data about private homes surrounding streets and highways. People can opt-out of data collection, and in Germany three percent have done so.[95] Each of these requirements limits the accuracy of navigational maps and the ability to update maps over time.

Many countries within Europe have different approaches to policy, legal, and regulatory questions, and this lack of uniformity creates problems for systems designers. According to Peter Mertens, Volvo's senior vice president of research and development, "if there was one solution in Europe, one solution in North America and one solution in China, it would be really, really difficult to make that happen. That not only goes for the technology, it also goes for the regulation."[96]

LEGAL LIABILITY

In Great Britain, an insurance company called Adrian Flux is offering a special policy for semi or fully autonomous vehicles. Since the firm expects fewer accidents and fewer liability claims, its spokesperson says "we expect premiums for fully autonomous cars to be considerably cheaper than regular cars, purely because of the expected reduction in accidents and claims." That will reduce the revenue for the company, but "the lower rate of accidents means the insurance company will get to save money overall because it won't be forced to issue as many payouts."[97]

ISSUES IN JAPAN AND KOREA

Japanese and Korean governments and car manufacturers have been cautious about autonomous vehicles. Nissan got the government's first autonomous vehicle license in 2013 and firms such as Toyota, Honda, Kia, and Hyundai are investing substantial resources. But they have to decide how high of a priority autonomous vehicles are for their firms. Otherwise, they will be left behind as businesses and consumers embrace these vehicles.

NATIONAL PRIORITIZATION

A *Wall Street Journal* headline summarized the situation in Japan as "Toyota's Late Shift Into Self-Driving Cars".[98] It described Toyota executive Akio Toyoda as an "autonomous-vehicle skeptic", but someone who was beginning to realize the technology is becoming more advanced and that car competitors elsewhere are moving into this area in a substantial way.

In April, 2016, the company said it was creating an "autonomous vehicle research base" at the University of Michigan as part of a billion dollar investment in the Toyota Research Initiative in the United States.[99] It will employ 50 engineers and help the company catch up with research on artificial intelligence and high definition data mapping. Its goal is to build prototyping labs and engage in low speed vehicle testing on simulated road conditions.

Companies seems dubious regarding the prospects for fully autonomous vehicles, despite the demonstrated track records of Google, Baidu, and various car-makers in this area.

However, even in making this investment, company officials stated that "Toyota believes that its vehicles will never become autonomous to the point where the driver no longer has hands on the steering wheel."[100] The firm seems dubious regarding the prospects for fully autonomous vehicles, despite the demonstrated track records of Google, Baidu, and various car-makers in this area.

The irony is that in 2012, Google used Toyotas in its early testing of self-driving cars. When the tech giant requested a partnership to cooperate on the technology, Toyota turned them down because it did not want to share information on car design. The result now is that the manufacturer is playing catch-up in a sector that has shifted in favor of autonomous vehicles.[101]

The major question, then, is how important is autonomous vehicles and how much investment do Korean and Japanese firms want to make in this technology. It is not just a question of moving into advanced manufacturing and incorporating robotics in factories. A serious move requires substantial investments in artificial intelligence, data analytics, and high definition mapping because they represent the foundation of autonomous vehicles.

POLICIES AND REGULATION

Japan currently requires that all cars operated in its country be controlled by a real person. Its automotive companies need special permission to engage in road tests there. Rules promulgated by the local National Police Agency requires "that all tests on public roads should be made with a driver behind the wheel," which limits testing of fully autonomous vehicles.-[102]

In addition, the country is considering several restrictive policies. These include "limiting autonomous passing to expressways and holding a human driver accountable for any accident" and requiring "the installation of a device designed to prevent operators from falling asleep or looking away. The device could use a sensor to judge an operator's condition."[103]

In 2015, the Japanese government issued guidelines that established 2020 as the time for semi-autonomous features in cars and 2025 for fully autonomous vehicles.[104] In Korea, carmakers Kia and Hyundai have set their goal of fully autonomous vehicles in operation by 2030. The former has put $2 billion into its effort, while the latter is devoting $9.75 billion.[105] Each of these plans, though, is on a significantly slower schedule than the United States or China, where semi-autonomous cars already are on the road and fully autonomous vehicles are expected by 2020. Its government needs to expedite vehicle testing and deployment in order to reap the economic, social, and environmental benefits of autonomous vehicles.

The country has been slow to develop technical standards for this sector. So far, it doesn't have "common parts specifications and safety regulations" that are needed to sustain the industry.[106] Suppliers such as Hitachi, Denso, and Panasonic complain about the need for standards that would help them know what the marketplace needs. They worry that American or European parts standards will put Japanese suppliers at a global disadvantage.

Companies have requested that Japan's Ministry of Land, Infrastructure, Transport and Tourism develop "smart-road infrastructure standards that can relay traffic and accident data in real time. This technology could be used to change the speed limits on electronic signs to calm traffic, or to relay road construction warnings directly to smart car dashboards."[107]

The Korean government meanwhile has designated autonomous vehicles as one of its top 13 Industrial Engine Projects. Its Ministry of Trade, Industry & Energy has budgeted 295.5 billion KRW (or $259 million) for this sector between 2016 and 2022.[108] The goal is to position Korea as a major global parts supplier. Given the lack of standards in most nations, though, it will be difficult to implement this strategy.

To organize governmental activities, officials have put together a Smart Car Council to coordinate actions across ministries. That includes the Ministry of Science, ICT and Future Planning, Ministry of Land, Infrastructure and Transport, and the Ministry of Trade, Industry & Energy.[109] The Council's task is to make sure officials are working together.

But similar to the situation in Japan, commercial deployment has been slow. In Korea, Hyundai has tested semi-autonomous cars in Seoul. But the company reports that fully autonomous vehicles won't be available until 2030, which is well behind many other countries. Lim Tae-won, the vice president of Hyundai's Central Advanced Research and Engineering Institute, said "fully-autonomous vehicles are still some way off, and a great deal of research and rigorous product testing will need to be carried out to make the 'self-driving car' a reality."[110]

In May, 2016, the government authorized road testing across the whole country, instead of in certain regions as previously been the case.[111] That is a positive step for autonomous vehicles because without actual testing, it is hard to perfect the technology.

ISSUES IN THE UNITED STATES

The biggest American challenge is overcoming the fragmentation of 50 state governments and having uniform guidelines across geographic boundaries. Public officials should address questions such as who regulates, how they regulate, legal liability, privacy, and data collection.

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NATIONAL INVESTMENT

President Barack Obama has called for $4 billion over 10 years "to test connected vehicle systems in designated corridors throughout the country, and work with industry leaders to ensure a common multistate framework for connected and autonomous vehicles."[112] However, so far, Congress has not approved this investment so this is an expenditure that awaits legislative authorization. Representatives should approve this budgetary request so that the country can finance needed infrastructure improvements.

NATIONAL GUIDELINES FOR THE STATES

Right now, there are few agreed-upon technical standards and a hodge-podge of regulation at the state government levels.[113] Industry officials have to deal with 50 sets of state rules that can differ dramatically. According to Chris Urmson, formerly of Google, "in the past two years, 23 states have introduced 53 pieces of legislation that affect self-driving cars – all of which include different approaches and concepts. Five states have passed such legislation, and – although all were intended to assist the development of the technology in the state – none of those laws feature common definitions, licensing structures or sets of expectations for what manufacturers should be doing."[114] All of this complicates the task of car developers who need a more unified approach. Companies can't design cars for Texas that can't operate in Illinois, Florida, or New York.

California, in particular, has passed legislation that is overly restrictive. It sets back fully autonomous vehicles by requiring a driver in the front seat, and prevents companies from removing human-operated steering wheels and brakes. That potentially negates some of the benefits of driverless cars while also creating a barrier to innovation in the automotive industry.

In an effort to simply the regulatory apparatus, the National Highway Traffic Safety Administration is expected to release new rules designed to promote innovation while protecting consumer safety. Among the likely features are proving guidelines for uniform regulations in the states, providing exemptions to outmoded safety regulations, operational guidance for new features, and new tools for encouraging autonomous vehicles.[115]

But in a setback for manufacturers, the national government is expected to insist that fully autonomous vehicles retain a steering wheel and brakes, and that there be a licensed driver in the car. Some designers argue that having those override features opens the door to drunk drivers and creates a sense of complacency with passengers that can be dangerous.

In its phasing in of autonomous vehicles, American regulations are likely to mandate "many years – at least five – of demonstrated safety and economic benefits" in its rules. That would be consistent with the introduction of front airbags and other automotive features in the past. Manufacturers generally are given 5 to 10 years to meet new safety standards.[116]

LEGAL LIABILITY

Consumers cite lower insurance costs as one of the things they like about autonomous vehicles.[117] Almost one-third gave that reason, followed by increased safety and switches to self-driving model as reasons they would buy a partially autonomous vehicle.

It is not clear, though, how insurance companies will handle liability claims in the new world of transportation. Is the accident the fault of the driver, the writer of the software code that controls automated features, or the car manufacturer who made the hardware? It will take some law suits to resolve attributions of responsibility. Insurance firms will take a while to develop actuarial tables based on accident records so they know what premiums to charge drivers.

A RAND study recommends "no fault" insurance for autonomous vehicles. Its rationale is that driverless cars are less prone to human errors and therefore they represent a fundamental change in legal liability.[118] Driverless cars essentially shift more of the responsibility from drivers to manufacturers and software designers.

For the latter, product liability law is a promising way to think about legal responsibility. Manufacturers are responsible for defective conditions so their liability would hinge on whether there was a reasonable expectation than their products would operate as expected and not pose undue risks to passengers.[119]

In his analysis of product liability, Brookings nonresident senior fellow John Villasenor describes seven categories of liability, including negligence, strict liability, manufacturing defects, design defects, failure to warn, misrepresentation, and breach of warranty. There is well-established case law in these areas and he notes that "products liability law has proven to be remarkably adaptive to new technologies."[120]

Automotive liability is complicated right now because there are 262 million registered passenger vehicles in the United States with an average age of 11.5 years.[121] With the expected slow phase in of driverless vehicles equipped with advanced safety features, it will be years before all the old vehicles leave the road. That will create a complex blend of new and old vehicles for a decade or longer.

DATA PROTECTION, PRIVACY, AND SECURITY

By 2020, the coming 5G network is expected to support 50 billion connected devices and 212 billion connected sensors as well as enable access to 44 zettabytes (ZB) of data.[122] This will range from smart phones and tablets to smart watches, driverless cars, machinery, appliances, and remote monitoring devices.[123] All of these will generate a massive amount of "useful data" that can be analyzed. Indeed, researchers estimate that this connected ecosystem will make it possible to utilize a much larger percent of digital data (35 percent) than before (5 percent).[124]

Data collected through vehicles enable new business models. For example, in the insurance industry, "a connected vehicle allows an insurance company to really look at you individually in terms of your actual driving and your real risk and real time situational awareness, so they can innovate a lot of products and a lot of pricing strategies aimed at trying to keep you out of harm's way, and almost pivot from selling insurance to selling assurance."[125]

Several American insurance companies such as State Farm and Progressive have safe driving policies that "collect the miles driven, acceleration, braking, right and left turns, speeds over 80 mph, and the time of day the vehicle is driven, and use the data to calculate insurance rates."[126] Consumer rights activists worry that this information will be sold to third-party vendors and used against drivers. It is clear that vehicles compile a wealth of information on people's locations, their text messaging, e-commerce purchases (including credit card numbers), and other activities in which they engage while in connected cars.

Given this situation, there need to be safeguards to protect people's IP addresses, personal information, and GPS location data. According to Khaliah Barnes of the Electronic Privacy Information Center, the privacy policies of car manufacturers and service companies working on autonomous vehicles allow disclosure of driver information for "troubleshooting, evaluation of use, and research" and to unnamed third-parties "for marketing purposes".[127]

In a study undertaken for the Transportation Policy Research Center at Texas A&M University, Karlyn Stanley and Jason Wagner call for additional privacy legislation. This includes "protection of the data privacy of certain populations (e.g., juveniles) and protection of citizens' data privacy in specific circumstances (e.g, the use of location data in search warrants)."[128] They warned about "a rush by stakeholders to monetize vehicular data" and uncertainty over "who owns the data from vehicles."

In addition, stronger cybersecurity standards would strengthen compliance and make sure all manufacturers have effective protections. This is especially the case for wi-fi connections, which usually are not encrypted and therefore are relatively easy to compromise. Security is different from privacy protection because it focuses on malicious actions seeking to inflict harm on drivers and passengers.

A group called "I Am The Calvary" co-founded by Josh Corman recommends five steps to protect consumers: "safer design to reduce attack points, third-party testing, internal monitoring systems, segmented architecture to limit the damage from any successful penetration, and the same Internet-enabled security software updates that PCs now receive."[129] Adoption of those recommendations would go a long way towards easing data collection concerns involving autonomous vehicles.

MALICIOUS ACTION LEGISLATION PENALIZING DISRUPTION OF AUTONOMOUS VEHICLES

One of the things that sometimes happens with emerging technologies is a testing of limits and efforts to disrupt their operations. This can be very serious when applied to large vehicles moving at a fast rate of speed.

With autonomous vehicles, threats may come in a variety of forms. It can include using lasers directed at car cameras to throw off its navigational systems, hacking of computer code to take control of vehicle braking or steering, placing objects in front of the vehicle to alter its movements, or sending electronic signals that change its course, among other actions.

Policymakers should consider legislation that outlaws malicious behavior directed at autonomous vehicles and applies criminal penalties for those engaging in this conduct. It is crucial that autonomous vehicles operate safely and that people do not disrupt vehicular software or hardware in ways that would be harmful to passengers. Anyone who engages in that kind of behavior should be punished to the full extent of the law.

CONCLUSION

To summarize, the technology underlying semi- and fully autonomous vehicles is well-developed and poised for commercial deployment. Major automotive companies and software developers have made considerable progress in navigation, collision avoidance, and street mapping.

But in each country, there are budgetary, policy, and regulatory issues that need to be addressed in order to gain the full benefits of autonomous vehicles. Governments can accelerate or slow the movement towards self-driving vehicles by the manner in which they regulate. Addressing relevant issues and making sure regulatory rules are clear should be high priorities in all the countries considering autonomous vehicles.

> Governments can accelerate or slow the movement towards self-driving vehicles by the manner in which they regulate..

A detailed report by the Australian National Transport Commission on automated vehicles argued that the most important regulatory priorities should be "supporting on-road trials and clarifying the meaning of control and proper control". Currently, there is uncertainty over "who or what is in control" and what constitutes proper control.[130] Its authors called for national guidelines on road trials, driver rules, control expectations, and legal liability.

From an outside standpoint, work needs to be done to overcome obstacles such as poor infrastructure, bad weather, spectrum limitations, hacking, and public acceptance. That will enable drivers and businesses to reap the advantages of digital innovation. If car developers can overcome these barriers, there will be substantial advances for transportation and society.

There remain broader societal and ethical considerations, though, that must be considered as we move closer to commercialization. How should programmers build ethical choices into automated features and advanced algorithms? For example, if an automated car is facing the outcome between hitting one child or a group of 10 kids, how does it make that choice? What are the factors in the algorithm that would lead its system to veer one way or another? One can imagine a wide variety of ethical issues that come along and software designers have to make choices regarding how to deal with them.[131] Learning how to navigate these complicated issues is a major challenge facing the world.

ENDNOTES

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The Brookings Institution
1775 Massachusetts Ave., NW
Washington, DC 20036
Tel: 202.797.6090
Fax: 202.797.6144
brookings.edu/governance

PRODUCTION & LAYOUT
Cathy Howell