COUNCIL on FOREIGN RELATIONS

# Driverless Cars

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## Introduction

Autonomous vehicles have quickly moved from science fiction writers' dreams to test labs, but what exactly is coming? Several manufacturers have announced their intention to roll out vehicles by 2020 with self-driving modes that fully operate the car in certain scenarios, such as highway cruising or stop-and-go traffic. Over time, self-driving modes could handle more situations with less human intervention, and declining costs might allow the technology to spread from luxury cars to the mainstream.

Even limited automation promises great benefits, vexing problems, and perhaps an industry shakeup. The United States and top auto-producing states in Europe and Asia are competing to be at the forefront of innovation through research funding, sponsoring competitions, and building a legal framework for extensive road tests and eventual adoption. Even emerging auto markets like China are showing increasing interest in autonomous driving by hosting competitions to spur their industries.


People ride on a driverless electric vehicle at the Nanyang Technological University (NTU) in Singapore, September 4, 2013. (Photo: Edgar Su/Courtesy Reuters)

## How Do Driverless Cars Work?

Autonomous systems use a variety of tools analogous to those of a human driver. Instead of eyes and mirrors, an autonomous system deploys an array of sensors that computers then interpret to make sense of surroundings and decide whether to accelerate, slow down, or change lanes. Actuators and **drive-by-wire** systems allow the computer to physically control the vehicle in place of human hands and feet. Whether the car is electric or a traditional gas combustion engine is irrelevant; a well-designed autonomous system could control either.

Google's system relies upon a roof-mounted laser radar, or "lidar", system that scans the immediate environment and builds a **three-dimensional map** of its surroundings; the system deploys **$150,000 in autonomous equipment**. CMU demonstrated a **Cadillac SRX** that made a **thirty-three-mile drive** in September 2013 with lower cost sensors and a conventional appearance. More automakers appear to be following this latter approach with multiple embedded sensors, including lasers, ultrasonic sensors, radar, and cameras. Radar provides distances to other cars and their speeds, cameras can detect lane markings, etc. Google and others also incorporate GPS with a detailed map database, just as a human brain navigates by incorporating sight and memory of the street layout.

While automated systems have the advantage of a constant 360 degree perspective unaffected by fatigue or inattention, today's systems are not as adept as humans in dealing with unusual circumstances, such as a policeman manually directing traffic or snowfall that obscures road markings and creates noise for radar systems. Because of these limitations, the autonomous vehicles of 2020 will likely self-drive only under certain conditions and relinquish control to a human driver if situations change.

The performance of even limited self-driving systems will need to be near perfect to gain acceptance of consumers and regulators. As Professor **Ragunathan Rajkumar** of Carnegie Mellon University (CMU) explained in a CFR interview: "Autonomous driving is happening sooner than people anticipated, but we need to be cautious in the near time."

## Potential Benefits

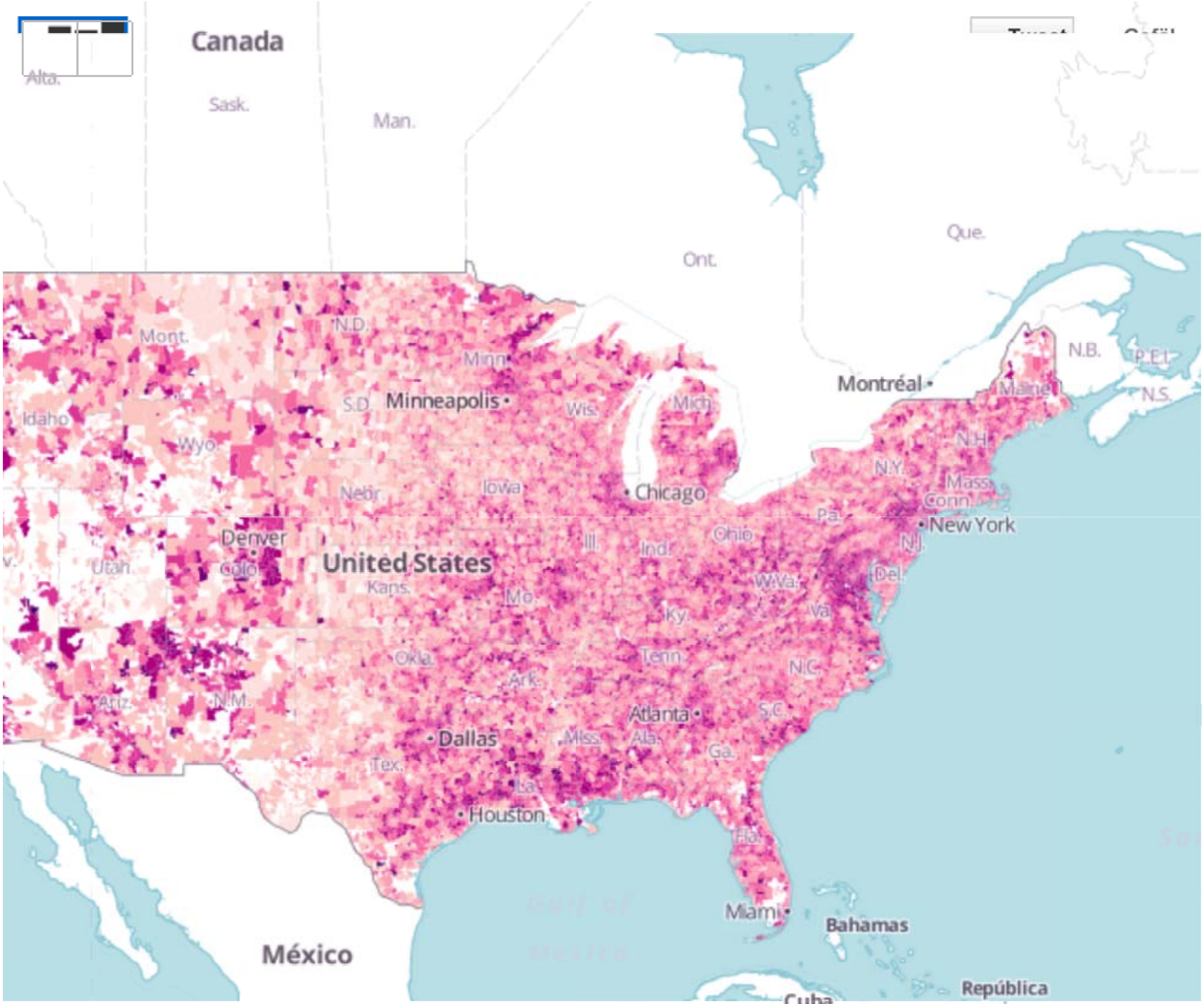
Autonomous driving has vast potential benefits: reduced crash fatalities, effectively greater highway capacity, and the ability to make productive use of transit time. More than **1.2 million people** die globally each year due to motor vehicle accidents. A 2008 study by the U.S. Nation Highway Traffic Safety Administration (NHTSA) estimated that driver error is the critical reason behind **95 percent of motor vehicle accidents** in the United States—consistent with **estimates of global rates**—which autonomous driving systems could reduce by eliminating fatigue, drunkenness, inattention, and speeding. While U.S. motor vehicle fatalities have declined since the 1970's, they remain the **leading cause of death** for Americans aged five to thirty-five.

Some public benefits from autonomous vehicles will require wide adoption. For instance, autonomous vehicles could travel close together in high speed platoons, effectively boosting the capacity of the nation's highways and improving fuel efficiency by cutting down air drag for vehicles travelling in the wake of another car.

The potential payoff is huge, according to MIT's **Erik Brynjolfsson**, who explained at a **CFR event**, "When a highway is totally packed and full, traffic jam, about 90 percent of the pavement is not being used, because on average if you measure it, there's about four to five car lengths that people leave between them. "

As autonomous driving systems evolve and require less supervision, the average morning commute of **25.5 minutes** could become a productive time to catch up on email or hold a conference call. In the more distant future, fully driverless cars could bring new independence to **owners who are blind** or infirm. Rajkumar pointed out that where people live could even change; a long morning commute from a home in the far suburbs is less of a burden if you can sleep through it.

In recent years some large dollar estimates have been attached to driverless auto systems. Morgan Stanley estimated full conversion to driverless cars could save the U.S. economy **$1.3 trillion annually**, while a paper by the Eno Center for Transportation calculated that number at **$450 billion annually**, with 90 percent conversion.

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## Legal and Security Risks

Yet there are substantial legal risks to greater vehicle autonomy. Even if most accidents are avoided, there will still be some, and likely a few that could have been avoided with an expert human driver at the wheel. Creating a legal framework to give reasonable safeguards and guidance to automakers will be critical for widespread adoption. Lawmakers in states and nations vying to lead this innovation are beginning to build this legal foundation.

California, Florida, Michigan, Nevada, and Pennsylvania have all legalized the testing of autonomous vehicles on their roads. In May 2013, NHTSA issued a **policy on autonomous driving** that gave states advice on guidelines for legalizing testing, but saw guidelines for commercial adoption as premature. Outside the United States, Japan is allowing **Nissan to conduct road tests**, and while the European Union discusses amending the 1968 **Vienna Convention on Road Traffic**, the British government is designing a **legal framework for autonomous vehicles**.

Ethicists and lawmakers face thorny questions about potential liability and how to program vehicles to make split second decisions. Problematic scenarios include whether a vehicle should swerve to avoid a certain crash if swerving could cause a collision with another vehicle, or if a traffic law should be broken to **prevent an accident**.

Autonomous driving systems would create new security and privacy concerns. Could someone remotely **hijack your vehicle**? Could data on where and when you car had been be used by police investigators? One way around these concerns would be to not use vehicle communication, whether to another vehicle or to a centralized system, but some experts see this as unlikely given the many advantages of vehicle communication.

## The Auto Industry vs. Silicon Valley?

Auto industry stalwarts like GM and Daimler and new entrants like Google are competing to develop affordable, reliable autonomous systems. Automakers already offer driver assist technologies such as lane departure warnings and adaptive cruise control that maintain a distance with the vehicle in front of it. The **2014 Mercedes S-class** can steer through city traffic and drive within a highway lane.

New developments are on the horizon. Volvo is planning a **2017 pilot program** of one-hundred autonomous cars in Gothenburg, Sweden's second-largest city. GM is developing **Super Cruise to guide a vehicle on highways**. Nissan has promised to introduce limited **autonomous driving technology by 2020**, and other automakers are expected to as well, though a human driver will need to be ready to take over control if a particularly difficult situation arises.

While most experts expect limited autonomous systems in luxury vehicles by 2020, **Tesla Motors**—the Silicon Valley automaker that launched in 2003 and specializes in high performance and luxury electric cars—has a more aggressive target. Elon Musk, Tesla's founder and CEO, plans to offer an autonomous system that can handle **90 percent of miles driven by 2017**, but sees great difficulty in reaching fully driverless operation.

Autonomous driving will make software, sensors, and perhaps wireless connectivity an even more important part of the automobile. It creates an opportunity for technology firms to insert themselves into more of the automotive value chain. But if a car's software becomes a core source of value, like engine design, then automakers have a vested interest in owning the intellectual property.

While Google's driverless vehicle tests have **attracted much attention**, no commercialization plans have been publicized, and Google has not announced autonomous driving partnerships with any major automaker. Still, technology firms may have other roles to play, from providing mobile data to **rich infotainment systems** that mesh well with autonomous systems that periodically need to recall the driver to duty.

Entrepreneurs could create new models of vehicle use, like a Zipcar that drives to you. A 2013 MIT study estimated that the population of Singapore could reduce the total number of motor vehicles by almost **two-thirds with full automation**, with only a fifteen-minute peak wait time. More sharing of automobiles would mean smaller fleets, but each vehicle would get more usage and thus wear out faster, so annual production of vehicles may not decline precipitously.

As with any technological change, there will be winners and losers. Safer highways and lower fatalities will benefit all, though if collisions are reduced it will mean less work for body shops and tow trucks, and a **declining role for insurance companies**. More car-sharing would reduce the need for car dealers who principally handle retail sales. Full self-driving vehicles may eliminate cab-drivers, bus-drivers, or even truck-drivers if **large vehicles are automated**. Some of those jobs will remain but require a different skill set.

## National Initiatives

Research on autonomous driving has been underway for decades. From 1987 to 1995 multiple European governments funded the **Eureka PROMETHEUS Project**, whose lessons have been **applied by Daimler** and other automakers to create driver assistance systems and build a foundation for the development of autonomous systems.

In the United States, the military led on early research through the Defense Advanced Research Projects Agency (**DARPA**) which funds early stage research in technologies that could provide a military advantage, like **automated truck convoys** that could cross hazardous terrain without putting lives at risk. Autonomous driving is another example of the enormous potential commercial value derived from government funded research; like DARPA's creation of the **ARPANET**, the forerunner to the Internet.

In the 1980s, the state of the art was the DARPA-funded **autonomous land vehicle**, which devoted much of its boxy bulk to computer racks. In successive years, DARPA funded demonstration projects with increasing capability, but innovation greatly accelerated through competitions in the mid-2000s. The DARPA Grand Challenge of 2004 offered a $1 million prize to complete a 150-mile desert course, but **all entrants failed after less than eight miles**. Lessons were learned and quickly applied. Five vehicles—of 23 finalists culled from 195 teams that applied—completed a follow-up 2005 event, with the winning **Stanford vehicle averaging 19.1 mph**. The **2007 DARPA Urban Challenge** brought autonomous vehicles to a simulated urban setting and a victory to **CMU**. U.S. support for universities developing autonomous technology continues through grants from agencies such as the National Science Foundation, and the Department of Transportation.

Other nations are accelerating efforts along similar lines: close partnerships between research universities and automakers, government-funded research, and competitions. DARPA has not set up further driverless competitions because it sees its mission to **demonstrate the feasibility** of autonomous driving complete, even as **China** and **South Korea** are conducting annual competitions. The United Kingdom's **National Infrastructure Plan** includes a £10 million prize "for a town or city to develop as a testing ground for driverless cars."

Still, competition is not wholly nationalistic as the global nature of the auto business is reflected in cross-border research efforts. For example, Stanford's **Center for Automotive Research** is affiliated with automakers from many nations.

## Long-Term Evolution

Despite the promise of fully autonomous vehicles, this will not be a sudden revolution, but a gradual evolution along a continuum. Indeed, human drivers have been slowly yielding more control to vehicles, from antilock brakes and static cruise control to adaptive cruise control that keeps a safe distance from the next vehicle and cars that parallel park themselves.

Even if the technology was fully developed, it would still take a long time for vehicle automation to yield substantial system-wide benefits because of the lag between introduction and market conversion. It takes at least fifteen years to replace the entire U.S. auto fleet of close to 250 million vehicles, even assuming **2013's strong sales record of 15 million**, and it will be a long time before every new car has automation.

As the technology improves, designers and drivers will be more comfortable yielding more control and having fewer occasions to jump in and override the system. In 2020, you probably won't be able to safely fall asleep during your commute, but a new, high-end vehicle could take over the mundane parts of your drive to work while you supervise.