

5 TECHNOLOGICAL FACTORS REGULATORS AND POLICYMAKERS NEED TO KNOW

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Regulators and policymakers are playing an increasingly large role in making decisions about public policy and the regulation of automated vehicles (AVs). AVs are more than a vehicle with a camera and a hands-free steering wheel; AVs are a transformative technology. They promise to change the traditional paradigms of mobility, road safety, communication technologies, and conceptions of privacy, as well as challenge ethical norms and change the way humans interact with robots.

The technical, social, and economic complexities of automated vehicles have resulted in highly specialized silos of expertise. Specifically, the subject engages experts on AI, privacy, telecommunications, infrastructure, and standardization bodies, as well as car manufacturers and electrical engineers. However, these seemingly disparate fields have often failed to cohesively communicate across disciplines. Consequently, policymakers may have difficulty both understanding the full extent of the opportunities and challenges of AV technology, and prioritizing between the most effective policy actions.

Understanding the key technological aspects of AVs could help policymakers with this information asymmetry problem between technology experts and policymakers. These technology insights will enable policymakers to make sense of the ongoing technical discussions and build synergies among the isolated sectors and territories.

This policy paper explores these key technological dimensions of AVs, giving an inclusive, high-level view of AV technology, and presents five essential elements policymakers should know. It intends to inform regulators and policymakers, bridging information asymmetries between policymakers and technologists. It also aims at expanding policymakers' governance toolbox to help policymakers create more effective policies and regulations.

INTRODUCTION TO AUTOMATED VEHICLES

Automated vehicles (AVs) are vehicles with driving functions or tasks that do not require human intervention. There are different degrees of automation, which depend on the number of automated tasks embedded in the vehicle and how machines and humans share the driving responsibilities.

AVs are classified according to their level of automation. There are many existing taxonomies of AVs, but the most widely adopted at an international level is the one produced by the Society of Automotive Engineers-SAE (International Standard J3016-2014).¹ The SAE taxonomy includes six levels of automation, ranging from manual vehicles to fully automated ones.² In the 0 level, the vehicle is fully controlled by the human. In

levels 1-3, the vehicle's autonomous mode is only available in certain traffic situations or places—like highways—and the human is expected to be ready to take over control of the vehicle if the system requires it. In levels 4 and 5, the artificial intelligence system is fully responsible for driving the vehicle. The vehicle can ask for human intervention—allowing the human to take over the vehicle whenever he or she chooses—but cannot rely on receiving it.

Level 0 and 1 vehicles are widely distributed, and several Level 2 vehicles are already being offered. A KPMG report³ estimates the deployment of Level 3, 4, and 5 vehicles by end of 2020-2025; 2025-2030; and beyond 2030, respectively.

¹ The SAE J3016 has been adopted by the U.S. Department of Transportation in September 2016; it has been adapted by the OECD in 2015; and the European Union has referred to it in its strategy of AV deployment.

² See Society of Automotive Engineers-SAE, *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems* (Jan. 2014); https://www.sae.org/standards/content/j3016_201401/

³ See KPMG, *Impact of Autonomous Vehicles on Public Transport Sector* (2017); <https://assets.kpmg.com/content/dam/kpmg/ie/pdf/2017/07/ie-impact-av-vehicles-public-transport-2017.pdf> (page 6)

Examples of automated functions of the levels of automation⁴

Level 0

Providing audio or visual signals when parking

Level 1

Providing parking assistance with automatic steering wheel movements

Level 2

Providing assistance with staying inside lanes or automatically using an emergency brake

Level 3

Automatically slowing the vehicle during a traffic jam

Level 4

Total automated driving function in certain geographic areas and road types, or under favorable weather conditions (avoiding rain, fog, or other adverse conditions), but requiring human intervention in the rest of cases

Level 5

Full automated driving that would not require human intervention

	SAE Level	Name	Steering, acceleration, deceleration	Monitoring driving environment	Fallback performance of dynamic driving task	System capability (driving modes)
Human monitors environment	0	No automation the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems				n/a
	1	Driver assistance the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.				Some driving modes
	2	Partial automation the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task				Some driving modes
Car monitors environment	3	Conditional automation the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene				Some driving modes
	4	High automation the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene				Some driving modes
	5	Full automation the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver				All driving modes

Source: European Parliament Briefing in automated vehicles in the EU (which used the Automated and Autonomous Driving OECD/ITF, 2015 (adapted from SAE Standard J3016)). [http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573902/EPRS_BRI\(2016\)573902_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573902/EPRS_BRI(2016)573902_EN.pdf)

⁴ See European Road Transport Research Advisory Council (ERTRAC), *Automated Driving Roadmap* (2017); http://www.ertrac.org/uploads/documentsearch/id48/ERTRAC_Automated_Driving_2017.pdf

UNPACKING AV SYSTEMS AND SENSORS

The automation of a vehicle requires three different systems to function. Like a human driver, it needs (1) a controlling brain which decides the driving strategy, such as whether to pass another vehicle or to yield to pedestrians; (2) location information, in order to assess the current position and destination; and (3) contextual information about the surrounding environment. In an AV, an artificially intelligent system would be the controlling brain, and the vehicle's sensors, which act as inputs for the AI system to control driving functions, would provide location and contextual information.

The sensors utilized by an AV provide two main types of information: location and vision/perception. For *location*, the use of a Global Navigation Satellite System (GNSS) is an essential subsystem for navigation and guidance. The GNSS that is the most widely used is the American GPS (Global Positioning System). However, there are other GNSS systems available and in the development process, such as the Russian GLONASS, the European GALILEO, and the Chinese COMPASS/Beidou. In the GNSS, the receiver analyzes the signal of at least four of the GNSS satellite constellations that orbit at 20,000 km from earth in order to calculate the position of the vehicle/person in absolute terms (latitude, longitude, and height).⁵ This has a marginal error of 3 meters, (the most precise GPS can get to 1-2 cm) through a geometric principle called *trilateration*.⁶

GNSS positioning services are suitable to address current demand of Intelligent Transport Systems (ITS), but future vehicle-to-everything (V2X) communications and AVs will require continuous, accurate position information. Since GNSS signals can get blocked by physical barriers, including canyons and tunnels, AVs need to complement the GNSS system with other techniques that provide relative positioning. One example is inertial guidance, which does not require any signal input. The inertial guidance device, known as Inertial Measurement Unit (IMU), is attached to the vehicle as a platform that includes three gyroscopes and three accelerometers oriented in the X, Y, Z axes.⁷ The IMU provides data that is used to calculate the motion and position of the vehicle, with the initial location given by GNSS.

To account for *vision*, the most current prototypes of AVs use four different subtypes of sensors: cameras, radar, ultrasounds, and LiDAR. Each type of sensor has its own limitations, however. In turn, AVs use a combination of some or all of the sensors to provide the most vision for the vehicle.⁸

⁵ See Felipe Jimenez, *Intelligent Vehicles: Enabling Technologies and Future Developments* (Sept. 2017).

⁶ See Society of Automotive Engineers-SAE; *Centimeter-accurate GPS for self-driving vehicles* (Nov. 2016); <https://www.sae.org/news/2016/10/centimeter-accurate-gps-for-self-driving-vehicles>

⁷ See Felipe Jimenez, *Intelligent Vehicles: Enabling Technologies and Future Developments* (Sept. 2017).

⁸ See Varuna De Silva et al., *Fusion of LiDAR and Camera Sensor Data for Environment Sensing in Driverless Vehicles* (Sept. 2017); <https://arxiv.org/ftp/arxiv/papers/1710/1710.06230.pdf>

Cameras are the sensors that provide the most amount of data, as they have the highest resolution of all of the sensor options. Contrary to the other sensors, cameras are also capable of capturing texture and contrast and processing colors. The ability to distinguish colors is particularly useful for interpreting traffic lights, line markings, and emergency brake lights. An array of cameras can offer a 360-degree view, with a range of action from 0-120M, capturing 30 to 60 frames per second. However, cameras have several limitations, including that images require heavy graphic processing; their quality is severely affected by external conditions, such as lighting and shadows; and they fail to offer reliable depth estimation. Currently, work is being conducted into far infrared (FIR) thermal cameras, which can work better in conditions such as night, fog and rain, during sunset and sunrise. These tools, which have a range of 200 meters, may be available by 2020.

Radar sensors use radio waves to determine distances relative to objects in a general range 0-250 meters, and are able to detect objects and track other vehicles' speed in real time. Radar sensors offer only low resolution, but they perform well in extreme weather conditions and are more affordable than other sensors.

Ultrasound sensors use sound waves and are the most effective at detecting objects in short ranges (0-2 meters). They are usually incorporated into the four corners of the bumpers of the vehicle.⁹ Ultrasound sensors excel at automated parking applications and detecting immediate obstacles.

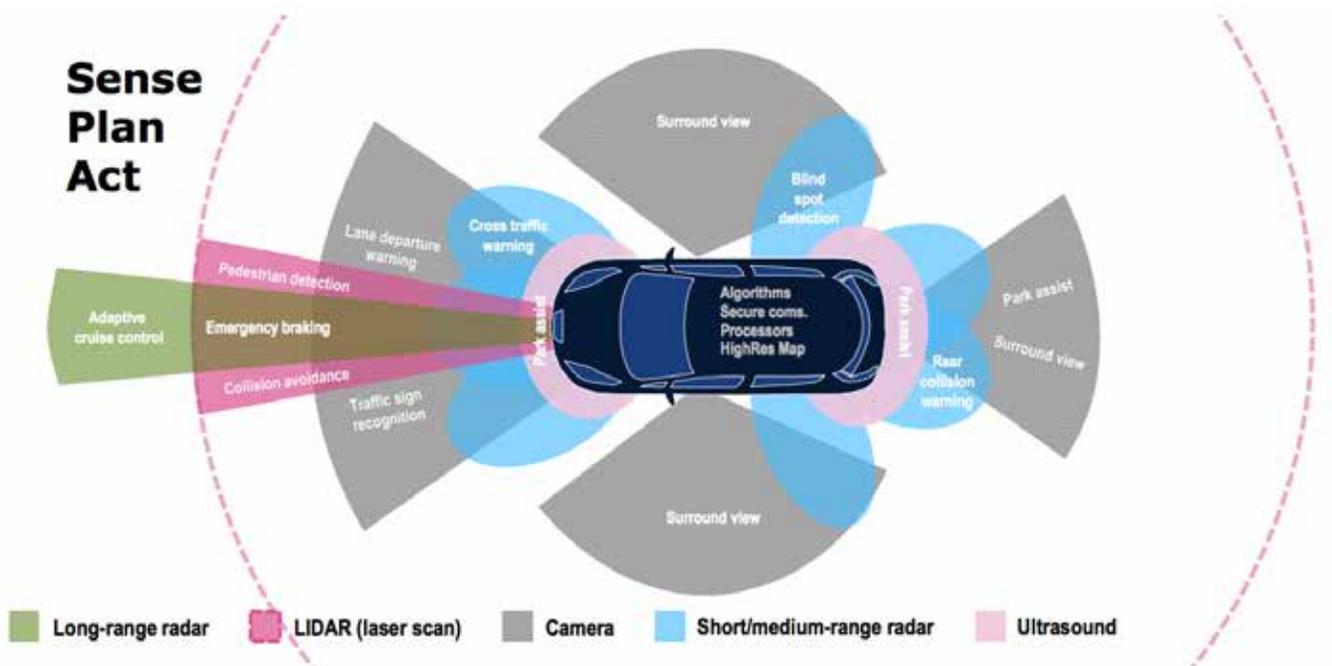
Currently, the primary vision unit of AVs are *LiDAR* (Light Imaging Detection and Ranging) sensors.¹⁰ By releasing an invisible laser beam, LiDAR creates an accurate 3D, 360-degree rendering of the vehicle's surroundings with a range of 0-200 meters. LiDAR was first used in archeology and agriculture to map large plots of land in 3D. Unlike cameras, LiDAR sensors work well in low light areas and with glares. They are sensitive to weather phenomena, however, and are highly priced (being, in many cases, more expensive than the vehicle itself). LiDAR sensors also look at predetermined angles (i.e. a configuration that cannot be changed), which can force the sensor to focus and provide very detailed information about areas that might not be relevant at that time. Startups are working on a new hybrid type of sensor that would allow their version of LiDAR to focus its laser beams on the areas that a camera flags as a priority for that moment of driving.¹¹

9 See International Transport Forum/OECD, *Automated and Autonomous Driving: Regulation under uncertainty* (2015); https://www.itf-oecd.org/sites/default/files/docs/15cpb_autonomousdriving.pdf

10 See Varuna De Silva et al., *Fusion of LiDAR and Camera Sensor Data for Environment Sensing in Driverless Vehicles* (Sept. 2017); <https://arxiv.org/ftp/arxiv/papers/1710/1710.06230.pdf>

11 See MIT Technology Review; *A New Sensor Gives Driverless Cars a Human-Like View of the World* (Dec. 2017); https://www.technologyreview.com/s/609718/a-new-sensor-gives-driverless-cars-a-human-like-view-of-the-world/?utm_source=newsletters&utm_medium=email&utm_content=2018_01_20&utm_campaign=weekendreads&utm_source=MIT+Technology+Review&utm_campaign=cef025b677-EMAIL_CAMPAIGN_2018_01_19&utm_medium=email&utm_term=0_997ed6f472-cef025b677-154443221

The following figure illustrates the complexity of the technologies that the vehicle would need to operate in autonomous mode.



Source: Automated and Autonomous Driving – Regulation under uncertainty, 2015.¹²

A combination of the above sensors provides information that is then used by the vehicle’s *artificial intelligent system* to determine the driving strategy. Most of the current AI systems in AVs are based on what are called “deep learning algorithms” and “neural networks.” *Deep learning algorithms* are a group of techniques, under machine learning, that turns raw, complex data into information that can be used to take actions.¹³ It creates a representation of the information provided as an input and improves its accuracy with

the amount of data used to train it, using neural networks. These algorithms work well in situations where the system, in this case an AV, needs to respond to unseen examples and manage a massive amount of data when interacting with the environment.

¹² See International Transport Forum/OECD, *Automated and Autonomous Driving: Regulation under uncertainty* (2015); https://www.itf-oecd.org/sites/default/files/docs/15cpb_autonomousdriving.pdf.

¹³ See MIT Deep Learning for Self-Driving Cars Lecture from Prof. Lex Fridman (2018) <https://selfdrivingcars.mit.edu/>

The learning method for *neural networks* is inspired by human biology, and specifically the way the human neurons function.¹⁴ For example, when the network is provided with new training data, it guesses the output. If the network guesses correctly, then the system reinforces the parameters that were used in the prediction. However, if the network guesses incorrectly, the system punishes the network. This learning process can also occur with human intervention, which is called “supervised learning,” or without human intervention, called “unsupervised learning.” Most successes have occurred with supervised learning. The learning capacity of neural networks differentiates them from the traditional AI expert systems, in which the universe of their knowledge was limited to the data and rules that a human expert manually introduced. The manual introduction

made these systems unmanageable because they required an extensive amount of data and frequent updates.

Although deep learning is currently the best approach for AI driving systems, it has many downsides. For instance, 99% of the driving represents only trivial tasks for AI systems; the biggest challenge are the edge cases. However, it is difficult to train the system in these situations because they represent only a 0.1 % of driving, a very small number of cases. The training for deep learning also requires such a large amount of data that makes its learning process very inefficient and expensive. In addition, these systems lack transparency, working as black boxes that cannot explain their processes or resulting outputs.

¹⁴ See Luke Dormehl, *Thinking Machines: The Quest for Artificial Intelligence and Where It's Taking Us Next* (2017).

AUTOMATED VS. CONNECTED VEHICLES: HOW VEHICLES COMMUNICATE WITH EACH OTHER

In public policies related to AV, the terms “connected,” “automated,” and “autonomous,” are often used interchangeably, when in fact they refer to different technologies. Additionally, there are a wide range of interpretations about how the terms interrelate. For example, in the US, “autonomous” and “connected” vehicles are considered to be different types of AVs¹⁵; an *autonomous* vehicle would refer to a vehicle that only uses its sensors to operate, whereas a *connected* vehicle would also communicate with either the surrounding infrastructure or other vehicles. On the contrary, in the EU, autonomous vehicles represent a general type of AV (fully automated) that can either be connected to other vehicles or not. Connectivity to other participants of the transportation network is a different attribute.

Although there is no general agreement for how these terms relate to each other, there is a consensus about the definition of *connected vehicles*.¹⁶ They are defined as vehicles that can communicate with other vehicles, infrastructure, as well as the mobile devices of pedestrians and cyclists. These communications are known respectively as vehicle-to-vehicle (V2V) or Vehicular Ad-hoc Networks (VANETs),¹⁷ vehicle-to-infrastructure (V2I), and vehicle-to-device. Through vehicle-to-everything (V2X) communications, participants share a group of basic safety information such as their location, direction, speed, distance and the surrounding traffic conditions. V2X communications, when added to AVs, facilitate, for instance, planned maneuvers among vehicles and cooperation on perceiving the environment, leading to a higher quality of information.

¹⁵ See Intelligent Transportation Systems Joint Program Office, US DoT official website; https://www.its.dot.gov/automated_vehicle/index.htm

¹⁶ See. A.S. Chekkouri et al., *Connected vehicles in an intelligent transport system*, in Vehicular Communications and Networks: Architectures, Protocols, Operation and Deployment, Edited by Wai Chen (2015).

¹⁷ Wireless networks that allow the exchange of data that are designed ad hoc for the vehicle environment, in which networks need to reconfigure themselves continuously to add the different mobile participants.

Connected vehicle applications

V2X communications allow three main categories of applications: safety, mobility, and environmental recognition.¹⁸ *Safety* applications aim to reduce accidents through V2I and V2V communications that alert drivers of imminent peril or sign warnings. Some examples of safety applications are forward collision warning; blind spot warning; red light warning; or curve speed warning. *Mobility* applications seek to contribute to the overall optimization of the transportation system's performance by collecting information from all types of vehicles and pedestrians connected to the network. For example, these applications could optimize the transportation flow by harmonizing vehicles' speed and coordinating cruise controls. *Environmental Recognition* applications offer knowledge about real-time traffic conditions and environmentally friendly transportation alternatives to avoid traffic congestions and promote more fuel-efficient trips. For example, these applications could include recommending driving speeds and optimal acceleration to save fuel and GHG emissions.

¹⁸ See US DoT, *Connected Vehicle Impacts on Transportation Planning—Primer and Final Report* (June 2016); <https://www.pcb.its.dot.gov/eprimer/module13.aspx>

V2X communications can use multiple wireless technologies and protocols such as Wi-Fi, Bluetooth, WiMAX,¹⁹ WAVE,²⁰ UMTS,²¹ or LTE,²² but only a few currently offer the quality of service in terms of latency, availability, coverage and bandwidth, required by V2X safety applications. These technologies are the ones based on the IEEE 802.11p standard (IEEE 1609 WAVE/Dedicated Short-Range Communications-DSRC in the US, ETSI ITS-G5 in the EU, and ARIB STD-109 in Japan) and cellular technologies.²³

The *IEEE 802.11p* adapts the 802.11 family standards (Wireless Local Area Networks-WLAN, of which the Wi-Fi protocol is a part) to the specific characteristics of the V2X communication. With the 802.11p standard, the information is broadcast in a short to medium range (from 300 up to 1000 M approx.), and the basic safety related content is transmitted in a token called Basic Safety Communication (BSC) in the US or Cooperative Awareness Message (CAM) in the EU.

The 802.11p has been allotted a 75 MHz spectrum in North America and 70 MHz in Europe in the 5.9 GHz frequency band, and an 80 MHz spectrum in the 5.8 GHz band in Japan. The main characteristics of DSRC and ITS-G5, both based on the 802.11p standard, are ultra-low latency (200 to 100 milliseconds), and that creates a distributed network which is available as long as the participants remain inside the range of the broadcast.²⁴

¹⁹ Worldwide Interoperability for Microwave Access.

²⁰ Wireless Advance Vehicle Communication

²¹ Universal Mobile Telecommunications System

²² Long Term Evolution

²³ See Felipe Jimenez, *Intelligent Vehicles: Enabling Technologies and Future Developments* (Sept. 2017)

²⁴ See A.S. Chekkouri et al., *Connected vehicles in an intelligent transport system*, in *Vehicular Communications and Networks: Architectures, Protocols, Operation and Deployment*, Edited by Wai Chen (2015).

Cellular communications have advanced quickly due to the extensive use of mobile telephones.²⁵ They use base stations to transfer voice and data over relatively wide areas. Cellular technology for the specific use of connected vehicle communication—5G—is still pending for full standardization by the 3rd Generation Partnership Project (3GPP), which is expected by the end of 2018. For nearly 20 years, earlier generations of mobile networks (2G, 3G, and 4G) have already allowed some communications in connected driving to transmit information about accidents or road conditions. However, full V2X communications, with critical safety applications, cannot be achieved without the 5G technology, a standard tool for vehicle communication.

The cellular technology has a higher latency than the 802.11p standard (1.5-3.5 seconds), and it allows mainly point-to-point communications instead of broadcasts to all surrounding vehicles. Its coverage depends of the cellular network infrastructure, but it nonetheless offers a longer range

of communication (up to 2 km) and a higher capacity of transmission (75 upload-300 download Mbps vs 27 Mbps in 802.11p).

There is an ongoing debate about whether governments should intervene and determine the standards and technology to be used in V2X communication, or whether they should leave this question open to industry developments. The Obama administration plan, which mandated all vehicles in the US to be equipped with V2V technology by 2023, seems to have been put on the backburner by the current administration. In contrast, in the European Union, all vehicles in the EU will have to be equipped with the eCall technology, a technology that automatically calls emergency services if a severe accident occurs, from April 2018 onwards.²⁶ In addition, the EU's 5G Action Plan aims to provide all urban areas, major roads, and railways in Europe with uninterrupted 5G coverage before 2025.²⁷ This will allow vehicles to interact at the same time, while co-existing with ITS-G5 and 4G.

²⁵ See US DoT, *Connected Vehicle Impacts on Transportation Planning—Primer and Final Report* (June 2016); <https://www.pcb.its.dot.gov/eprimer/module13.aspx>

²⁶ See European global Navigation Satellite Systems Agency, *eCall Emergency Alert System Launched* (April 2018). <https://www.gsa.europa.eu/newsroom/news/ecall-emergency-alert-system-launched>

²⁷ See European Commission official website on Digital Single Market, *5G for Europe Action Plan* (May 2017) <https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan>

EU 5 Cross Border Pilots for Connected Vehicles

EU and EEA Member States are working on cross border pilots to test data transmission in connected vehicles.²⁸ In December 2016, it created the European Alliance of Telecoms and Automotive, which includes sectoral associations and telecom operators, vendors, vehicle manufacturers and suppliers, to develop cross-border testing for connected driving in real traffic conditions. The current digital cross-border sections for testing are: Merida-Evora and Porto-Vigo (corridor Lisbon – Madrid); Metz-Merzig-Luxembourg; Rotterdam-Antwerp-Eindhoven; the E8 “Aurora Borealis” corridor between Tromsø (Norway) and Oulu (Finland); and the “Nordic Way” between Sweden, Finland and Norway.



²⁸ See European Commission official website on Digital Single Market, *Cooperative, connected and automated mobility: stepping up the efforts of in Frankfurt* (Sept. 2017); <https://ec.europa.eu/digital-single-market/en/news/cooperative-connected-and-automated-mobility-stepping-efforts-frankfurt>

AV DEVELOPMENT STRATEGIES

The aim of AV technology is to achieve full automation (level 5); a self-driving car, replacing human drivers with artificial intelligent systems. To reach this objective, AV manufacturers and companies are using two main strategies.²⁹ The first strategy, called “something everywhere,” focuses on gradually developing more automated functions so that the driver can progressively delegate more driving tasks to the vehicle. This is the strategy most used by traditional car manufacturers.

The second strategy, called “everything somewhere,” aims to deploy an autonomous vehicle that does not need human intervention in a specific context, and then gradually expand its functionalities to operate in more contexts. This strategy is favored by technology companies.

TIMEFRAME

Currently, levels 0 and 1 of automation have already been developed. Level 2 is beginning to be offered in some vehicles. As for levels 3, 4, and 5, a KPMG report³⁰ estimates their deployment by end of 2020-2025; 2025-2030; and beyond 2030, respectively.

In the “AV race,” it is estimated that autonomous trucks will be commercialized earlier than passenger vehicles because the economic incentive

for automating trucks is greater than for cars. Automating trucks would also be technically easier than cars, as much of truck driving happens on highways where autonomous driving has fewer challenges than city driving. Some successful experiences such as platooning (see below) have already taken place in Europe and self-driving truck deliveries have already taken place in the United States.³¹

²⁹ See International Transport Forum/OECD, *Automated and Autonomous Driving: Regulation under uncertainty* (2015); https://www.itf-oecd.org/sites/default/files/docs/15cpb_autonomousdriving.pdf

³⁰ See KPMG, *Impact of Autonomous Vehicles on Public Transport Sector* (2017); <https://assets.kpmg.com/content/dam/kpmg/ie/pdf/2017/07/ie-impact-av-vehicles-public-transport-2017.pdf> (page 6).

³¹ See Business insider, *Here's how Tesla, Uber, and Google are trying to revolutionize the trucking industry* (June 2017); <http://www.businessinsider.com/autonomous-trucks-tesla-uber-google-2017-6>.

The European Truck Platooning Challenge

Truck platooning consists of connecting two or more trucks in a convoy using wireless technology and automated driving systems. The trucks maintain a defined distance between each other, following the truck leader at the head of the convoy and automatically adjusting to its movements. Drivers monitor the vehicle and can decide to abandon the platoon mode at any time. Truck platooning reduces fuel consumption (up to 16% of CO₂ emissions), are safer (platooning braking time takes one-fifth of the human reaction time), and increases road use efficiency.³²

The European Truck Platooning Challenge took place in April 2016. It was the world's first cross-border initiative with intelligent trucks.³³ It included six platoons of semi-automated trucks that completed their trip to Port of Rotterdam from various European cities, the longest trip consisting of 1,500 km, from Gothenburg.³⁴ It demonstrated the feasibility of the technology for mono-brand platooning. The success fostered further cooperation between stakeholders throughout Europe and encouraged cross-border driving and regulatory advances.

32 See European Automobile Manufacturers Association, *Truck Platooning Roadmap*; http://www.acea.be/uploads/publications/Platooning_roadmap.pdf

33 See European Truck Platooning, *ERTICO and ITS partners to present the Truck Platooning Challenge to MEPs* (May 2017); <https://www.eutruckplatooning.com/News/801341.aspx?t=ERTICO+and+ITS+partners+to+present+the+Truck+Platooning+Challenge+to+MEPs>

34 See European Automobile Manufacturers Association, *First cross-border truck platooning trial successfully completed* (April 2016); <http://www.acea.be/press-releases/article/first-cross-border-truck-platooning-trial-successfully-completed>

Finally, it is worth mentioning that automated driving is not only happening on road transportation. For several years, it has been already happening within the aviation industry, informing the development of AV technology with the use of black boxes and V2X communications, and more recently, with unmanned aerial vehicles (UAV). Similar automation has also been happening on railroads and in waterways. For example, the

Netherlands recently deployed a fleet of autonomous boats to analyze how to improve transportation in Amsterdam.³⁵ Similarly, the UK recently launched an Industry Code of Practice for autonomous and semi-autonomous vessels of less than 24 meters to guide their design, manufacturing, and safe operation.³⁶ Lastly, an Australian mining company has completed the world's first trial of a fully autonomous train for 100 km.³⁷

35 See MIT News, *An autonomous fleet for Amsterdam* (2016); <http://news.mit.edu/2016/autonomous-fleet-amsterdam-roboat-0919>.

36 See Maritime UK, *UK launches Industry Code of Practice for autonomous vessels* (Nov. 2017); <https://www.maritimeuk.org/media-centre/news/uk-launches-industry-code-practice-autonomous-vessels/>

37 See Rio Tinto media release; *Rio Tinto completes first fully autonomous rail journey in Western Australia* (Oct 2017); http://www.riotinto.com/documents/171002_Rio_Tinto_completes_first_fully_autonomous_rail_journey_in_Western_Australia.pdf

CONCLUDING REMARKS

Policymakers may find it challenging to make sense of the full extent of the opportunities and risks of AV technology because of the technical, social, and economic complexities of automated vehicles. AVs are a technology that has the potential to transform traditional paradigms, not only of mobility and road safety, but also of the way humans interact with robots.

This policy paper has explored the key technological dimensions of AVs, introducing AV technology, presenting five essential elements about AV technology that policymakers should understand. Elements of the paper included the concept of AV and levels of automation; sensors and AV systems; communications among vehicles, infrastructure, and devices; AV development strategies; and timeframe. These technology insights will help to bridge information asymmetries and enable policymakers to better comprehend the ongoing technical discussions to generate more efficient and effective AV policies.

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ADDITIONAL READINGS

A permalink to this paper can be found here:

<http://cyber.harvard.edu/publication/5-technological-factors-regulators-and-policymakers-need-know>

For further information about AVs, their threats and opportunities, international trends in AV governance, and potential tools to address their regulatory challenges, regulators and policymakers can access the following complementary policy papers of the series:

[A Smart Move? Twenty-Four Essentials of a SWOT Analysis Policymakers Need to Consider](#), which analyzes the most relevant strengths, weaknesses, opportunities, and threats (SWOT analysis) facing governments as they design comprehensive AV policy.

[What Governments Across the Globe Are Doing to Seize the Benefits of Autonomous Vehicles](#), which introduces some of the AV strategies and initiatives that other governments are employing to navigate the challenges of AVs and to facilitate reaching the full potential of AVs.

[Three Practical Tools to Help Regulators Develop Better Laws and Policies](#), which analyzes different types of AV regulatory challenges and provides three practical tools—Legal Interfaces, Law Labs, and structured dialogues—that policymakers and regulators can use to develop better AV policies and expand their toolkit of instruments to govern the technology.