CHAPTER ONE

Introduction

The General Motors *Futurama* exhibit presented at the 1939 World's Fair in New York piqued the collective American and world imagination. Among other wonders, it promised that the United States would have an automated highway system and foretold the coming of a fundamental revolution in the surface transportation of passengers and freight. Today, nearly 75 years later, the advances in autonomous vehicle (AV) technology (also known as automated driving systems) place us on the cusp of that revolution.

AVs have enormous potential to allow for more productive use of time spent in a vehicle and to reduce crashes, costs of congestion, energy consumption, and pollution. They may also alter models of vehicle ownership and patterns of land use, and may create new markets and economic opportunities. Yet policymakers are only beginning to grapple with the immense changes AVs portend. They face many policy questions, the answers to which will be influential in shaping the adoption and impact of AVs. These include everything from when and whether this technology should be permitted on the roads to the appropriate liability regime. This report seeks to aid policymakers by summarizing a large body of knowledge relevant to these policy issues, and suggesting appropriate policy principles.

Our methodology was straightforward. We conducted a comprehensive literature review of the work on AV technologies and formally interviewed approximately 30 stakeholders—including automobile manufacturers; technology firms; communications providers; representatives from National Highway Traffic Safety Administration

(NHTSA), state departments of transportation (DOTs), state departments of motor vehicles (DMVs), and others. (A summary of the interviews is included in the appendix.) We talked to many others at the Transportation Research Board Annual Meeting and the Transportation Research Board's Workshop on Road Vehicle Automation.

In the remainder of this chapter, we briefly define different levels of vehicle autonomy, explore why they merit the attention of policymakers, and enumerate questions that policymakers will need to address.

What Are Autonomous and Automated Vehicles?

Technological advancements are creating a continuum between conventional, fully human-driven vehicles and AVs, which partially or fully drive themselves and which may ultimately require no driver at all. Within this continuum are technologies that enable a vehicle to assist and make decisions for a human driver. Such technologies include crash warning systems, adaptive cruise control (ACC), lane keeping systems, and self-parking technology.[1]

NHTSA has created a five-level hierarchy to help clarify this continuum.[2] We summarize this below and use it throughout this report:

- **Level 0 (no automation):** The driver is in complete and sole control of the primary vehicle functions (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and for safe vehicle operation.
- **Level 1 (function-specific automation):** Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently of each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a pri-

1 These technologies are sometimes called advanced driver assistance systems.

2 The Society of Automotive Engineers (SAE) International has created a somewhat similar taxonomy to describe automation for on-road vehicles (SAE On-Road Automated Vehicle Standards Committee, 2013).

mary control (as in ACC); the vehicle can automatically assume limited authority over a primary control (as in electronic stability control); or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies).

- **Level 2 (combined-function automation):** This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of controlling those functions. Vehicles at this level of automation can utilize shared authority when the driver cedes active primary control in certain limited driving situations. The driver is still responsible for monitoring the roadway and safe operation, and is expected to be available for control at all times and on short notice. The system can relinquish control with no advance warning and the driver must be ready to control the vehicle safely.
- **Level 3 (limited self-driving automation):** Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions, and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time.
- **Level 4 (full self-driving automation):** The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles. By design, safe operation rests solely on the automated vehicle system. (NHTSA, 2013).

The type and magnitude of the potential benefits of AV technology will depend on the level of automation that is achieved. For example, some of the safety benefits of AV technology may be achieved from function-specific automation (e.g., automatic braking), while the land-use and environmental benefits are likely to be realized only by full automation (Level 4).[3]

Why Is Autonomous Vehicle Technology Important Now?

AV technology merits the immediate attention of policymakers for several reasons. First, the technology appears close to maturity and commercial introduction. Google's efforts—which involve a fleet of cars that collectively have logged hundreds of thousands of autonomous miles—have received widespread media attention and demonstrate that this technology has advanced considerably. Every major commercial automaker is engaged in research in this area and full-scale commercial introduction of truly autonomous (including driverless) vehicles are being predicted to occur within five to 20 years. Several states have passed laws to regulate the use of AVs, and many more laws have been proposed. As these technologies trickle (or flood) into the marketplace, it is important for both state and federal policymakers to understand the effects that existing policy (or lack thereof) are likely to have on the development and adoption of this technology.

Second, the stakes are high. In the United States alone, more than 30,000 people are killed each year in crashes, approximately 2.5 million are injured, and the vast majority of these crashes are the result of human error (Choi et al., 2008). By greatly reducing the opportunity for human error, AV technologies have the potential to greatly reduce the number of crashes.[4]

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[3] AV technology is closely related to, but distinct from, connected vehicle technology, which enables the vehicle to share information with other vehicles or transportation infrastructure. For example, cars could share location information electronically with nearby vehicles, which could aid AVs. More ambitiously, cars might share sensor information with nearby vehicles, which could provide an AV with more information on which to base its decisionmaking. While some have argued that connected vehicle technology will be central to achieving AV operation (KPMG and Center for Automotive Research, 2012), this view is not universally shared and many of our interviewees believe that sensor-based systems will be sufficient. We discuss connected vehicle technology in Chapter Four.

[4] Similarly, a study of commercial vehicles found that a bundled system of collision warning, ACC, and advanced braking could prevent 23–28 percent of rear-end crashes (Batelle, 2007).

AVs may also reduce congestion and its associated costs. Estimates suggest that effective road capacity (vehicles per lane per hour) can be doubled or tripled. The costs of congestion can also be greatly reduced if vehicle operators can productively conduct other work. AV technology also promises to reduce energy use.[5] Automobiles have become increasingly heavy over the past 20 years partly to meet more rigorous crash test standards. If crashes become exceedingly rare events, it may be possible to dramatically lighten automobiles.

In the long run, AVs may also improve land use. Quite apart from the environmental toll of fuel generation and consumption, the existing automobile shapes much of our built environment. Its centrality to our lives accounts for the acres of parking in even our most densely occupied cities.[6] With the ability to drive and park themselves at some distance from their users, AVs may obviate the need for nearby parking for commercial, residential, or work establishments, which may enable a reshaping of the urban environment and permit new in-fill development as adjacent parking lots are made unnecessary.

Along with these benefits, however, AVs could have many negative effects. By reducing the time cost of driving, AVs may encourage greater travel and increase total vehicle miles traveled (VMT), which could lead to more congestion.[7] They may increase sprawl if commuters move ever farther away from workplaces. Similarly, AVs may eventually

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[5] One study found that "because [adaptive cruise control] reduces the degree of acceleration relative to manual driving, and because [adaptive cruise control] would be used more than [conventional cruise control], deployment of [adaptive cruise control] systems will result in increased fuel efficiency and decreased emissions" (Koziol et al., 1999, pp. 5–17).

[6] Anticipating the future importance of the car, modernist architect Le Corbusier famously designed the ground floor of La Villa Savoye in 1928 to mirror the turning radius of the owners' car (a 1927 Citroen) (Kroll, 2010).

[7] The U.S. DOT Highway Economic Requirements System (HERS) estimates vehicle-demand price elasticity in the most likely scenarios to fall by –0.7 to –0.8 in the short run, and to fall about twice that in the long run, with a range of –1.0 to –2.0 (Lee, Klein, and Camus, 1999; Litman, 2012). This implies that as travel costs (time and expenses) reduce by 10 percent, travel is expected to increase: by 7 to 8 percent in the short run (time period over which exogenous demand factors remain fixed, probably about one year) and by an additional 2 to 12 percent in the long run (time for exogenous characteristics to change, frequently assumed at five to 20 years).

shift users' preferences toward larger vehicles to permit other activities. In theory, this could even include beds, showers, kitchens, or offices. If AV software becomes standardized, a single flaw might lead to many accidents. Internet-connected systems might be hacked by the malicious. And perhaps the biggest risks are simply unknowable.

From seatbelts, to air bags, to antilock brakes, automakers have often been reluctant to incorporate expensive new technology, even if it can save many lives (Mashaw and Harfst, 1990). Navigating the AV landscape makes implementation of these earlier safety improvements appear simple by comparison. Negotiating the risks to reach the opportunities will require careful policymaking, and this report identifies the critical issues and context as policymakers collectively define a path forward.

What Decisions Do Policymakers Face?

Policymakers have a number of opportunities for shaping the adoption and impact of AV technologies. Key questions include:

- How, if at all, should the use of AVs be regulated, and at what level?
- What kinds of vehicles should be allowed on the road, and who is allowed to operate them?
- How should the safety of AVs be tested, and by whom? To what safety standards should AVs be held?
- How might different liability regimes shape the timely and safe adoption of AVs, and what are the tradeoffs? Under what conditions would limitations on tort liability be appropriate?
- What are the implications of a patchwork of state-by-state laws and regulations, and what are the tradeoffs in harmonizing these policies?
- To what extent should policymakers encourage the adoption of AVs; e.g., through smart road infrastructure, dedicated highway lanes, manufacturer or consumer incentives?

Different policymaking bodies will have different roles in addressing these questions. In recent years, state legislatures have passed laws on what types of AVs may be driven, and have directed DMVs to clarify testing and regulation procedures. Legislatures may also be responsible for providing specific incentives for manufacturers to create AVs and for the public to adopt them. Historically, DMVs test the safety of and regulate drivers (i.e., issuing driver's licenses), while federal bodies like NHTSA regulate and test the safety of vehicles. AVs blur the line between vehicle and driver, and DMVs are beginning to test and license AVs. State DOTs maintain and operate highway infrastructure, and thus would be responsible for any investments in intelligent infrastructure or the creation and operation of dedicated lanes for AVs.

The goal of this report is to summarize available information on AV technologies, identify the most salient policy issues, and provide tentative guidance to policymakers. At the outset, we must note that there are far more questions than answers. Further research can and should be conducted on almost every topic we touch.

The remainder of the report is organized as follows. Chapter Two summarizes the potential of these technologies to improve social welfare and potential detrimental effects. Chapter Three summarizes recent state legislation in this area. In Chapter Four, we review the history of AV technology and discuss its current status. In Chapter Five, we address the particular policy issues raised by telematics and communications issues. In Chapter Six, we address the role of standards and regulations. In Chapter Seven, we discuss the liability implications of AV technology and the risks that are raised to the goal of maximizing social welfare. Chapter Eight summarizes the policy implications of this work and proposes some tentative suggestions. We also summarize our findings and propose directions for further research in this area.