Preparing the Workforce for Automated Vehicles

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Truck Platooning State of the Industry 2018

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1. Executive Summary

We are rapidly approaching a world of automated vehicles. Such a world is anticipated to lead to numerous benefits, having potential to reduce traffic accidents, increase mobility efficiency, and allow the elderly and disabled to become more independent. However, automated vehicles may lead to a variety of societal changes that need to be well understood and addressed in order to avoid a tumultuous transition. A prime concern of businesses and policy makers is whether and how automated vehicles could impact the workforce.

In this report, we take a holistic approach to study how automated vehicles may impact the various segments of the U.S. workforce. This entails understanding, not only the magnitude of the potential job changes in the transportation workforce, but also how the transportation, technology, and other sectors of the workforce will need to adapt to automated vehicles. Specifically, we undertake to learn: (i) which, if any, segments of the workforce are likely to either be enhanced or displaced by automated vehicles, or require new skillsets to function effectively in their current environment, (ii) the expected pace of workforce transition for certain industries and geographies, and (iii) what new skillsets, if any, will automated vehicles require of different workers and how workers can best acquire them.

To undertake this research, the interdisciplinary team of research scholars, with support from the American Center for Mobility, interviewed industry leaders in affected business segments and conducted interdisciplinary focus groups to bring together diverse, but expert, viewpoints concerning how automated vehicles could impact the workforce. The team then analyzed interview and focus group data along with employment data from public data sources to answer the questions of interest. While the results presented in this report reflect the views of the industry leaders included in this study, not even these industry experts included can fully predict the pace and effects of automated vehicles on the workforce.

As we show in this report, in the foreseeable future, the adoption of automated vehicles and related technologies may lead to displacement of driving jobs in certain segments of the transportation sector (largely in the taxi and chauffeur segment, though more so in the taxi than chauffeur segments). However, at least in the coming decade, at worst, displaced jobs are likely to number in the low hundreds of thousands compared to the almost 3.5 million jobs in this sector that are the subject of this report. Moreover, much of the anticipated displacement will likely not take place until the latter half of the 2020s, at which point automated vehicle adoption will begin to grow.

Automated vehicles will, however, necessitate substantial change in the way that employees perform their job in the transportation and many other sectors. For many, this will require the acquisition of new skills and, in some cases, perhaps reimagining of what their job entails. The advent of automated vehicles is also likely to result in the creation of thousands of new jobs in engineering, data analysis, cybersecurity, and vehicle “monitoring” areas. It will also require many different stakeholders to work together on creative approaches that better prepare current and future workers to enter the labor force.

1.1. How Automated Vehicles Will Affect the Transportation Workforce

1.1.1. Trucking

The transition to automated driving in the trucking industry is in the early stages and anticipated to be gradual. Moreover, in the foreseeable future, automated vehicles could supplement, rather than substitute vehicle operators, even at the highest levels of automation, allowing freight transportation and other delivery service companies to address an existing labor shortage.

- In the coming decade, automated vehicles will not significantly, if at all, impact truck driving jobs.
- Largely self-functioning highly automated vehicles (SAE level 4 or higher) will not reach a high level of penetration in trucking within the next decade.
- Once highly automated vehicles do reach a high level of penetration, truck operators will need to understand how to monitor software and hardware used to automate the driving function and how to make appropriate use of advanced safety systems in these vehicles.
- Current drivers who are able to retool their skillsets as their jobs become more technology oriented may see the public perception of their trade improve.
- While truck platooning can occur at all levels of automation, the current industry focus is on Level 1 and Level 2 systems.
- Truck platooning may increase the efficiency of truck freight movement and provide other widespread benefits. Level 1 truck platooning has demonstrated the potential for significant fuel savings, enhanced mobility and associated emissions reductions from platooning vehicles.
- Truck platooning is not expected to impact the workforce in early implementation.
- The capabilities of automated vehicle technology coupled with the need to resolve the driver shortage in long-distance freight trucking may result in a shift from long-distance interstate delivery to local delivery and logistics jobs. This could ultimately prove detrimental for truck operator wages—though beneficial to parties seeking to have goods delivered and fleet operators facing lower costs. It may also have positive impacts on driver quality of life as they may be home more often.

1.1.2. Passenger Transportation

The transition to automated driving among transit buses and especially taxicabs, on-demand, and shared use vehicle transportation is likely to proceed much more rapidly than in trucking. Moreover, particularly among taxicab drivers, chauffeurs, on-demand and shared use drivers, except in certain niche categories, automated vehicles are expected to displace, rather than supplement drivers. However, whereas there are more than 3 million trucking and related delivery jobs, the number of jobs in the passenger transportation segment numbers slightly under a million (only approximately 400,000 of which are subject to projections in this report).

- Suppose that automated vehicles displace, rather than supplement drivers, as agreed on by most expert study participants discussing taxi driver and chauffeur jobs, though there was less agreement in regards to chauffeur jobs. Then, we project that a decade from now, the total number of taxi driver and chauffeur jobs could range from an expected 128,000 if automated vehicles are adopted at rates predicted by participants to 254,000 if there is no automated vehicle uptake at all.
- Drivers in certain categories of services in which face-to-face interaction with a passenger is necessary (i.e., luxury and paratransit) are less likely to be displaced by automated vehicles in the foreseeable future.
- Suppose that automated vehicles displace, rather than supplement, transit bus drivers. In this case, we project that a decade from now, the total number of transit bus driver jobs could range from an expected 118,000 if automated vehicles are adopted at rates predicted by participants to 170,000 if there were no automated vehicle uptake at all.
- Unlike with taxi drivers, there was not a consensus among study participants as to whether automated vehicles would, indeed, displace transit bus drivers. Moreover, several participants suggested that it is likely that a transit employee would continue to occupy an automated bus in a bus “ambassador” or attendant role to assist passengers, suggesting that the lower range jobs estimate above is less likely to transpire than among taxi drivers.

1.2. How Automated Vehicles Will Affect the Non-Driving Workforce

1.2.1. Technology Jobs

Automated vehicles are part of a larger, structural shift in society related to increased use of robotics and artificial intelligence technologies. Technology jobs associated with automated vehicles will continue to expand and grow. Expert participants referred to more than 30 different job titles or phrases associated with automated vehicle technology. These job titles and phrases corresponded to 18 Bureau of Labor Statistics technology occupations. In the motor vehicle industry alone, in 2017, these 18 occupations comprised 118,000 workers with a median income of $63,000 (we note that we do not know the proportion of these workers involved directly in vehicle automation). Moreover, technology occupations associated with automated vehicles will not only be confined to the motor vehicle industry, but to numerous startup and larger technology firms. In the U.S., the 2017 median income for the 18 technology occupations was approximately $86,000 across all industries, well above the motor vehicle industry counterpart. A shortage of many technology professionals in both the private and public sector gives entrants to these professions substantial bargaining leverage.

- Engineering jobs associated with automated vehicles will continue to see substantial labor demand in the coming years. Among others, interviewees cited a need for design engineers, software engineers, and systems engineers.
- Core needs discussed by interviewees include cybersecurity and data science. With regard to data science, the need transcends data analysts, comprising individuals who

can design better algorithms for analyzing the vast data output anticipated to be produced by automated vehicles.

- Motor vehicle companies and technology companies are both seeking more cross-functional and multidisciplinary technology (and other) workers. In the short term, the complexity of training and backgrounds needed by these companies make it a challenge to find individuals to fill upper level automated vehicle positions, particularly given that many of the necessary skills (e.g., machine learning and AI related skillsets) are already in high demand in the field of automation and other technology industries

1.2.2. Other (non-Driving) Occupations

Experts in our study anticipated growth in other job categories, as well as the emergence of entirely new occupations. Some participants discussed potential ramifications of automated vehicle adoption and proliferation that could put some existing fields in jeopardy of experiencing job losses. Among others, occupations that could be impacted include mechanics and technicians, customer service professions, assembly and construction, as well as legal and health professionals.

- The complexity of automated vehicles entails a rise in demand for maintenance and repair services, though perhaps a decrease in crash repair services. However, this complexity also implies that employees in these occupations will require new skillsets, particularly related to the repair and maintenance of automated vehicle sensors and other equipment.
- The need to remotely serve private automated vehicle passengers, monitor automated vehicle content, and monitor operations will generate substantial labor demand for customer service and related professionals. Interviewees suggested that employees that may be negatively affected by automated vehicles (e.g., driving occupations) could have the ability to transition into some of these positions.
- The need to retrofit existing infrastructure and design new infrastructure to accommodate connected, as well as automated – though to a lesser degree, vehicles entails an increasing demand for a variety of design, construction, and operations related jobs.

In sum, using interviewee predictions about the uptake of automated vehicles in different vehicle segments together with public employment data, we found that in the next decade, of the approximately 3.5 million driving jobs that were subject to our analysis, at most, only a few hundred thousand were likely to be displaced. In contrast, automated vehicles are creating demands for various technology and other non-driving occupations, suggesting a brighter aggregate jobs outlook than suggested by various earlier studies. Nevertheless, as we emphasize throughout this report, while in many cases, automated vehicles will not change the job that a person holds, they have the potential to significantly alter how that person does the job. Stakeholders, including automakers, educational organizations, technology companies, and others, will need to develop strategies and work together if they are to adequately prepare the workforce for the future of automated vehicles.

2. Introduction and Project Description

The development and dissemination of a range of new types and levels of automated vehicles is anticipated to have substantial impacts across a range of groups and elements in society. One element that features prominently in conversations concerning the ramifications of automated vehicles is the workforce. As with prior periods of automation, a major worry is that automated vehicles will supplant drivers and myriad other professionals whose labor is contingent on the current state of automobile technology. Whether or not such fears are founded, stakeholders are beginning to accept that automated vehicles precipitate changes in the way that many jobs are done, leading to declines in the demand for certain skills, and growth in the demand for others.

Though interest is increasing in workforce impacts of automated vehicles, much of it is speculative at best at this point. With funding from the American Center for Mobility, we brought together an interdisciplinary team comprised of sociologists, economists, engineers, and a geographer to conduct a detailed study on workforce impacts of automated vehicles. This project required an understanding of: (i) the expected pace of transition across different industries and geographies, (ii) which segments of the workforce are likely to either be displaced by automated vehicles or require new skillsets to function effectively in their current environment, and (iii) the demand for new skillsets and jobs necessitated by automated vehicles.

In order to inform stakeholders about these factors we interviewed 19 industry leaders in affected business segments across the U.S., and conducted three interdisciplinary focus groups (Texas, California, and Michigan; N = 33 focus group participants total) that sought to bring together diverse stakeholders. Participants came from a range of automotive, technical, governmental, and related organizations and industries. In addition, we carried out empirical (qualitative and quantitative) analyses of interview and focus group findings together with existing employment data. Combined, these components allowed us to develop a better understanding of how automated vehicles will impact employment prospects and skills and training needs in the foreseeable future. Our findings enable us to make recommendations concerning education and training needs that leverage our findings.

Section 3 of this report begins with an extended literature review, starting with an in-depth detail of the levels of automobile automation, so that all readers have a current interpretation of the industry accepted levels. We then delve into a brief history of automation in relation to automobiles, as well as current regulations regarding automated vehicles. While the concept of automation is much broader than in relation to automobiles, we strive to concisely review the most relevant aspects of automation within the automobile realm. Next, we review empirical and other research examining the anticipated impacts of automated vehicles, as well as public perceptions of automated vehicles.

Section 4 details the methodology used to conduct the three phases of the study. The main results of the study are detailed in Sections 5 and 6. Results are broken down by jobs that rely on a vehicle, with subcategories for truck driving, passenger transportation, and selected other jobs that require vehicle use. In this section, in addition to discussing how automated vehicles will entail new skills from today’s drivers, we conduct projections of the employment outlook for major driving jobs in the coming decade. We then present results for non-driving related jobs that automated vehicles will impact. Here, we break our results into technology jobs versus other non-driving occupations. For technology jobs, in particular, we discuss some challenges related to the workforce as well as emerging areas of need for the technology workforce. We end Section 6 with a brief discussion of some occupations that may decline as a result of automated vehicles.

Section 7 discusses education and training needs resulting from the advent and proliferation of automated vehicles. Our results clearly indicate that educational organizations must be proactive in striving to meet the education and training needs related to automated vehicles. We discuss needs for the technology workforce, as well as the importance of acquiring skills through certificate programs and on-the-job training opportunities. We note the importance of multi-institutional and flexible approaches to enhance trade education in particular, as well as industry and educational groups working together to ensure that those in higher education have skills that meet workforce needs.

Brief conclusions are offered in Section 8. State CDL information, a detailed listing of technology occupations corresponding to those detailed in the focus groups and interviews, and economic details on the projection methodology are all detailed in Section 9 (Appendix). Additional state by state data projections are provided in the Appendix, as well as a short review of the history of automobiles and AVs, AV technologies and object detection, social perceptions of AVs, and regulation of AVs.

Short biographical details on the study authors are provided after the references cited in the study. Contact information for the study investigators is also detailed in this section.

3. Literature Review

The workforce is a broad category that encompasses multiple industries and segments of society. In this extended literature review, we take a step toward better understanding how these segments will develop as automated vehicles establish a growing foothold throughout the world.[1] The scope of the literature review includes existing peer reviewed publications, as well as industry and other organization reports and white papers concerning autonomous/automated vehicles and other forms of automation as appropriate. Our primary focus revolves around how automated vehicles are expected to impact the United States (U.S.) workforce; in particular, what kind of jobs may be created or will need to be created, what types of jobs could be eliminated or reduced, and what labor expertise will become necessary in the future to accommodate the development, dissemination, and maintenance of automated vehicles.

We begin this review by defining automated vehicles in Section 3.1. In Section 3.2 we create context concerning how automated vehicles may impact the workforce. In Section 3.3, we explore various reports that have sought to define what it means for automated vehicles to impact the workforce. Finally, in Section 3.4, we discuss literature concerning the existing and prospective impacts of automated vehicles on the workforce. We note that the literature is in its infancy, and much work remains to be done.[2]

3.1. Automated Vehicles and the Levels of Automation

To discuss how automated vehicles can impact the U.S. workforce, it is important to first understand what constitutes an automated vehicle (AV). Although many vehicles in use today contain driver assistance features and partial automation such as acceleration, braking, and steering assistance, these features aid, but do not substitute for, a driver, and as such, do not present a clear means to displace driving related positions in the workforce.

We acknowledge, from our review of the extant literature, that authors and the popular press often conflate AVs with connected vehicles (CVs). Automated vehicle technologies and connected vehicle technologies are distinct but complimentary to each other. CVs, unlike some lower level AVs, are designed to communicate through dedicated short-range communication (DSRC) networks and other forms of Internet connectivity (e.g., Wi-Fi, satellite signals, long-term evolution (LTE) telecommunication) with vehicles (vehicle to vehicle communication, V2V) as well as with Internet connected components of the transportation system (e.g., traffic lights, retrofitted roadside sensors, and transportation agencies) (Zmud, Goodin, Moran, Kalra & Thorn, 2017). Though AVs can, and likely will, include CV technology, which can reduce the likelihood of accidents and improve traffic flow, AVs can function without CV technology. In addition, CVs do not need to consist of AV technology. CV technology can be used to provide

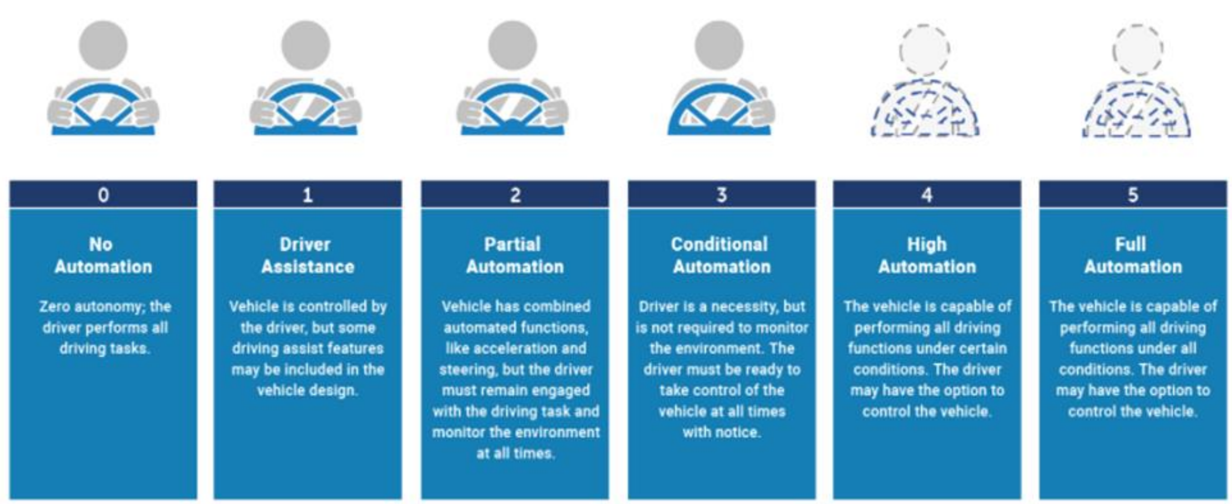
[1] Throughout this literature review, we use the words automated and autonomous. Much of the scientific and popular press literature uses these words interchangeably. We acknowledge that there is a continuum in terms of the level of automation associated with vehicles and we provide more detail on this continuum in a following section.

[2] In section 9.4 of the Appendix, we briefly review existing literature on the history, development, and perceptions of AVs. Section 9.5 of the Appendix discusses the state of regulation as of the time of this writing of these vehicles in the U.S.

useful information to human operators that can increase efficiency and safety. For instance, global positioning systems (GPS) that are built into passenger vehicles can be categorized as CV technology, in that, it can update via cellular or Wi-Fi networks and provide real-time traffic updates and suggestions for route adjustments for the human operator to consider. When possible in this report, we have tried to articulate whether studies referred to AVs, CVs, or some combination like CAVs (connected and automated vehicles). We note that some studies and reports do not clearly identify upon which they focus, often using these terms interchangeably.

In this literature review and elsewhere throughout this report, we will rely on the definition developed by the Society of Automotive Engineers (SAE) International,[3] which comprises the levels of automation from zero, indicating no automation, to five indicating "full" automation—defined as sustained and unconditional performance by an automated driving system of the entire dynamic driving task without any expectation that a user will respond to a request to intervene (SAE International, 2016).

Figure 1: Society of Automotive Engineers (SAE) Levels of Automation



In this literature review, we focus on AVs in which the vehicle, rather than a driver, is in charge of object and event detection and response—colloquially, self-driving cars. This encompasses SAE levels 3 to 5, though the degree to which levels 3 (Conditional Driving Automation) and 4 (High Driving Automation) could lead to major shifts in the workforce will depend in part on federal, state, and local regulations requiring an individual to be ready to take control of the vehicle.

SAE International (2016) established the classification levels of automated vehicles that perform some or all of the dynamic driving task (DDT) on a continuous basis. DDT refers to all of the

[3] SAE International is a global association of engineers and related technical experts in the aerospace, automotive and commercial-vehicle industries that seeks to advance self-propelled vehicles and system knowledge. See SAE International, About SAE International. Available at https://www.sae.org/about/.

real-time operating and strategic functions required for a vehicle to operate in on-road traffic. However, DDT does not include the planning tasks involved to schedule a trip and the selection of destinations or waypoints. DDT is relevant to understand the impact of AVs on the future workforce because driving-based occupations involve a variety of decisions and actions that may not involve a vehicle being in motion or in an active lane of traffic.

Driving, in general, entails three types of efforts: strategic, tactical, and operational (Michon, 1985). Strategic effort involves all the aspects of trip planning and includes whether, when, where, and how to execute travel. Tactical effort involves maneuvering the vehicle in traffic during a trip, including deciding whether and when to pass another vehicle, changing lanes, selecting correct speeds, and checking mirrors. Operational effort involves immediate reactions that are typically based on driver experience and muscle memory. For instance, making corrections to steering, braking, and accelerating to maintain lane position in traffic or to avoid a sudden obstacle or hazardous event in the vehicle's pathway involve aspects of tactical and operational effort. Tactical and operational effort are portions of driving that specifically entail maneuvering a vehicle in active traffic when the vehicle is either about to be or in actual motion.

As noted above, the classification levels for AVs range from no driving automation (level 0) to full driving automation (level 5). Each successive level includes automating an increasing degree of the tactical and operational effort that goes into driving compared to the level before it.

Level 0 No Automation: A human driver performs all tactical and operational aspects of the DDT, even when enhanced by warning or intervention systems.

Level 1 Driver Assistance: A level 1 AV can use information about the driving environment to either steer or accelerate/decelerate; yet, the human driver performs all remaining tactical and operational aspects of the DDT. The AV does not perform both steering and acceleration/deceleration at the same time.

Level 2 Partial Automation: A level 2 AV uses information about the driving environment to perform both steering and acceleration/deceleration. The remaining aspects of tactical and operational driving tasks are assumed to be the responsibility of the human driver. A level 2 AV still requires drivers to detect, recognize, and classify objects and events; however, the driver supervises the AV on an as-needed basis.

Level 3 Conditional Automation: With a level 3 AV, the human operator is expected to respond to intervention requests, but the AV generally performs all tactical and operational aspects of the DDT. While the AV is responsible for the non-strategic aspects of the DDT, the driver is the fall back for requests to intervene from the AV. The human operator is also responsible for DDT performance-relevant system failures in other vehicle systems on the road.

Level 4 High Automation: The driving mode-specific performance required of a level 4 AV entails an ability to perform all tactical and operational aspects of the DDT. Thus, level 4 or higher AVs may be appropriately referred to as "driverless cars." The driver of a level 4 feature is also a passenger who may not respond to requests to intervene or to DDT performance-relevant system failures. For example, a level 4 AV may be capable of performing all tactical and operational aspects of the DDT during the transportation component of goods and services delivery without the worker supervising. A level 4 AV may be dispatched by a fleet monitor who verifies the operational readiness of the AV, engages and disengages the vehicle, and performs the strategic component of the DDT (e.g., specifying the address where goods should be delivered). In either instance, a level 4 AV can operate without a human driver whether or not there is any dispatcher or fleet monitor involved.

Level 5 Full Automation: Level 5 automation entails the full-time performance by an AV of all tactical and operational aspects of the DDT under all roadway and environmental conditions that can be managed by a human driver. For example, the AV can operate regardless of weather, time of day, or geographical restrictions. However, there may be conditions under which the AV and the human driver are unable to complete a given trip (i.e., white out snow storm conditions, flooded roads, and glare ice) until the adverse conditions clear. Under such conditions, the AV achieves a minimal risk state by pulling over to the side of the road and waiting for conditions to change.

The advent of level 3 to 5 AVs has potential to directly impact the workforce in terms of required tactical and operational input demanded from a human driver; the completion of job related tasks; and unintended scope of knowledge, skills, and abilities. Moreover, different organizations in which driving tasks are important will likely respond differently to level 3 to 5 automation. For example, the American Trucking Associations, the largest national trade association for the trucking industry, in late 2017, envisioned a role for drivers in automated vehicles, viewing AV technology as a means to improve driver safety and productivity.[4] In contrast, the Domino's Pizza chain, in 2017, began to assess how customers would interact with a driverless pizza delivery car, suggesting that the company envisions a different role for AVs.[5]

The indirect impact of AVs on the workforce may not be as obvious and is also very important. For instance, consider the impact of AVs on emergency personnel, such as police officers or certain health professionals in the area of emergency response. Whereas in these cases one may conjecture that even a level 5 capable AV might not be able to replace most of what such workers do, as we discuss in Section 5.3.1, these workers' frequent interactions with AVs may entail changes in the way they perform their job. As such, before we discuss how automated vehicles impact the workforce, in the following sections we examine existing literature that seeks to understand how AVs impact society at large.

3.2. Automation and the Workforce

Changes to the workforce precipitated by AVs may be viewed in a broader historical context of how automation has impacted labor demand in the past. Although AVs distinguish themselves from many previous periods in which technology allowed for firm fixed assets like equipment and other capital stock to directly substitute for (and complement) labor, they are not without

[4] American Trucking Associations, Automated Truck Policy, October 24, 2017. Available at http://www.trucking.org/ATA%20Docs/News%20and%20Information/docs/Proposed%20Automated%20Truck%20Policy_24OCT2017_final.pdf.

[5] See, for instance, Abuelsamid, S. (2017). Domino's Takes High-Tech Pizza Delivery to Level 4 With Ford. Forbes, August 29, 2017. Available at https://www.forbes.com/sites/samabuelsamid/2017/08/29/dominos-takes-high-tech-pizza-delivery-to-level-4-with-ford/#19ca82b299e8.

precedent. For example, major developments in information and communication technologies in the past two decades presented both major technological breakthroughs for consumers while disrupting or modifying the way that business and commerce is undertaken. Thus, before reviewing existing findings concerning the prospective impact of AVs on the workforce, in this section we review the literature concerning how automation and labor interact broadly, not only with respect to AVs, but also in other industries (including both service and production). This is particularly important because the interaction of AVs and the workforce is an emergent but little studied topic.

In this Section, when we discuss the workforce or labor force, we are referring to all individuals presently employed or looking for work in the U.S. In the section that follows, we discuss existing research that seeks to define the segments of the workforce that are likely to be impacted by AVs.

In 2015, the Journal of Economic Perspectives published a symposium on automation and labor markets. Articles in the symposium highlight the fact that workforce transition concerns regarding AVs are far from the first time that individuals, organizations, and policy makers have worried about how technology can impact workers.[6]

In the lead article, entitled “Why Are There Still So Many Jobs?” David Autor notes that twentieth century examples of concerns regarding automation destroying jobs include a commission empaneled by Lyndon B. Johnson to address “the problem that productivity was rising so fast it might outstrip demand for labor,” (Autor, 2015, p. 4). He finds that whereas automation does substitute for labor, it also complements labor by enhancing per-worker productivity, which can increase earnings and augment labor demand. Autor notes that changes in technology do alter the types of jobs available and what those jobs pay—some of which have little to do with the technology.[7] Autor points out that over the very long run, gains in productivity have not led to a shortfall of demand for goods and services or paid employment opportunities, but presents evidence that wage gains in the last few decades have gone disproportionately to those at the top and bottom of the income and skill distributions relative to those in the middle.

In their companion article, Mokyr et al. (2015) discuss what the authors view as three prominent (work related) anxieties over technology (Mokyr et al., 2015, p. 32):

- That technological progress will cause widespread substitution of machines for labor, which can increase inequality in the short run, even if the long-run effects are beneficial.
- That technological progress can be dehumanizing by eliminating work, which can serve as a source of human satisfaction.
- Conversely, that the epoch of major technological progress may be behind us.

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[6] One of the aims of the Journal of Economic Perspectives is to “synthesize and integrate lessons learned from active lines of economic research.” As such, the symposium may be viewed as the current state of economic views on the topic. See American Economic Association, About the Journal of Economic Perspectives. https://www.aeaweb.org/journals/jep/about-jep.

[7] An interesting example that Autor presents, that is somewhat relevant here, is the rise of roadside motel and fast food industries to serve the “motoring public” that resulted as passenger cars displaced equestrian travel.

The authors note that while predictions of widespread technological unemployment by earlier generations of economists were, by and large, wrong, we should not trivialize the costs borne by the many workers who were displaced. Importantly, the authors state that whereas it is true that, in the long run, wages for laborers increased to reflect increased productivity, it is also true that, for the Industrial Revolution, by many estimates, it took longer than an average working lifetime to do so.

Mokyr et al. (2015) also suggest that the pattern this time may be different due to the increasing capabilities—e.g., due to say artificial intelligence—of machines to substitute for an increasing number of human capabilities. In forecasting the future, they write that the substitution of capital for labor can impact average annual work hours as well as how work will be distributed. For instance, citing earlier findings, they state that between 1870 and 1998, the number of annual hours worked per employee in industrialized western economies fell from approximately 2,950 hours per worker to 1,500 (Mokyr et al., 2015, p. 43).

However, between 1965 and 2003, whereas people with less than a high school education increased their leisure by almost ten hours per week, college graduates increased it by less than one hour per week. Additionally, although part of the widening inequality in hours worked is driven by the highest-skilled workers increasing their work effort, a part is driven by declines in work for lower-skill workers (Mokyr et al., 2015, p. 44). Thus, the path of transition to the economy of the future may be disruptively painful for some workers and industries. As a result, the authors believe that wages for some classes of workers may need to be supplemented through income redistribution.

In the last article in the symposium, Gill Pratt briefly describes ongoing advances in robotics and implications for the economy. Pratt (2015) singles out eight technologies that are relevant to the development of robotics, including exponential growth in computing performance and scale, performance of the Internet, worldwide data storage, and global computation power; exponential expansion and availability and performance of local wireless digital communications; and improvements in electrical energy storage and electronics power efficiency. Pratt's conclusions regarding the impact of these technologies resemble those of Mokyr et al. (2015) and he similarly suggests that certain kinds of redistribution may need to occur (though not necessarily direct income redistribution).[8]

Whereas the above symposium articles focused on automation and labor markets broadly, Bresnahan and Yin (2017) discuss how more recent innovations in information and communications technologies (ICTs) have shifted the relative demand for different kinds of labor, raising the demand for already highly compensated managers and professionals relative to other workers. Like AVs, ICTs do not necessarily represent an innovation that is purposefully intended to substitute for human capital; instead, for instance, they often serve as a set of consumer goods with the potential to improve life quality. Additionally, like AVs, ICTs are "enabling technologies," permitting, but not directing, the invention of applications that address market demands and organizational supply processes (Bresnahan and Yin, 2017, p. 96). Thus, certain lessons concerning the impact of AVs might be drawn by comparison to ICTs.

[8] For instance, the authors suggest expanding the set of publicly provided goods to include those that are necessary for "a modern life to go well" (Mokyr et al., 2015, p. 47).

As the authors point out, the bulk of ICT innovation is generated outside the tech sector, by firms that are users of ICTs through a process of “coinvention.” Coinvention refers to the product and process improvements created by industries as they apply new ICTs to address market demands (Bresnahan and Yin, 2017, p. 96). Consequently, the authors believe that the debate over technology enabling capital to displace labor misses the point. The authors state that the complexity of the coinvention process sows the seeds of its own sustained labor demand. However, like the authors in the above symposium, Bresnahan and Yin (2017) note that coinvention leads toward a continued expansion of variation in wages, with incomes of the less educated, less established, less successful workers rising very slowly or falling relative to their ICT-complementing counterparts.[9]

A number of recent reports, including one by the Executive Office of the President, have sought to study how automation, broadly put, can impact the U.S. workforce. In December 2016, the Office of the President released a report investigating the effects of Artificial Intelligence (AI) driven automation on the U.S. job market and economy, outlining recommended policy responses.[10] The report builds on research studies such as the ones discussed above, echoing the finding that automation threatens lower-paid, lower-skilled, and less-educated workers while increasing the productivity of those engaged in abstract thinking, creative tasks, and problem-solving, shifting demand towards more skilled labor and raising the relative pay of this group.

The report makes three strategy recommendations:

i. The government should invest in research and development around AI technology (2016 AI, Automation, and the Economy Report, pp. 27-30).
ii. Educate and train Americans for jobs of the future. This includes, assisting U.S. workers in successfully navigating job transitions, including expanding the availability of job-driven training (e.g., apprenticeships) and opportunities for lifelong learning and providing workers with improved guidance to navigate job transitions (2016 AI, Automation, and the Economy Report, pp. 30-34).
iii. Aid workers in transition, by for instance, modernizing the social safety net (e.g., unemployment insurance, SNAP, TANF, etc.). This also includes pursuing strategies to address differential geographic impacts to address concerns related to displacement amid shifts in the labor markets and reducing geographic barriers to work (2016 AI, Automation, and the Economy Report, pp. 34-42).

To home in on the type of transitions that may be necessitated by AI, the report (2016 AI, Automation, and the Economy Report) detailed above undertakes a brief AV case study. It notes that the Council of Economic Advisors estimates that 2.2 to 3.1 million existing part- and full-time U.S. jobs may be threatened or substantially altered by AV technology. However, this figure is not a net calculation, and thus does not include the types of new jobs that may be

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[9] The authors refer to the work of James Bessen, who finds that others’ computer-use lowers employment growth in the bottom three quartiles of the wage distribution significantly, but has a positive impact on the top wage quartile. Relatedly, they cite to evidence for increasing wage dispersion, which they explain results from an increase in product quality leading to relative increases in demand for more capable labor. See Bessen (2016).

[10] We note that this report originated during the previous Presidential Administration and may not represent the views of the current administration.

developed. Moreover, the report does not attempt to assess the length of time over which these jobs could be displaced, nor what positions may be created due to the adoption of AVs.

Two additional relevant reports include one by McKinsey Global Institute and another by the New America Foundation in partnership with Bloomberg. Both reports seek to forecast how various technologies could impact the workforce by automating existing activities. Although neither report exclusively focuses on AVs, interestingly, both undertake some analysis concerning the prospective impact of automation in trucking.

The 2017 McKinsey Report analyzes how a range of technologies could automate current work activities and the resulting global impact. The report proceeds by disaggregating occupations into 18 performance capabilities pertaining to sensory perception, cognitive capabilities, natural language processing, social and emotional capabilities, or physical capabilities. The authors then estimate the level of performance for each capability required to perform each work activity and assess the performance of existing technologies based on the same criteria.[11] By doing so, using U.S. Department of Labor data, the authors are able to estimate the technical automation potential of more than 2,000 work activities in more than 800 occupations across the economy. The authors also draw on industry experts to develop scenarios for how rapidly the performance of automation technologies could improve each of the analyzed capabilities.

The authors estimate that while less than 5 percent of occupations can be fully automated, about 60 percent have at least 30 percent of activities that can technically be automated and overall, 50 percent of activities that people are paid to do in the global economy have the potential to be automated using currently demonstrated technology (McKinsey, 2017, p. 5). Additionally, as suggested by the studies above, the authors find a significant degree of variation among sectors of the economy. Sectors involving predictable physical activity, such as manufacturing and retail trade, have a relatively high technical potential for automation.

The report is broad in its scope, and among other things, includes case studies of several industries, but does not focus on AVs except insomuch as it assesses the impact of technologies that are essential in the production and functionality of AVs (e.g., machine learning technologies). Interestingly, to illustrate their discussion of factors influencing the automation of work activities—specifically, technical feasibility, the cost of developing and deploying solutions, labor market dynamics, economic benefits, and social and regulatory acceptance—the authors point to the example of driving heavy trucks (McKinsey, 2017, p. 78). Although the authors note that the technologies to automate the required capabilities required in driving heavy trucks exist, the individual capabilities must be integrated into a solution: the hardware and software that would constitute an autonomous driving truck.

The authors estimate the time required to engineer such a solution (a truck capable of Level 4 autonomy) could take more than seven years. They further estimate that based on wages paid in the U.S., automation is modeled to become economically feasible within three to ten years *after* Level 4 autonomy is available, though widespread adoption could take significantly longer because of the number of tractor-trailers in the U.S. (assuming that U.S. regulations allow

[11] To do so the authors used a machine-learning algorithm to score the more than 2,000 work activities in relation to 18 performance capabilities (McKinsey 2017, p. 123).

businesses to displace a truck driver with a Level 4 vehicle). Current tractor-trailer rigs in the U.S. support only a limited level of automation.

In order to assess the potential future impact that technological advancement will have on work and workers, New America and Bloomberg organizations assembled over 100 industry, policy, academic, and technology experts, referred to as the Shift Commission, across five cities to create 44 different scenarios that were distilled into four potential futures concerning the labor force.[12] The four scenarios that were envisioned are:

i. A task-based economy with less work that prioritizes work in person-to-person interactions.
ii. A corporate-centered economy with high corporate productivity with high levels of automation, but low levels of employment and high income-disparities.
iii. A task-based economy with more work, in which people build reputational rankings with each task they complete and combine multiple income streams.
iv. A technology-driven economy in which automation has replaced all routine tasks, but creates numerous new jobs that entail creative thinking and idea generation.

Among activities pursuant to this research, the Shift Commission hosted a focus group with truck drivers. Participating truck drivers were concerned about layoffs and reduced union leverage, and wanted a more consistent income stream. Moreover, focus group participants resisted the idea of autonomous trucks completely displacing human drivers after watching a video of an autonomous truck driving on the highway (Shift Commission, 2017, p. 21).

3.3. Automated Vehicles: (Re)Defining the Workforce

In the previous section, we viewed the workforce as comprising of all individuals presently employed or looking for work. In this section, we discuss whitepapers and reports that have attempted to codify and enumerate the type of jobs that are associated with AVs and driving more broadly. By narrowing the meaning of the word "workforce" to the set of job categories likely to be affected due to their association with AVs or driving, we are able to be more precise when speaking of how AVs are anticipated to impact the workforce in the next section.

Our goal is not to view innovation in AVs as simply a change that is likely to destroy jobs, but rather an innovation that fosters broader societal change and leads to shifts in the workforce. This implies that whereas some positions become obsolete or require employees to pick up new skills, demand for other jobs or skills rises. Two recent reports, respectively from the Department of Commerce (DOC) and the Center for Global Policy Solutions, enumerate and characterize existing jobs likely to be either adversely impacted by AVs or require employee retraining. In contrast, a report stemming from a collaboration between the Workforce Intelligence Network for Southeast Michigan and the Atlas Center (jointly, WIN-Atlas), focuses on skills gaps that result from emerging AV technology integration into new and/or existing jobs.

[12] This scenario-based analysis consisted of examining economic trends and survey research. Trends that were identified as almost inevitable included an aging workforce; the decline of the movement of people between jobs, firms, and places; a societal shift to non-work income; and growing geographic gaps.

For expositional convenience, we treat these two job categories, (1) those at risk, and (2) those in demand, as distinct. Jobs in the two categories typically require different sets of skills, but may be in the same industries.

3.3.1. Jobs at Risk

The 2017 DOC Report on the employment impact of AVs states that as of 2015, 15.5 million U.S. workers were employed in occupations that could be affected by the introduction of AVs. The authors divide these occupations into two broad categories according to the importance of operating a vehicle:

- **Motor vehicle operators**: occupations for which driving vehicles to transport persons and goods is a primary activity.
- **Other on-the-job drivers**: these workers use roadway motor vehicles to deliver services or to travel to work sites.

In 2015, there were 3.8 million motor vehicle operators—occupations viewed by the authors as facing the greater risk of displacement—and 11.7 million other on-the-job drivers (DOC, 2017, p. 1).[13] To identify workers who operate or travel in motor vehicles on roadways, the authors use Occupational Information Network data that includes attributes of occupations like work activities, work context, and the use of tools and technology (see DOC, 2017, p. 7). This data provides an average score, on a scale of 1 to 5, of the importance of 41 generalized work activities, one of which is "operating vehicles or equipment." It also includes scores for occupations for how frequently work is performed in vehicles and identifies occupations that use motor vehicles as a tool.

Seven occupations are classified as motor vehicle operators in order of 2015 employment in the U.S. (DOC, 2017, pp. 11-12):

- Heavy and Tractor-Trailer Truck Drivers
- Light Truck or Delivery Service Drivers
- School or Special Client Bus Drivers
- Driver/Sales Workers
- Taxi Drivers and Chauffeurs[14]
- Transit and Intercity Bus Drivers
- Ambulance Drivers and Attendants (Except Emergency Medical Technicians)

As the authors find, the degree to which these seven occupations involve driving is substantially higher than for job categories that fit into the "other on-the-job drivers category," putting these seven occupations at greatest risk of facing displacement by AVs. The authors' list of other on-the-job drivers consists of 101 occupations, including workers from diverse occupations such as

[13] The authors report that the "average importance score" for operating vehicles is 86.1 for motor vehicle operators, much higher than the score of 58.7 for other on-the-job drivers (for more detail and interpretation, see DOC, 2017 pp. 22-24).

[14] The Taxi Drivers and Chauffeurs category does not include the ride share drivers who work for companies such as Uber and Lyft.

personal care aides, security guards, police officers, postal service mail carriers, HVAC mechanics, and automotive service technicians, indicating that far more than 3.8 million jobs could be impacted by AVs. However, the 2017 DOC Report does not elaborate on what the actual impact for either the motor vehicle operator or other on-the-job driver categories entails, leaving room for future work to do so.

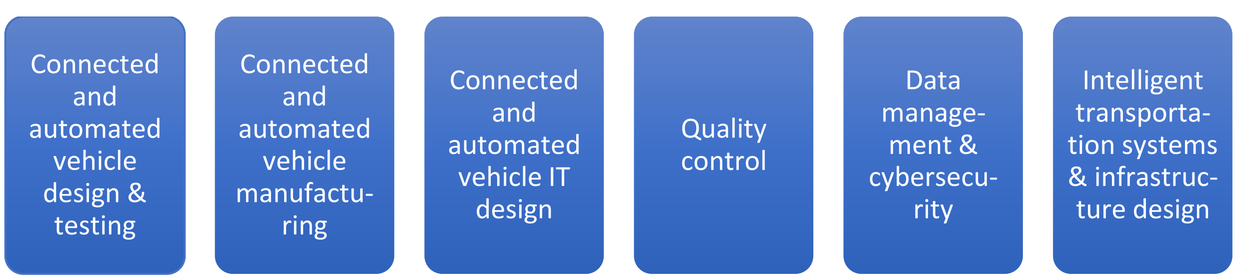
In 2017, the Center for Global Policy Solutions, a think tank aimed at promoting safe and sustainable environments, released the Stick Shift report that projected a similar number of jobs would be at risk of displacement following the transition to AVs. Specifically, using American Community Survey (ACS) data, the report indicates that approximately four million jobs are likely to be lost, with occupations such as delivery and heavy truck drivers, bus drivers, and taxi and chauffeur drivers at greatest risk of displacement. We note that unlike the 2017 DOC report, the 2017 Stick Shift report does not elaborate on reasons for focusing on particular occupations, beyond suggesting that these occupations are at risk because they comprise driving as a core component of the job. We note that both the 2017 DOC and Stick Shift reports, which focus specifically on the impact of AVs, project a higher number than the aforementioned Council of Economic Advisors estimates of 2.2 to 3.1 million existing part- and full-time U.S. jobs that may be threatened (2016 AI, Automation, and the Economy Report).

3.3.2. Jobs in Demand

The 2017 WIN-Atlas report analyzes job postings for a broad set of occupations that may be involved in the design, manufacture, and infrastructure development in the connected and autonomous vehicle (CAV) product cycle. The authors find that 49 occupations across a variety of skillsets are directly related to CAVs. These workers include those in IT, cybersecurity, civil engineering, mechanical engineering, transportation systems design, and various others. In particular, three occupations, software developers, information security analysts, and computer systems engineers, comprised 61 percent of all CAV-related demand in the U.S. (WIN-Atlas, 2017 p. 15).

To better analyze the data, the WIN-Atlas report groups the 49 occupations into six sub-groups associated with CAVs, illustrated in Figure 2. The top three occupations among these groups are associated with cybersecurity, IT design, and managing the data related to connected transportation systems.

Figure 2: Occupational Categories Expected to Expand Due to AVs



Demand for CAV workers as gauged by online job ads in any year between 2011 and 2016 is substantially smaller than the number of jobs perceived as at risk from AV or CAV technology. During this time-period, there were 793,230 software development jobs posted in the U.S., but only 0.3 percent of these listed CAV skills.

Comet Labs holistic assessment of startup companies developing essential components of AVs is indicative that many of these technology-oriented occupations associated with CAVs may be associated with startup companies.[15] In a 2017 blog post, Comet Labs identified 263 companies currently working on AV technology, consisting of sub-sectors that include mapping and annotation, autonomy, on-board sensors, fleet management, and material characterization.

The WIN-Atlas report focused on occupations directly associated with CAVs, but AVs or CAVs may create other positions that remain to be systematically analyzed or enumerated by existing literature or have yet to be envisioned at the present stage of development. For example, we note that while the WIN-Atlas report considers the need for infrastructure redesign associated with CAVs, it does not focus on the installation and maintenance of the infrastructure needed to support CAVs. However, they do not differentiate between connected and automated vehicles in their report. Confounding these two different systems does not enable readers to understand the impacts of AVs on the driving workforce.[16]

Clements & Kockelman (2017) review the prospective economy-wide impacts of CAVs by examining the net economic benefits to society due to the shift to connected and highly automated vehicles. The authors find that the net economic benefit will be as large as $1.2 trillion per year (approximately 8 percent of the U.S. gross domestic product), but also entails substantial workforce related changes in numerous industries. As with the WIN-Atlas report, Clements & Kockelman's (2017) review focused on CAVs and not on AVs specifically. Further work specifically focusing on workforce impacts of AVs is needed.

3.4. Automated Vehicles and the Workforce

Building on the sections above, particularly Section 3.3, we now provide an overview of existing literature through the end of 2017 concerning how AVs can impact the workforce. This consists of peer reviewed publications, reports, and white papers seeking to assess:

- Changes in infrastructure precipitated by AVs;
- Worker displacement and changes in workforce needs and employment due to AVs;

[15] Stewart, T. (2017). 263 Self-Driving Car Startups to Watch. Available at https://blog.cometlabs.io/263-self-driving-car-startups-to-watch-8a9976dc62b0. Comet Labs is a venture capital firm focused on artificial intelligence and machine learning.

[16] Though one reviewer of this report noted that there would be no significant workforce impacts of CAVs, we note that the connected component does pertain to drivers. For example, we cannot go to full SAE-5 level if an AV is disabled by visual and LIDAR limitations; it will need a backup driver. However, a CAV may be able to navigate, at least in developed regions, via V2X, for example lane marking sensors. We, however, assert there is a workforce relationship there with respect to backup drivers. Further workforce issues arise in platooning, which is most effective including V2V, and perhaps V2X as well. Non-driver workforce issues may also be created by CAVs, such as monitoring road conditions via V2X, including ice/snow for prioritizing removal, or potholes for prioritizing repairs.

- Changes in organizational structures and business practices caused by AVs, with implications for how such changes can impact the workforce.
- Policy responses and expectations that relate to labor aspects of AVs.

We note that the literature on this topic is relatively new, which necessitates the need for future investigations that can inform stakeholders. Many of the papers listed only touch on the interrelation between AVs and the workforce as part of a more general discussion. Similarly, even the three reports discussed in Section 3.3 only categorize and enumerate jobs likely to be displaced or current skill gaps that need to be met, and do not, for instance, attempt to forecast the potential transition resulting from AVs for the coming decades.

We subdivide the work discussed in this section into two strands, the first of which explores the characteristics of workers who will be impacted by AVs and to what extent such workers could be impacted, and the second of which focuses on local, state, or nationwide impacts from a policy perspective.

3.4.1. Who Will Be Impacted

As was the case with previous periods of technological innovation), AVs are likely to adversely impact workers with lower levels of education, and conversely, create jobs for better educated and technically oriented individuals.

For instance, according to the 2017 DOC Report, only 7.6 percent of workers classified as motor vehicle operators held a bachelor's or higher degree compared to 33.4 percent across all workers whereas 45.6 percent of motor vehicle operators had only a high school diploma, compared to 24.7 percent of workers overall. This relative lack of education is exacerbated by the fact that motor vehicle operator jobs require less in terms of performance for almost all cross-functional skill categories compared to both other on-the-job drivers and all occupations. The authors note that motor vehicle operators may have less of a knowledge and skills base that could be transferable to other jobs. The 2017 Stick Shift report similarly finds that the vast majority (93.2 percent) of workers in driving occupations identified possess less than a bachelor's degree.[17] In contrast, the 2017 WIN-Atlas Report finds that CAV workers must have higher educational attainment, with a bachelor's degree often being a minimum requirement. These trends may also apply to specific sectors of the economy. For instance, in a working paper assessing the impact of AVs on municipal budgets, Clark et al. (2017) suggest that in the public sector, whereas jobs likely to be displaced require a lower level of education, public sector jobs that are likely to grow include IT sector, data analysis, and other higher-skilled jobs.

The vulnerability and availability of positions stemming from AVs also varies according to geography and other demographic characteristics besides education. For instance, motor vehicle operators are predominantly male (88 percent according to DOC, 2017 and a similar

[17] However, the report indicates that workers in driving occupations have a poverty rate (7.32 percent) lower than the overall workforce (8.06 percent) and higher shares of union memberships (15.68 percent) than the overall workforce (11.44 percent).

figure according to Stick Shift, 2017)[18] and have higher minority representation (Stick Shift, 2017, Table 5). There is substantial geographic variation in the number of workers in driving occupations by state, so that some geographic locations may be disproportionately burdened by the loss of driving jobs. The most vulnerable states in terms of percentages of the workforce in driving jobs (as opposed to absolute numbers of individuals in these jobs) are North Dakota, Idaho, Wyoming, West Virginia, Mississippi, Arkansas, and Iowa (Stick Shift, 2017). In contrast, CAV job postings were concentrated in particular areas, primary among these, the Washington DC, Detroit, Boston, and Baltimore metropolitan areas (WIN-Atlas, 2017).

Studies yield mixed results with regard to the extent or rate at which workers are likely to be displaced. For instance, Frey & Osborne (2017) use Occupational Information Network data combined with objective variables describing the level of perception and manipulation, creativity, and social intelligence required in different occupational tasks to assess the susceptibility of different occupations to computerization. They find that many jobs associated with driving have a very high probability of computerization. For instance, cargo and freight agents and drivers/sales workers are respectively associated with probabilities of 99 percent and 98 percent of computerization.

On the other hand, industry experts suggest that in the foreseeable future there will still be a human operator on autonomous trucks making final deliveries or loading and unloading cargo, and that autonomously operated trucks may face significant resistance from labor groups (Center for the Study of the Presidency & Congress, 2017; Fagnant & Kockelman, 2015). It is also likely that age and technology experience may intersect to influence truckers' participation in the AV workforce (e.g., ITF, 2017). In the U.S., the median age of truck and transportation drivers is well above that of the average worker.[19] Although this might imply a lesser willingness for typical truck drivers to acquire training to enhance their technological skillset to enable them to operate an AV, as we suggest in Section 5.1, the dearth of younger adults willing to pursue a driving career could also mean that existing drivers face a lower risk of being displaced by an AV.

AVs may also positively affect the employability and productivity of certain segments of the population. For instance, AVs may help individuals with physical disabilities re-enter, or enter for the first time, the workforce. Some of these individuals may need assistance to enter the AV; it is not clear whether that assistance will need to be provided by human beings. Research is needed in this area. In addition, AVs may allow older adults to work throughout latter stages of the life course. Certain estimates indicate that several million Americans that have disabilities could become eligible to enter the labor force if they had access to AV transportation (Claypool, Bin-Nun, Gerlach, 2017). We note that this has the potential to result in shifting funds from social supports to economic production. Detailed analysis will be needed to better ascertain this

[18] Specifically, the 2017 Stick Shift report states that of the 3.1 million delivery and heavy truck drivers, 600,000 bus drivers, and 340,000 taxi drivers or chauffeurs in the U.S, approximately 3.6 million are men, about 6.5 times the share of women in these occupations.

[19] Estimates vary. For example, using data from the Current Population Survey, BLS reports that the average age of, respectively, truck and driver/sales workers, bus drivers and chauffeurs, and taxi drivers in 2017 was 46.2, 53, and 46.8. Bureau of Labor Statistics, Labor Force Statistics from the Current Population Survey, Household Data Annual Averages, Employed persons by detailed occupation and age, 2017. Available at https://www.bls.gov/cps/cpsaat11b.htm.

potential. For example, it may be necessary to break the newly employable disabled into high skill and low skill, as the latter might compete with displaced drivers for jobs requiring only electronic interface to automated equipment (for example, like a manager of a trucking platoon that is largely automation enabled and simply needs local decision-making capability carried out through electronic means).

In attempting to synthesize existing analyses of the economic effects of CAVs, Clements & Kockelman (2017) provide an overview that includes some workforce implications for various industries.[20] However, as Milakis et al. (2017) note in a recent review article, there are few in-depth studies on the economic and social equity impacts of AVs, which necessitates future work on how AVs will impact different type of workers and segments of the population. Thus, additional research is needed to fully gauge the workforce impacts of AVs—both in terms of job displacement and job creation.

3.4.2. Policy Considerations

Policy makers and other organizations have written local, state, or national focused analyses that gauge institutional preparedness and seek to shape policy responses to AVs. The reports have substantial overlap with the various aforementioned studies in terms of informing readers concerning myriad regulatory, socioeconomic, and technological factors associated with AVs. Moreover, although for concision, in this literature review, we focus on workforce related developments, these are not the primary focus of most of the policy reports discussed below.

Organizations in certain U.S. states have put together focused policy reports concerning AVs. Here, we focus on reports concerning Delaware, Massachusetts, and Pennsylvania, because in each case, the reports' authors discuss (but do not study in depth) potential workforce implications.

Delaware: The University of Delaware's Institute for Public Administration report states that there are nearly 10,000 Delawareans employed as heavy and light truck drivers, bus drivers, taxi drivers, and chauffeurs (based on 2015 Bureau of Labor Statistics data), referencing prior studies that suggest labor-displacing technologies stimulate economic growth in unintended and unanticipated ways (Barnes and Turkel 2017, p. 20). Beyond these pronouncements, the report does not attempt to rigorously assess the potential future AV impact on the workforce.

The report does discuss the fact that by fostering more efficient fuel consumption, AVs could significantly depress critical sources of transportation-related revenue for Delaware, a quarter of which stems from a motor vehicle fuel tax. AVs could also depress local government revenue generation by, for instance, decreasing revenue collected from traffic violations and parking fees. We envision that these revenue decreases will occur concurrently with declines in demand for jobs associated with such revenue streams.

Massachusetts: The Massachusetts Metropolitan Area Planning Council (MAPC) adopted a set of legislative and policy considerations aimed at encouraging Massachusetts to support

[20] Clements & Kockelman (2017) look at the following industries: automotive, technology, freight movement, personal transport, auto repair, medical care, insurance, law, infrastructure, land development, digital media, police, as well as oil and gas.

regulations and planning that would ensure safe, accessible, and equitable mobility for its citizens. Workforce impacts number among MAPC's various concerns, with the potential for substantial job losses in the trucking and delivery, auto-repair, and law enforcement sectors (MAPC 2017, p. 10). Although MAPC does not evaluate the extent of these potential losses or the benefits from the creation of new industries and employment opportunities due to AVs, the 2017 MAPC policy report authors encourage the proactive evaluation of workforce impacts and the examination of workforce education and training needs.

Pennsylvania: The Pennsylvania Department of Transportation (PennDOT) commissioned a project with Carnegie Mellon University to assess the implications of CAVs on the management and operation of the state's surface transportation system. Among other things, this 2014 PennDOT report explores the impacts of CAVs on workforce training needs.

The report states that workforce training will need to change significantly with the introduction of CAVs. The authors examine training offered by professional organizations, government agencies, and educational institutions, suggesting several changes (PennDOT 2014, pp. 32-37) concerning certification and training by a range of different organizations which would incorporate topics or training concerning CAVs and CAV related technologies. Organizations discussed in the report include:

- The Institute of Transportation Engineers, which is associated with Professional Traffic Operations Engineer (PTOE) and Professional Transportation Planner (PTP) certification.
- Society of Automotive Engineers (SAE), which offers curriculum and professional certification for career advancement.
- State Departments of Transportation (DOTs).
- U.S. DOT, which offers Intelligent Transportation System (ITS) training.
- Community colleges, trade schools, and universities.

We suggest it is also worthwhile to differentiate among workforce training and retraining opportunities aimed at college graduates—such as, for instance, Udacity's self-driving car nanodegree[21]—versus individuals at the pre-college level.

The prospective impacts of AVs and CAVs have also been explored at the municipal or city level. For instance, focusing on San Francisco, Clark et al. (2017) consider the impact of AVs on municipal budgets. Clark et al. (2017) point out that declines in municipal budgets caused by factors such as declines in parking ticket revenues may occur concurrently with gradual declines in employment in the public sector. Potential employment declines may be seen in trash collection or in public transit, particularly if competition from AV based rideshare services diminishes demand for transit circulators. Thus, while local government revenues may decline, so might payrolls, including long-term costs like pensions and retiree healthcare.

Similarly, in a 2015 report commissioned by the City of Toronto Transportation Services Division, David Ticoll examines AV related changes to safety, equity and accessibility, the environment, vehicle operating costs, congestion, and various policy relevant topics. Ticoll

[21] See Udacity, Nanodegree Program. Available at https://www.udacity.com/course/self-driving-car-engineer-nanodegree--nd013.

suggests that vehicle automation is likely to make profound, systemic economic and fiscal impacts on Toronto.

Ticoll notes that sectors that innovate for and facilitate emerging AV capabilities will thrive if they seize opportunities offered by AV technologies, whereas sectors that depend on current transportation models are at risk. He states that AVs will create some new jobs and that an estimated $6 billion in savings from collisions, parking, insurance, and congestion will create others. However, he believes that the net job impact could be negative (Ticoll, 2015, p. 46).

Ticoll states that productivity could improve in mobility-intensive jobs like law enforcement and home care, certain full-time driver jobs could be eliminated, certain other jobs may become redundant (e.g., parking lot attendants, parking enforcement), and AVs with function-specific automation may replace jobs in occupations like street cleaning and courier delivery. Specifically, Ticoll anticipates job growth in construction (due to AV related infrastructure changes in Toronto), but job losses in manufacturing (including motor vehicle related), wholesale and retail trade, truck transportation, bus transportation, waste collection, home health care, public administration, gasoline stations, taxi and limousine service, insurance, and automotive rental, leasing, repair, and maintenance (for percent estimates, see Ticoll, 2015, pp. 47-49).

At the nationwide level, to address potential challenges posed by AVs, the Center for the Study of the Presidency & Congress convened off-the-record roundtables, with an aim of beginning a dialogue between the government and private sectors to identify solutions to potential problems. The 2017 report, which documents the Center's findings, notes that the deployment of AV technology in commercial industry could provoke significant political reaction due to concerns about job losses, but recommends that leaders in the Executive Branch and Congress should highlight the broader societal benefits of AV technology. The report further advocates that policy makers should base policies on sound economic analysis of automation's impact on the American workforce, including providing policies addressing retraining and rehiring opportunities for those displaced by this technology.

In view of its findings concerning driving jobs, the previously discussed 2017 Stick Shift report makes the following recommendations to policymakers that are intended to offset the workforce impacts of AVs:

i. Automatic unemployment insurance, job training, and placement benefits;
ii. Progressive basic income to compensate for potential changes in the labor market;
iii. Education and retraining to assist displaced workers;
iv. Automatic Medicaid eligibility for lower income displaced workers;
v. Expanded support for displaced entrepreneurs.

Policy recommendations related to AVs are not limited to the United States. The International Transport Forum (ITF), an intergovernmental organization of 57 countries within the Organization for Economic Co-operation and Development (OECD), provides policy recommendations that are international in scope based on findings concerning automation in trucking. Of relevance to the workforce, the 2017 ITF Report considers various prospective scenarios for the adoption of driverless trucks and details the ensuing job losses due to each scenario. As the report notes, a driver shortage or surplus can emerge, depending on the scenario for adoption.

As do several of the reports above, the ITF report states that truck drivers are at a disadvantage in being able to transition to new job opportunities because of lower average formal education levels than persons in other occupations. The report suggests a number of measures to facilitate the introduction of driverless road freight. These include setting international standards, road rules, and vehicle regulations for self-driving trucks; establishing a temporary transition advisory board for the trucking industry; and creating a temporary permit system to manage the speed of adoption and to support an equitable transition for displaced drivers, while ensuring fair access to markets (ITF, 2017, pp. 56-61).

3.5. Discussion of Literature: Current Knowledge and Future Directions/Needs

Although limited, prior research suggests that the development and proliferation of AVs is likely to significantly impact the workforce in the U.S. and other parts of the world. As we have noted, the workforce is diverse, and AVs have the potential to disproportionately affect certain segments of the population and sectors of the economy. Individuals with less education and technical or cross-functional expertise are more likely to be adversely affected. Though it is likely that sectors that rely heavily on vehicles (i.e., various transportation sectors) will experience worker displacement, other sectors may experience significant positive impacts in terms of the types of new jobs created, and the range of reskilling needed in other sectors.

The bulk of existing research also confounds CAVs, CVs, and AVs. As we have noted, there are differences in these systems – which will result in differential impacts across workforce sectors. The majority of research is not specific enough at this point to denote the range of workforce elements likely to be displaced as a result of AVs, nor is it detailed enough to know the full range of new jobs that will be created. Given the increasing development of AV technologies and the policy level initiatives that may affect AV development, deployment, and utilization, additional cross-sectional and longitudinal research such as that focused on in this report is needed to understand the workforce implications of AVs and the types of educational training systems that will need to be designed to accommodate these changes.

4. Methodology

4.1. Interviews

We conducted in-depth audio interviews with 19 industry leaders and stakeholders in the automotive and affected industries and organizations to understand how AVs could impact the workforce (Table 1 lists types of industries and organizations). Interviewees were recruited through the American Center for Mobility's extensive network of industry, government, and related organizational contacts. Among other things, we asked interviewees to assess how AVs could impact jobs in different industries and what skills would become more valuable or necessary as a result of the emergence of AVs. To gain maximal insight from each interviewee, we tailored the open-ended interview questions to the interviewees' background and experience related to AVs.

For industries involved in the manufacture and distribution of AVs, we generally asked interviewees to:

i. Discuss functions, skills, and education levels of employees in various manufacturing jobs;
ii. Categorize skillsets that are required to manufacture AVs and related components;
iii. Consider existing skillsets in the manufacturing sector and evaluate potential skills gaps.
iv. Assess the projected market demand for AVs by demographic group (e.g., age), vehicle category, and geography; and
v. Describe the anticipated pace of adoption across different industry segments.

For industries expected to be impacted by, but not explicitly involved in the manufacture of AVs (e.g., transportation and delivery industries), we asked interviewees to:

i. Discuss the job categories in their industry expected to be impacted by AVs;
ii. Describe job categories that are expected to be created and/or eliminated;
iii. Describe new skills that existing workers will need to acquire and the skills that new workers will need to possess;
iv. Discuss the anticipated pace of adoption of AVs; and
v. Explain new business models envisioned due to AVs.

Interviews lasted approximately one hour and yielded rich information. All interviewees received an informed consent form approved by the Institutional Review Board at Michigan State University prior to the interview. Before the actual interview, a member of the research team asked if the person agreed to participate and asked if the interview could be audio recorded for accuracy. All interviewees agreed to participate and to the audio recording. The audio recordings were transcribed by a third party and the interviewee's name and organization were removed to ensure anonymity and confidentially.

4.2. Focus Groups

In addition to the in-depth interviews, we conducted three focus groups with industry leaders, major stakeholders, and government officials in Texas, California, and Michigan (N = 33 focus group participants total; Table 1 lists types of industries and organizations). Focus group participants were recruited through the American Center for Mobility. The length of each focus group session was approximately three hours. Participants received an informed consent form approved by the Institutional Review Board at Michigan State University (MSU) prior to the focus group. In addition, participants were asked to complete a brief survey to obtain demographic and industry related information. The focus groups were also audio and video recorded to ensure accuracy. The audio recordings were then transcribed by a third party and the participants' names and organizations were removed to ensure confidentially. Only the investigators from MSU had access to the interviewees and focus group participants' data.

One of the team members (Cotten) led the focus groups and asked open-ended questions about the potential changes to the workforce, worker skills, regulations, business models, and organizational structures as a result of AVs. Focus group participants were also surveyed and asked about education and training needs resulting from the emergence of AVs.

4.3. Industry Specific State-by-State Projections

When time permitted, we asked interviewees to quantify the expected rate of Level 4 AV adoption across several vehicle categories in the next 2, 5, and 10 years. For years 5 and 10, we obtained nine responses for each of the following vehicle categories: parcel and other delivery vehicles, transit circulators (e.g., public city buses), long haul trucks, and taxicabs/limousines. We used these responses together with industry specific employment and other data from the Bureau of Labor Statistics (BLS) to construct quantitative projections of how AVs could impact different segments of the product delivery and passenger transportation labor force as follows.

Using regression analysis, we first used state-level BLS data for the years 2010-2017 to project baseline job trends for 2018-2028 for long-distance freight drivers, delivery drivers, taxi drivers and chauffeurs, and transit bus drivers that do not account for the emergence of AVs. We use these baseline trends to forecast the number of jobs in each job category assuming no adoption of AV.

To conduct projections that account for the potential job losses resulting from the emergence of AVs, we estimated the adoption of AV technologies over time. An outline of the procedure we used is as follows. First, we used interview responses to calculate estimated adoption rates at given time periods. Second, we used these estimated adoption rates to create a set of simulated panel data. Third, we used the simulated data to estimate the adoption trend for that specific set of data. Finally, we repeated these steps 100 times to estimate a distribution of trend lines.

To conduct projections, we first associated vehicle categories and responses for which we asked interviewees to predict AV adoption to a corresponding BLS job category (e.g., taxicabs/limousines are associated with taxi drivers and chauffeurs). For example, if an interviewee stated that he or she believed that in 10 years, 25 percent of taxicabs/limousines on the road would be equipped with Level 4 automation, we inferred that this could lead to a displacement of 25 percent of taxi drivers and chauffeurs 10 years from now relative to the baseline in which we do not account for AVs.

We forecast adoption percentages and assume a 1-1 replacement of jobs to adoption. We note that the inference that a prediction of X percent of vehicles on the road implies a displacement of X percent is likely overly strong, even if the prediction is correct, leading us to err on the side of overestimating jobs losses. We do not have data to suggest a better alternative inference (i.e., a displacement smaller than X). However, extensive discussions with interviewees allow us to elaborate on the limitations of this inference throughout the report and to inform readers about the extent to which the emergence of AVs in a job category is likely to bring about job displacement in that category. As such, all of our quantitative projections should be viewed in light of our broader qualitative analysis.

We asked participants to forecast AV adoption rates over the next 10 years. Our forecasts of the adoption rate of AVs over the next 10 years come directly from the responses of interviewees. We did not estimate a separate structural economic model of AV adoption. The rationale for this decision is that the results of a structural model of AV adoption would depend on the form of the model and the availability of data. We operate under the assumption that the mental models of AV adoption used by interviewees—industry experts—to forecast AV adoption are superior in performance to those we might construct. Because interviewees' predictions were for 2, 5, and 10 years, without additional data, projections beyond 10 years will lead to excessively large confidence intervals which would not give our projections much explanatory power. In addition, the likelihood of unanticipated societal and technological changes increases with time, such that even if our predictions are quantitatively precise, qualitative issues are more likely to render them moot in the more distant future.

With this in mind, our analysis converted the forecasts provided by interviewees into a format commonly used to describe the diffusion of innovations. Georski (2000) provides an overview of modeling technology diffusion using survival analysis and fitting the data on technology diffusion to an appropriately formatted sigmoid, or S-curve. We chose to utilize a Gompertz diffusion model, under the premise that the likelihood of adopting AV technologies monotonically increases over time; that is, the spread of the technology will continue to accelerate over time. Link and Scott (2003) provide an overview of the hazard and survival functions of the Gompertz diffusion model.

As survival analysis requires panel data, and our data is in the form of forecasts at specific time periods, we used the interviewee forecasts to calibrate a simulated panel of data. To simulate data we used the interviewee forecasts of adoption to determine thresholds for adoption at the time periods for which we have data: 2 years, 5 years, and 10 years. We calculated the adoption thresholds as the average forecasted percentage of adoption using a random draw of 20, with replacement, of the interviewee forecasts. We randomly generated 1000 'individuals' with a non-adoption propensity that ranges from 0 to 1. We then converted these individual observations into a panel, maintaining the same adoption propensity. We then indicate that an individual has chosen to adopt AV if their assigned propensity is less than the adoption percentage at a given time period (e.g., year 2). This creates a set of panel data for which the interviewee responses determine the rate of AV adoption. With this data in hand we were able to apply the Gompertz model and derive the adoption trendlines.

To incorporate the variability of the interviewee responses we estimated the s-curve 100 times using a new random draw of 20 interviewee forecasts of adoption rate for each time period (i.e., bootstrapped).[22] This allowed us to approximate confidence bands around our estimates of the adoption trends. We used the bootstrapped-percentile approach to approximate our 90% confidence band, which a succinct description of is found in Lam and Veal (2002). This approach takes the 5th and 95th percentiles of the bootstrapped estimator, here the trendline for AV adoption, to be the upper and lower bound of the 90% confidence band.

The statistical routines and complete projection methodology are described in additional detail in Economic Appendix 9.3. Confidence intervals for our projections are available upon request.

[22] Efron (1979) developed the bootstrapping technique and Greene (2000) provides an overview of the technique.

Table 1: Study Participants' Industry Affiliations

	Participants' Industry Affiliation
CA Focus Group	• Automated and connected vehicle technology firm (4) • Multinational technology corporation • Automated vehicle development company • Department of Motor Vehicles • On demand mobility service provider • Multinational automotive manufacturer
MI Focus Group	• Subsidiary of a privately held automotive conglomerate (2) • US Department of Labor • R&D company focused on AI and robotics • Multinational automotive corporation • Architecture, engineering, and construction firm • Multinational accounting and professional service firm • University based transportation research organization • Multinational inspection, product testing and certification firm • Multinational automotive manufacturer • Workforce solutions firm
TX Focus Group	• Multinational electronics company • Multinational conglomerate • State-level trucking association • Multinational engineering and electronics conglomerate • Public transportation provider • Government Agencies (2) • American manufacturing, retailing, and marketing company • Transportation research organization • Multinational delivery service company • Multinational automated and software company • American manufacturing, retailing, and marketing company • Transportation research organization • Multinational delivery service company • Multinational automated and software company

Note: Numbers shown in parentheses indicates that multiple participants had that industry affiliation.

Table 1 Continued: Study Participants' Industry Affiliations

	Participants' Industry Affiliation
Interviews	• Global commercial real estate firm • International limousine company • R&D company focused on AI and Robotics • Trucking Association (2) • Automotive trade group • Reinsurance company • Military R&D facility • Multinational automotive manufacturer • Government agency (4) • AV testing organization • Subsidiary of a privately held automotive conglomerate • Multinational automotive corporation • Architecture, engineering, and construction firm • University based transportation research organization • Global automotive supplier

Note: Numbers shown in parentheses indicate that multiple participants had that industry affiliation

5. Jobs that Rely on a Vehicle

5.1. Truck Driving

Prior research has suggested that truck driving makes up the largest job category that can be affected by the emergence of automated vehicles. For instance, Frey & Osborne (2017) find that 79 percent and 69 percent of the tasks performed by respectively, heavy and tractor-trailer truck drivers and light truck or delivery service drivers can be "computerized," suggesting that these jobs may be subject to displacement at some point in the future. Moreover, according to U.S. occupational statistics, with more than 3 million truck or related delivery driving jobs in the United States in 2017, this combined driving category comprises more jobs than any other motor vehicle operator category,[23] indicating that the impact of AVs on this segment of the workforce may be substantial if truck and delivery jobs are lost.

As our research indicates, the actual effect of AVs on truck driving is substantially more complex and bodes better for drivers than earlier research may suggest. First, while driving may be considered the primary job of a worker in this category, trucking and delivery includes various other crucial skills and tasks that may be difficult to replace. Second, the transition to automated driving is expected to be relatively gradual in a large segment of this industry and is not expected to culminate in extensive and rapid job cutting. More likely, AVs will relieve the burden of certain individuals performing a physically demanding job and enhance the safety of vehicle occupants, while also helping to supplement the needs of companies, organizations, and individuals seeking to transport products from place to place. While current drivers who remain in their industry may need to retool their skillsets as the profession evolves, doing so is likely to improve the public perception of jobs in this category.

Although in this section we discuss truck driving in general, following prior work, for parts of our analysis, we divide truck driving into two distance-based subcategories: (i) Long-Distance Freight Trucking and (ii) Delivery Drivers. We categorize long-distance freight truck drivers as individuals who deliver goods over intercity routes, including across states. In contrast, we categorize delivery drivers as individuals who deliver goods within cities and other localities or from local distribution centers or warehouses to businesses or households.

Long-Distance Freight Trucking: During our interviews with industry professionals, we typically referred to "Long-Distance Freight Trucking" using the term "long haul trucks." This subcategory also might be viewed as synonymous with the Occupational Information Network (O*NET) and Bureau of Labor Statistics (BLS) occupational category termed "Heavy and Tractor-trailer Truck Drivers," which we use to perform jobs projections in Section 5.1.1.[24]

[23] This employment total is obtained by aggregating May 2017 BLS employment data for Heavy and Tractor-Trailer Truck Drivers (Occupation Code 53-3032), Light Truck or Delivery Service Drivers (Occupation Code 53-3033) and Driver/Sales Workers (Occupation Code 53-3031).

[24] BLS states that heavy and tractor-trailer truck drivers transport goods from one location to another and that most tractor-trailer drivers are long-haul drivers and operate trucks with a gross vehicle weight (GVW) capacity—that is, the combined weight of the vehicle, passengers, and cargo—exceeding 26,000 pounds. See Bureau of Labor Statistics, Heavy and Tractor-trailer Truck Drivers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm.

Long-distance freight truck drivers usually have a high school diploma and attend a professional truck driving school.[25] They must also have a commercial driver's license (CDL). To obtain a CDL, an applicant must pass skills and knowledge testing geared to the higher standards of operating a commercial motor vehicle.[26] Table 5 in Appendix 9.1 lists State URLs that outline the procedures and requirements necessary to obtain a CDL in each U.S. state.

Delivery Drivers: In discussing delivery driving with interviewees, we relied on terms such as "short haul trucks," "parcel, package, and food delivery," "parcel and other delivery," and "less than truck load," cognizant that some of these terms are not mutually exclusive from long distance freight trucking. For our projections in Section 5.1.1, we view these categories as related to the BLS category "Delivery Truck Drivers and Driver/Sales Workers."[27] We note that delivery drivers may additionally not drive trucks, relying on vans or other delivery vehicles to perform their duties. When conducting interviews, we did not explicitly single out this latter group, and as such include it in our discussion throughout this Section.

Like long-distance freight truck drivers, delivery drivers typically enter their occupations with a high school diploma or equivalent,[28] but do not generally require a CDL. However, on-the-job training for both categories often entails driving with a more experienced mentor-driver in the passenger seat for a time-period and along routes appropriate for the company or service.[29] According to BLS, as of May 2017, the median annual wages for light truck or delivery services drivers and for driver/sales workers were, respectively $31,450 and $24,040, compared to $42,480 for heavy and tractor-trailer truck drivers.[30]

Figure 3, borrowed from Camden et al. (2017), illustrates the different vehicle weight classes used by long-distance freight, delivery, and various other commercial drivers. Whereas delivery drivers typically operate vehicles in Classes 1 through 6, long-distance freight drivers operate vehicles in Class 7 and above.

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[25] Bureau of Labor Statistics, Heavy and Tractor-trailer Truck Drivers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm.

[26] Federal Motor Carrier Safety Administration, Commercial Driver's License Program. Available at https://www.fmcsa.dot.gov/registration/commercial-drivers-license. Applicants who wish to obtain a CDL must do so by meeting the requirements of their individual State licensing bureau. For instance, for the state of Michigan, the requirements for a CDL are specified at https://www.michigan.gov/sos/0,4670,7-127-1627_8669_53324---,00.html. Additional information is also available at https://cms.fmcsa.dot.gov/registration/commercial-drivers-license/how-do-i-get-commercial-drivers-license.

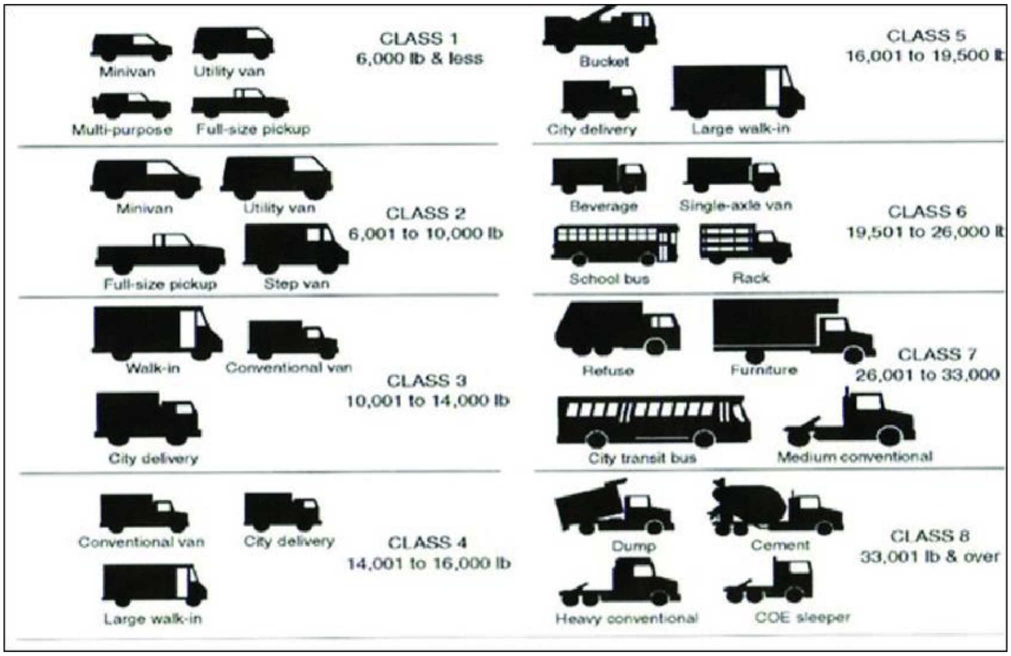
[27] BLS states that these categories of workers pick up, transport, and drop off packages and small shipments within a local region or urban area using trucks with a GVW of 26,000 pounds or less. See Bureau of Labor Statistics, Delivery Truck Drivers and Driver/Sales Workers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/delivery-truck-drivers-and-driver-sales-workers.htm.

[28] Bureau of Labor Statistics, Delivery Truck Drivers and Driver/Sales Workers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/delivery-truck-drivers-and-driver-sales-workers.htm.

[29] Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018.

[30] Table 9 and Table 12 in Appendix 9.3 present the median wages for these positions at the state level.

Figure 3: Vehicle Weight Classes[31]



Note: This image comes from: Camden, M. C., Medina-Flintsch, A., Hickman, J. S., Miller, A. M., & Hanowski, R. J. (2017). Leveraging Large-Truck Technology and Engineering to Realize Safety Gains: Lane Departure Warning Systems. Available at https://trid.trb.org/view/1484761.

5.1.1. How Automated Vehicles Will Transform Truck Driving

The transition to automated driving in the trucking industry is ongoing and anticipated to be gradual. Indeed, the transition could be said to predate more recent technology such as adaptive cruise control presently found in many vehicles on the market.[32] For example, a major change to heavy trucks (gross vehicle weight greater than 26,000 pounds) that occurred only in the past decade was the transition from manual to automatic transmission.[33] The operation of manual transmission vehicles continues to be a component in CDL training material.[34] As automation evolves, vehicle operator skills and training needs will change, so that, for instance, training in operation of a manual transmission truck will cease to be relevant whereas an understanding of the fundamentals of AVs and new technologies will become critical.

[31] See U.S. Department of Energy. Vehicle Weight Classes & Categories. Available at https://www.afdc.energy.gov/data/10380.

[32] Adaptive cruise control is a system that automatically controls the speed of the vehicle, adjusting the vehicle's speed to maintain a safe distance from the vehicle ahead of it.

[33] Trucking Industry Representative, Audio Interview, April 27, 2018.

[34] Because this transition to manual transmission remains ongoing, CDL driving instruction manuals continue to prepare drivers to use a vehicle with manual transmission and impose a restriction on drivers who do not take their test in a manual transmission truck. For instance, see "Restriction Code E" in the Michigan CDL manual. Michigan Commercial Driver License Manual (2015). Available at https://www.michigan.gov/documents/cdlmanul_16090_7.pdf.

When asked about how AVs could transform truck driving, many interviewees and focus group participants agreed that in the foreseeable future, AVs would supplement, rather than substitute vehicle operators, even at the highest levels of automation. The primary reason stated for this was a need to perform various non-driving functions that interviewees and focus group participants believed would not become automated. For instance, one focus group participant stated:

> *[T]he autonomous vehicle . . . can go from one point to [another], but to get to those locations you still [have to] have a driver . . . in our business model, we hook two 28-foot hooks. So you've still got to have a driver that hooks that set together.*[35]

Another focus group participant stated:

> *[For] any trucking company out there, their biggest liability is what happens to their product once it leaves their custody . . . that's where the driver comes in.*[36]

One interviewee made a similar comment, stating:

> *I don't see occupants disappearing from [freight] trucks, or even local urban delivery trucks completely. I personally believe that the companies that are operating these vehicles . . . want to safe guard the freight and . . . will want . . . a human there at all times*.[37]

However, whereas an "operator" may not disappear in a world of highly automated vehicles, the operator's skillset and duties are expected to change. Because the foremost change facing current truck drivers is the automation of the driving function, from this point on, we refer to the "driver" as an "operator," a term we believe encompasses a broader range of functions that becomes more important when the driving function is automated.

Tasks that all truck drivers presently perform might be broadly classified as those involved in driving and those related to vehicle and cargo maintenance.[38] The driving task includes following applicable traffic laws and reporting incidents encountered on the road. Vehicle and cargo maintenance tasks include reporting mechanical problems, keeping the truck clean and well maintained, and either securing (for freight trucking) or loading and unloading (for delivery drivers) cargo. Additional tasks specific to long-distance freight trucking include trailer inspection and maintaining a trip log using an electronic logging device.[39] Additional tasks specific to

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[35] Focus Group Participant, Texas, March 5, 2018.
[36] Focus Group Participant, Texas, March 5, 2018.
[37] Automotive Industry Representative, Audio Interview, May 2, 2018.
[38] See Bureau of Labor Statistics, Heavy and Tractor-trailer Truck Drivers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm; Bureau of Labor Statistics, Delivery Truck Drivers and Driver/Sales Workers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/delivery-truck-drivers-and-driver-sales-workers.htm.
[39] As of December 18, 2017, all drivers normally required to prepare hours-of-service records of duty status would be required to do so using electronic logging devices that synchronize with a vehicle engine to automatically record driving time. 49 CFR Parts 385, 386, 390, and 395. Available at https://www.gpo.gov/fdsys/pkg/FR-2015-12-16/pdf/2015-31336.pdf. See additionally, Federal Motor Carrier Safety Administration, Electronic Logging Devices. Available at https://www.fmcsa.dot.gov/hours-service/elds/electronic-logging-devices.

certain delivery drivers include communicating with and accepting payment from customers as well as handling paperwork associated with these interactions.

Advances in AV technology entail new skills that are relevant to driving and gradual handover of the driving task to the vehicle. In large part, due to the handover of the driving tasks, advances in AV technology also entail new skills associated with non-driving tasks like vehicle and cargo maintenance.

Currently, there is no specific BLS truck operator classification, in general, or, more specifically, in relation to AVs. Georgia Senate Bill No. 219, last revised 5/8/2017 and has since been enacted, defines 'operator' as "any person who drives or is in actual physical control of a motor vehicle or who causes a fully autonomous vehicle to move or travel with the automated driving system engaged" (Senate Bill 219, 2017). Similarly, California Senate Bill No. 3132, last amended on 2/16/2018, maintains "an 'operator' of an autonomous vehicle is the person who is seated in the driver's seat, or, if there is no person in the driver's seat, causes the autonomous technology to engage" (Senate Bill No. 3132, 2018).

Changes to Vehicle Operation Skills: Several interviewees indicated that AV systems will become more complex than those in operation today. While AVs will be largely self-functioning, vehicle operators will require greater knowledge and understanding as to what the systems are doing.[40] In particular, truck operators will need to have the ability to monitor software and hardware used to automate the driving function to ensure that they are functioning appropriately. They will also need to be familiar with advanced safety systems, how these systems interact with the driving environment, and how to make appropriate use of such systems to enhance operator safety.[41] Truck operators may also need to learn to perform more elaborate data entry tasks as they relate to trip scheduling or route planning.[42]

At minimum, future truck operators will need to understand "how the basic technology works so that they can understand [its] limitations."[43] For a level 2 or 3 vehicle, the driver or operator needs to be aware of driving scenarios that are difficult for the AV. For a level 4 vehicle, even though the operator does not perform the driving task, he or she must be aware of when it is appropriate to call for assistance. This awareness entails being able to understand enough about the technology to know when it is not working properly or effectively.

In contrast, in the future, truck operators may no longer need to retain certain driving related skills that are currently important. For example, large automated trucks may be able to efficiently back themselves into a loading bay, a difficult operation that large truck drivers are currently highly skilled at performing but may no longer need to perform in the future.[44]

[40] Transportation Agency Representative, Audio Interview, March 29, 2018.
[41] Trucking Industry Representative, Audio Interview, April 27, 2018.
[42] Transportation Agency Representative, Audio Interview, February 9, 2018. We note that data entry is already commonly required for long-distance freight trucking (See, for instance, O*NET OnLine, Summary Report for: 53-3032.00 - Heavy and Tractor-Trailer Truck Drivers. Available at https://www.onetonline.org/link/summary/53-3032.00.). However, new data entry skills might pertain to enhanced safety.
[43] Automotive Industry Representative, Audio Interview, May 2, 2018.
[44] Transportation Agency Representative, Audio Interview, February 9, 2018.

Changes to Non-Driving Skills: While automated truck operators do not necessarily need to become expert technicians, the proliferation of complicated equipment that a truck relies on to automate driving may require an operator to acquire new technical skills. Vehicle maintenance tasks may entail calibrating or maintaining certain equipment that is not presently found in trucks. As a trucking industry representative suggested, some understanding of the new technology is necessary to "know when to reboot [the automated system or component] and when to call somebody for help."[45]

Some interviewees suggested that future truck operators might need to possess a more diverse set of skills. One view was that truck operators might take on more technical or "specialist" roles related to maintaining the vehicle.[46] Another view was that by being relieved of the driving task, truck operators could "pick up other tasks such as logistics, planning, strategizing, or supervising the operation of the delivery of the product."[47] While interviewees did not view these additional roles as requirements for future truck operators, the view was that such additional skills would create opportunities for certain drivers to take on a higher cognitive workload and potentially raise the profile of drivers in the public eye.[48]

Table 2: Automated Truck Operation and Maintenance Skill Requirements

Task	Skill	Purpose
Driving	Comprehend and understand automation software and safety systems	Monitor vehicle and determine whether it is operating correctly while in motion. Know when to take over or call for assistance
Driving	Data entry	Trip scheduling and route planning and adjustment
Maintenance	Comprehend and understand automation hardware/software	Calibrate and/or maintain equipment used to perform the driving task
Logistics	Understand delivery, planning, and other logistics software	Logistics, planning, strategizing, or supervising operation and product delivery, possibly while driving

5.1.2. Educating Today's Truck Drivers and Tomorrow's Operators

At present, many truck drivers engage in a gradual process of continuous improvement and training that includes adapting to changes in automotive technology. For example, each year,

[45] Trucking Industry Representative, Audio Interview, 3:30PM EST, February 5, 2018.
[46] Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018.
[47] Automotive Industry Representative, Audio Interview, May 2, 2018.
[48] One interviewee stated "Truck drivers don't have the best reputations in terms of how society views [truck driving] as an occupation . . . That is going to erode a little because you are dealing with very sophisticated technology and equipment like LiDAR and radar." Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018.

American Trucking Associations (ATA), the largest national trade association in the U.S. trucking industry, hosts the National Truck Driving Championships (NTDC) for winners in eight classes of competition from 50 State Trucking Associations' Truck Driving Championships (TDC).[49] The NTDC and TDC competitions permit drivers to demonstrate driving and inspection skills, knowledge, and professionalism through a series of tests. These competitions, along with competitions hosted by individual truck companies, and training workshops for various trucking industry workers reinforce driver safety and knowledge.[50]

Thus, interviewed industry stakeholders emphasized that the training hurdle necessary for truck operators to become accustomed to operating an automated truck is expected to be relatively low.[51] Interviewees anticipate that truck driver education and training will evolve along two primary lines: (i) in-service training and (ii) certification and endorsements, including changes to CDL requirements.

In-Service Training: Trucking industry employers presently rely on in-service training, for new technology systems that are added to new or retro-fitted trucks, to improve driver skillsets.[52] Major firms that operate larger fleets and have more resources (e.g., top 250 fleets) tend to provide robust new driver training programs and additional in-service training that includes knowledge about new technology systems, such as "collision avoidance, safety or telematic systems used to improve driver awareness and information and the business process."[53] However, in-service training varies in quality across different trucking organizations, with smaller firms not consistently able to keep up with advances in technology.

Certification and Endorsements: Because it is difficult to maintain consistent standards of in-service training across trucking employers of different size, advances in automation may entail changes to standardized curricula. These changes could be supported by automotive manufacturers and their suppliers, who work with truck operation training programs, or through changes in CDL requirements.[54]

One possible approach that regulators may rely on as automotive technology levels advance over time is to provide an AV technology endorsement similar to the hazardous materials (HAZMAT) endorsement for drivers seeking to transport hazardous materials.[55] If standardized across states, such an endorsement could serve as a nationwide credential that a truck operator has the requisite skills to operate automated trucks, allowing the operator to seek employment in organizations operating fleets at different levels of automated technology.

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[49] American Trucking Associations. About National Truck Driving Championships. Available at http://www.trucking.org/Driving_Championships.aspx.
[50] Trucking Industry Representative, Audio Interview, April 27, 2018.
[51] For instance, one interviewee stated, "There are [many] technology functions that already exist on trucks . . . it would [not] take too much more training for current drivers . . . to go to a place where they can be endorsed to operate an automated vehicle." Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018.
[52] Trucking Industry Representative, Audio Interview, April 27, 2018.
[53] Trucking Industry Representative, Audio Interview, April 27, 2018.
[54] Trucking Industry Representative, Audio Interview, April 27, 2018.
[55] Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018.

5.1.3. How Automated Vehicles Will Change Trucking Jobs

As of May 2017, long-distance freight truck drivers and delivery drivers comprised respectively 1.23 and 0.92 percent of all workers in the United States.[56] As visualized in Figure 4 and observed in Table 9 in Appendix 9.3, displaying the number of drivers per U.S. state, for long-distance freight truck drivers, the percent of drivers ranges from 0.52 percent to 2.74 percent. Similarly, for delivery drivers, the percent of drivers ranges from 0.75 percent to 1.17 percent.[57]

If we ignore the potential ramification of advances in AV technology, using BLS data between 2010 and 2017, we project that the number of long-distance freight truck drivers and delivery drivers will grow by respectively 1.47 percent and 1.36 percent in the coming year. Figure 4 and Figure 5, along with Table 10 and Table 13 in Appendix 9.3, display these projections at the state level. Similarly, assuming a simple linear growth trend that ignores AV technology, Figure 6 and Figure 7 present the prospective numbers of long-distance freight truck and delivery driving jobs in the United States over the coming decade.

AV technology may alter the outlook for trucking jobs in two ways: (i) by changing the number of jobs available, and (ii) by altering the type of jobs that are available for current drivers and future operators.

Changes in the Number of Jobs: Using the approach detailed in Section 4, we estimated the prospective changes to the number of trucking jobs if AVs substitute rather than serve to supplement truck drivers. These estimates are also presented in Figure 6 and Figure 7 for, respectively, long-distance freight truck and delivery driving jobs in the United States. In each figure, the gray-colored curve below the light-blue colored linear trend line represents the counterfactual scenario in which automated trucks displace truck drivers. This counterfactual represents the median level of adoption of AV technology from our estimation. The orange- and yellow-colored trend lines represent the estimated counterfactuals in the event of low and high levels of AV technology adoption.[58]

Observe that as shown in Figure 6 and Figure 7, even in this “adjusted” counterfactual scenario in which automated trucks displace some drivers, compared to the linear trendline, in 2023, the total numbers of long-distance freight truck and delivery driving jobs fall from, respectively, 1.89 million to 1.86 million and from 1.40 million to 1.39 million. This represents a displacement of 35,000 jobs, or 1.8 percent of the total number of jobs in trucking in 2017. Similarly, in 2028, compared to the linear trendline, the total numbers of long-distance freight truck and delivery driving jobs fall from, respectively, 2.03 million to 1.57 million and from 1.50 million to 1.12 million. That is, in the adjusted counterfactual, in 2028, long-distance freight truck and delivery driving jobs would still be expected to make up respectively 0.96 and 0.69 percent of all jobs in the United States. Table 10 and Table 13 in Appendix 9.3 display the total number of projected jobs based on the linear trend and the adjusted counterfactual for 2023 and 2028 at the state level.

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[56] Bureau of Labor Statistics, Occupational Employment Statistics. Available at https://www.bls.gov/oes/.

[57] These ranges exclude the District of Columbia (DC).

[58] The orange- and yellow-colored lines represent the 5th and 95th percentile of adoption from the repeated estimations. These trend lines approximate the upper and lower bounds for a 90% confidence interval around the median level of adoption.

Figure 4: Long-Distance Freight Trucking Jobs per 1,000 and Growth (BLS 2010-17)

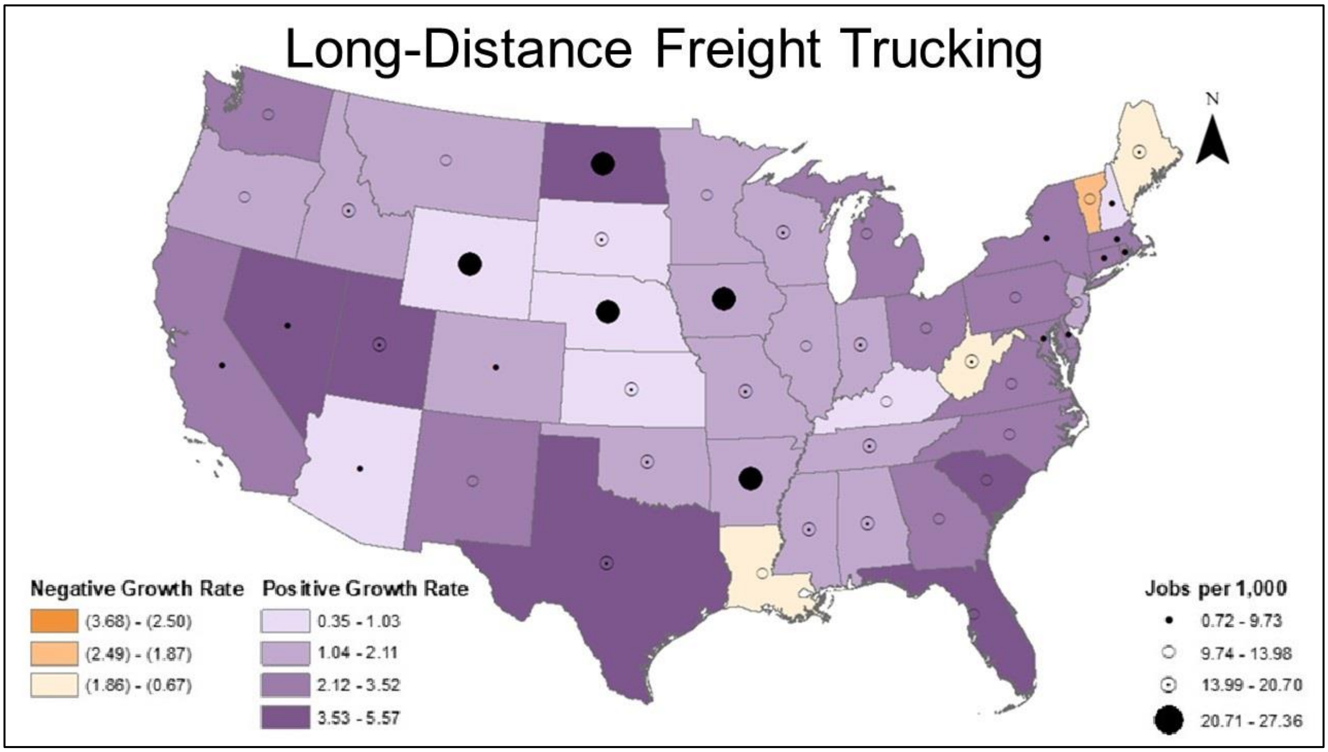


Figure 5: Delivery Driver Jobs per 1,000 and Growth (BLS 2010-17)

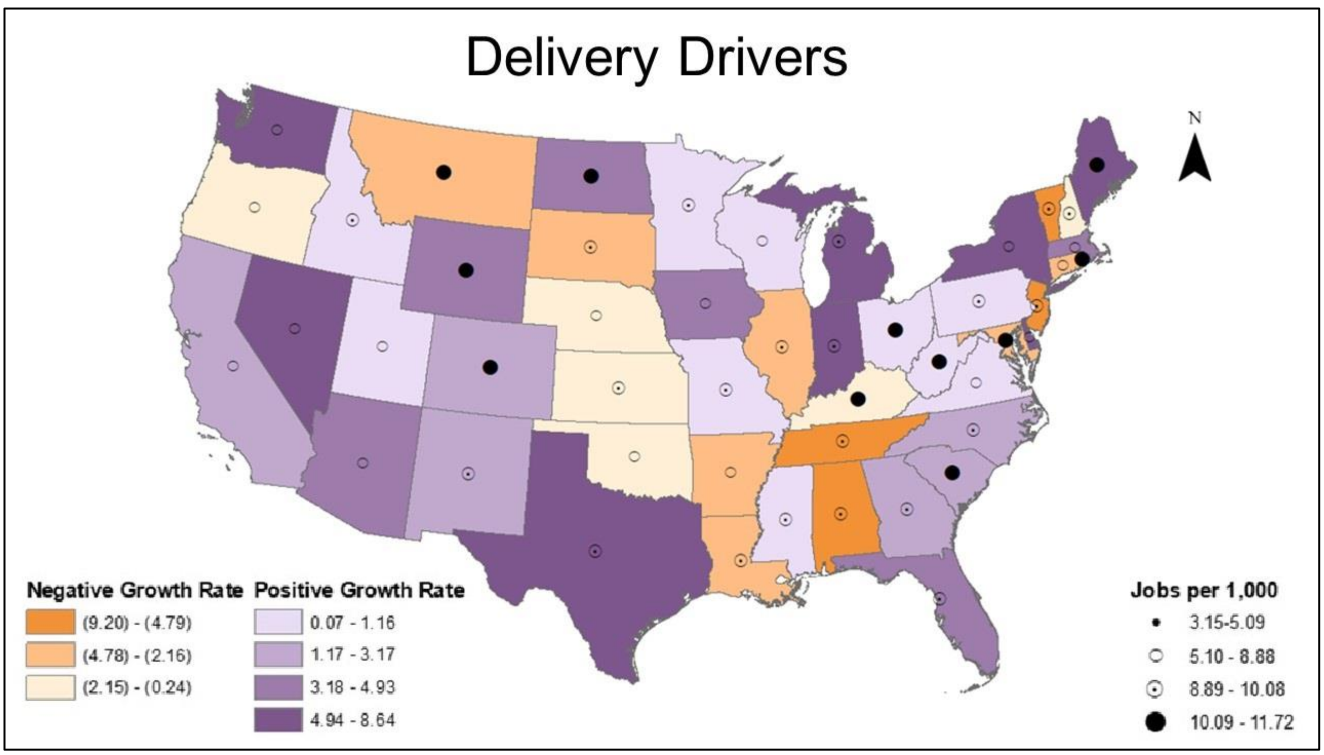
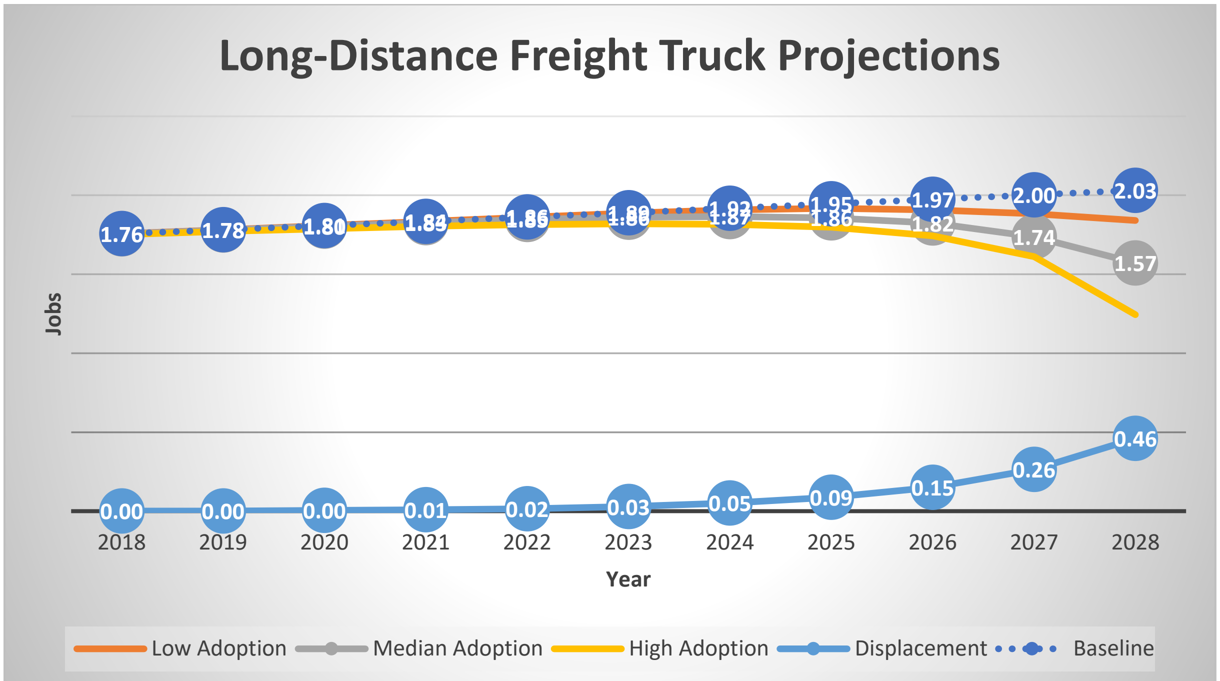
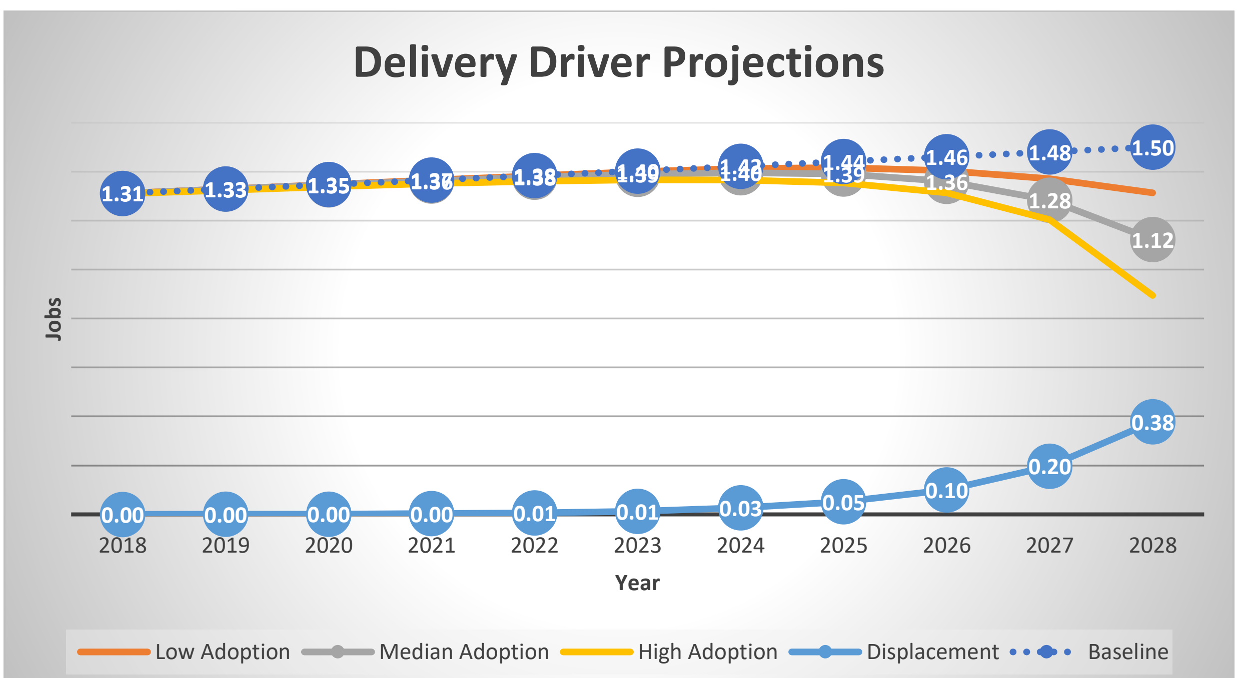


Figure 6: Long-Distance Freight Trucking Job Projections



We have indicated with a dashed line the scenario that we consider the most likely based on our qualitative results. Here, that scenario is the blue dashed line.

Figure 7: Delivery Driver Job Projections



We have indicated with a dashed line the scenario that we consider the most likely based on our qualitative results. Here, that scenario is the blue dashed line.

Our interviews and focus groups with industry stakeholders generally suggested that the simple linear projection (light-blue colored baseline in Figure 6 and Figure 7) is a more reasonable approximation of the numbers of truck driving jobs in the coming decade. This is, in part, because many interviewees and focus group participants believed that automated trucks are likely to supplement, rather than substitute, for existing truck drivers in the coming decade, and in part because there may be new opportunities for individuals who might otherwise be interested in employment in organizations that currently hire truck and delivery drivers.[59] As one interviewee put it:

> *[T]here [are] still, I think, plenty of opportunities for truck drivers, I hate to put a number out there, but probably for the next 20 to 30 years, anybody that wants to be a truck driver, I think there [will] be a job for [th]em."*[60]

As mentioned in Section 4, our projections are not based on estimates of supply and demand for different job categories. In discussing truck driving jobs, several interviewees pointed out that there is presently a shortage of drivers willing to enter the trucking industry at existing rates of pay. In 2015, focusing distinctly on long-distance freight truck drivers, American Trucking Associations (ATA) reported a 38,000 truck driver shortage that was forecast to increase to 47,500 the following year (Costello and Suarez, 2015), in part, because of the relatively high average age (49 years) of drivers compared to the average age (42 years) of other workers in the economy.[61] According to a more recent ATA report (Costello, 2017), in 2017 the "turnover" rate (e.g., people that left a specific trucking job) rose to 5% - however, Bob Costello (the chief-economist at ATA) explained that this figure reflects higher demand in the trucking industry (increased driver shortage) and that many of those drivers that left a specific fleet moved to another fleet for higher pay because of their experience and the lack of supply of drivers. From this same report, Costello suggests that from 2017 to 2026 the trucking industry will need an additional 897,500 drivers – 49% of that demand will be due to retirements, 23% will be due to drivers leaving the industry before retirement or because they were fired, and 28% of that demand will be due to industry growth (increasing shipping/transportation demands). This report, however, does not consider the role of AVs in these projections.

[59] We are hesitant to offer projections beyond 2028 because there are too many socioeconomic and technology-related factors that could alter the trucking landscape over the next decade that would require us to revisit, both, our baseline, and adjusted counterfactual scenarios.
[60] Transportation Agency Representative, Audio Interview, March 29, 2018.
[61] Bureau of Labor Statistics, Median age of the labor force, by sex, race and ethnicity. Available at https://www.bls.gov/emp/ep_table_306.htm. One interviewee noted that the average age of drivers is older (52 years) across privately owned fleets (Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018) and another suggested that it varies between the ages of 49 and 55 depending on the study (Trucking Industry Representative, Audio Interview, April 27, 2018). Certain interviewees and focus group participants pointed to industry efforts to lower the age at which CDL holders could drive vehicles across state lines from 21 to 18 in attempt to help resolve this shortage (e.g., Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018; Focus Group Participant, Texas, March 5, 2018).

As a trucking industry representative we interviewed noted:

> *… the changes that are coming in with new technology will not impact those workers before they retire.*[62]

As such, even if automated trucks do replace certain drivers, in the foreseeable future, such replacement may not lead to worker displacement, as fleet operators look to automated trucks to fulfill unmet transportation needs in the labor market.[63] Moreover, as one focus group participant suggested, filling unmet needs could entail further job creation:

> *[T]here is a shortage of drivers, and that [is] part of what is attractive for automation, for the logistics companies, is that they can fill some of their existing need. So, if we have [an] unmet need, one doesn't necessarily see a drop in the labor demand, but rather the opportunity to increase the amount of shipping, and with the increase of shipping, you . . . create other jobs related that support the increase in shipping.*[64]

A second participant in the same focus group concurred, stating:

> *[O]ur perspective is that we believe the drivers are going to be a part of the equation for a very long time . . . we believe that the technology is really there to assist the driver.*

We note that while AVs may fulfill unmet delivery needs and turn out to be beneficial to individual operators (and lead to myriad other desirable societal outcomes), our analysis suggests that they could also reduce pressure to raise wages to attract or retain truck drivers. This would be viewed as an additional benefit to parties seeking to have goods delivered and for certain fleet operators who see their costs reduced, but as a loss for drivers or truck operators whose wages may stagnate.

Additionally, while in the minority, some focus group participants were less optimistic about the future job prospects of truck drivers or the ability of industry stakeholders to attract prospective workers into truck driving. A focus group participant noted that:

> *[For] folks in their 40s and 50s that are using driving as a profession, I'm not necessarily sure that there is . . . a natural landing path for them . . . [W]e can try to change some of them to customer support jobs. We can try to retrain them for machine learning jobs but that's a difficult thing to do . . . I think there is this palpable fear in places like South Dakota and other places where truck driving and driving as a profession is the number one profession in these states . . . [N]ot a lot of people are thinking that they're going to put a machine learning center in Casper, Wyoming.*[65]

Another focus group participant stated:

> *If you look at commercial truck drivers, there used to be an aspiration to be a truck driver. You were a cowboy, you were managing yourself, you were not being filmed and micromanaged and having every breaking incident sent back to headquarters to check on you . . . I think that if we don't address the aspirational part of it, if we don't create a*

[62] Trucking Industry Representative, Audio Interview, April 27, 2018.
[63] Economic Development Agency Representative, Video Interview, April 3, 2018.
[64] Focus Group Participant, Michigan, April 12, 2018.
[65] Focus Group Participant, California, March 6, 2018.

> *sense that some of these jobs are aspirational and there is a reason why a self-respecting person would want to have them . . . that's a barrier that we face*.[66]

Nevertheless, even if the adjusted counterfactual were to transpire, as our projections indicate, at least over the next 10 years, relatively little—if any—job displacement is likely in trucking and delivery.

In our view, these projections serve as an important improvement over prior research seeking to understand how AVs will impact the workforce. Whereas previous studies (DOC, 2017; Stick Shift, 2017) identify the number of driving jobs that are "at risk" of displacement, our projections help to quantify the actual anticipated job displacement in the coming decade. A notable exception is the 2017 ITF study of freight truck driving, which estimates prospective new employee entry into truck driving (supply of drivers) using an age-based cohort analysis and demand for freight transportation to project employment over the coming decades. However, unlike our study, which systematically obtains interviewee predictions concerning AV technology uptake, the authors do not focus on an automated truck uptake scenario, leading to substantial variation in their estimated projections (including for the coming decade).

Changes in the Type of Jobs: Many interviewees and focus group participants believed that as AVs become more prevalent, they will create new opportunities for individuals in the trucking and delivery industries. Interviewees indicated that the capabilities of AV technology coupled with the need to resolve the driver shortage in long-distance freight trucking would necessitate a shift from long-distance interstate delivery to local delivery and logistics jobs. Interviewees also envisioned a new set of jobs related to remote monitoring of vehicles or vehicle fleets.

Interviewees expected that in the long run, long-distance delivery along certain routes could be performed without a driver in the truck. However, this would entail designating local drop-off points where large freight trucks could be unloaded and the deliverables placed into smaller trucks and vehicles that would include an operator (if not a driver) for local delivery.[67] A proliferation of such drop-off points would entail additional jobs related to local driving, cargo handling as well as logistics—determining where to route products in need of delivery. In particular, such a model would create greater opportunities for drivers for which a CDL is not required.[68] Additionally, as one interviewee suggested, a change from driving to logistic jobs could be beneficial to current driver health and job outlook:

> *[T]he jobs will change, and they'll be better and healthier jobs. But, there will be more jobs in freight logistics, rather than less, we think, over the foreseeable future.*
>
> *And, so the jobs picture is quite bright and positive and it's a good thing because the tremendous growing demand for freight movement, safe and effective freight movement, and yet, a shortfall of getting new workers to come into the industry. So, we're at an important transition point for the industry, for the logistics and freight industry as we try to*

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[66] Focus Group Participant, California, March 6, 2018.
[67] Trucking Industry Representative, Audio Interview, 3:30PM EST, February 5, 2018.
[68] Transportation Agency Representative, Audio Interview, February 9, 2018.

> *bring in a new generation of workers and improve the safety and efficiency of the overall system.*[69]

We caution that as we had discussed in Section 3, parallel improvements in automated technologies that are not associated with AVs might dissipate the need for additional cargo and freight agents, even as local freight centers grow in number (see Frey & Osborne, 2017; McKinsey 2017).[70] As a case in point, one interviewee pointed to potential future platform technologies like Uber Freight intended to "eliminate middlemen."[71] Such technology would have an ambiguous effect on job creation, possibly diminishing the need for localized logistics workers, but creating additional opportunities for entrepreneurial local delivery truck and vehicle operators.

Interviews and focus group participants also suggested that if an automated truck is driverless, there would nevertheless be a need to monitor a truck or fleet. Whereas the number of monitors per vehicle would not be expected to be one-to-one, monitors would be necessary to ensure that shipments are going to their destinations and, particularly in the near- to medium- term when AV technology remains relatively novel, that the vehicle is operating in accordance with specifications.[72] As focus group participants pointed out, monitoring involves different functions, including monitoring goods or monitoring diagnostic systems.[73]

As is detailed in the *Truck Platooning State of the Industry 2018* component of our larger report (see. p. 124), truck platooning also has the potential to impact the workforce. Truck platooning occurs when two or more commercial Class 8 heavy duty tractor-trailers travel in close proximity in formation through the use of various automated technologies. Presently, truck platooning deals with Level 1 automated systems; in the current systems drivers still need to be engaged in driving tasks. Benefits of truck platooning include fuel savings, enhanced mobility, reduced emissions, as well as reduced workload and stress of drivers. Given the early stage of truck platooning, there are not expected to be workforce impacts. If truck platooning advances to automated Levels 4 or 5 and platooning can be successfully commercialized, workforce impacts may occur. This is not likely to occur within the next five years at a minimum. See *Truck Platooning State of the Industry 2018* below for more details on truck platooning.

5.2. Passenger Transportation

While the outlook for trucking indicates relatively modest displacement in the adjusted counterfactual scenario in the foreseeable future, our findings concerning passenger transportation occupations indicate that a moderate to high amount of displacement is likely to

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[69] Trucking Industry Representative, Audio Interview, April 27, 2018.
[70] Moreover, as a focus group participant discussing aspirations to become a truck driver above suggests, long-distance drivers employed today may not be interested in local freight center jobs. Conversely, as various interviewees pointed out, the average long-distance driver employed today is in high demand in his or her current profession.
[71] Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018. Uber Freight is an app that matches carriers with shippers. See Uber Freight. Available at https://freight.uber.com/.
[72] Automotive Industry Representative, Audio Interview, May 2, 2018.
[73] Focus Group Participants, California, March 6, 2018.

occur over the coming decade.[74] This may be driven in part by the greater potential for these jobs to be automated; for instance, Frey & Osborne (2017) find that 89 percent of the tasks performed by taxi drivers and chauffeurs can be computerized (though for transit bus drivers, that number is a more modest 67 percent). This may also be due to existing business plans to transition to driverless AVs in these market segments. Nevertheless, interviewees and focus group participants indicated that there will continue to be a need for taxi drivers, chauffeurs, and bus drivers even with the introduction of AV technologies. Taxi drivers, chauffeurs, and bus drivers perform a number of non-driving tasks that are not necessarily automatable.

5.2.1. Taxi Drivers and Chauffeurs

During conversations with interviewees and focus group participants, we generally referred to occupations related to taxi driving and chauffeuring using the term "taxicabs/limousines," on occasion, separating the two terms, "taxicab" and "limousine." In our projections, we employ the BLS category "Taxi Drivers and Chauffeurs."[75] We note that our projections do not include the broader BLS category "Taxi Drivers, Ride-Hailing Drivers, and Chauffeurs," in which "ride-hailing drivers" are defined as those who pick up passengers who seek service through a smartphone app. BLS indicates that in this broader category, 1 in 4 drivers worked part time in 2016.[76]

According to BLS, as of May 2017, the median annual wages for taxi drivers and chauffeurs was $24,880, which is substantially lower than the median annual wage for all workers of $37,690 and is similar to the median annual wage of driver/sales workers, the lowest compensated of the truck driving categories discussed in Section 5.1.[77] There are no formal education requirements for taxi drivers and chauffeurs, though the majority of taxi and limousine companies provide new drivers with a short period of on-the-job training typically ranging from one day to two weeks. An executive at a passenger transportation company indicated that drivers in the company:

> *[S]pend about fifty hours in classroom and on the road training before they are allowed to do apprentice work, and then they spend another week doing apprentice work before they're actually driving clients.*[78]

All taxi drivers and chauffeurs must have a regular driver's license, though states and local municipalities may require taxi drivers and chauffeurs to obtain a taxi or limousine license. For

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[74] We acknowledge no separate federal data exists specifically on ride hailing/sharing jobs as of July 2018. Thus, our projections do not account for potential changes as a result of changes in ride hailing/sharing jobs due to AVs.

[75] Bureau of Labor Statistics, 53-3041 Taxi Drivers and Chauffeurs. Available at https://www.bls.gov/oes/current/oes533041.htm.

[76] Additionally, this broader category consisted of approximately 305 thousand jobs, compared to 189 thousand taxi drivers and chauffeurs (and 198 thousand in 2017). See Bureau of Labor Statistics, Taxi Drivers, Ride-Hailing Drivers, and Chauffeurs, https://www.bls.gov/ooh/transportation-and-material-moving/taxi-drivers-and-chauffeurs.htm#tab-1.

[77] Table 14 in Appendix 9.3 present the median wages for taxi drivers and chauffeurs at the state level. Bureau of Labor Statistics, Taxi Drivers, Ride-Hailing Drivers, and Chauffeurs. Available at https://www.bls.gov/ooh/transportation-and-material-moving/taxi-drivers-and-chauffeurs.htm#tab-1.

[78] Taxi and Limousine Industry Representative, Audio Interview, February 21, 2018.

instance, the New York City Taxi and Limousine Commission (TLC), which licenses and regulates over 50,000 vehicles sets rules for medallion taxicabs service, commuter van drivers, paratransit drivers, and other drivers who fall under its jurisdiction.[79] Additionally, the Federal Motor Carrier Safety Administration requires drivers who operate a vehicle designated to transport 16 or more passengers (including the driver) to obtain a CDL.[80]

How Automated Vehicles Will Change Taxi Driver and Chauffeur Jobs

As of May 2017, taxi drivers and chauffeurs comprise approximately 0.14 percent of all workers in the United States.[81] Figure 8, along with Table 14 in Appendix 9.3, presents the percentage of taxi drivers and chauffeurs per U.S. state. The percent of drivers ranges from 0.07 percent in Alabama to 0.82 percent in Nevada. When not taking into account potential AV technology advances, analysis of BLS data between 2010 and 2017 leads us to project that the number of taxi drivers and chauffeurs will grow 2.44 percent in the coming year. Figure 8, along with Table 15 in Appendix 9.3, displays these projections at the state level, while Figure 9 projects this trend for the U.S. in the coming decade.

Changes in the Number of Jobs: Employing the same methodology used to estimate an “adjusted” counterfactual in trucking, Figure 9 presents the adjusted counterfactual scenario, compared to the linear trendline for taxi drivers and chauffeurs. In the adjusted counterfactual, in 2023, the total numbers of taxi driver and chauffeur jobs fall from 225,000 to 222,000. This represents a displacement of 3,000 jobs, or 1.5 percent of the total number of taxi driver and chauffer jobs in 2017. In 2028, compared to the linear trendline, the total number of taxi driver and chauffeur jobs fall from 254,000 to 128,000. In other words, in the 2028 adjusted counterfactual scenario, taxi driver and chauffeur driving jobs would be expected to experience approximately 126,000 displaced jobs (49.6 percent) in the United States, a substantial job decline in the second half of the next decade due to the proliferation of AVs in this industry. Table 15 in Appendix 9.3, displays the total number of projected jobs based on the linear trend and the adjusted counterfactual for 2023 and 2028 at the state level.

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[79] NYC Taxi & Limousine Commission, TLC Rules and Local Laws. Available at http://www.nyc.gov/html/tlc/html/rules/rules.shtml.

[80] Federal Motor Carrier Safety Administration, Commercial Drivers License, Drivers. Available at https://www.fmcsa.dot.gov/registration/commercial-drivers-license/drivers.

[81] Bureau of Labor Statistics, Occupational Employment Statistics. Available at https://www.bls.gov/oes/.

Figure 8: Taxi Driver and Chauffeur Jobs per 1,000 and Growth (BLS 2010-17)

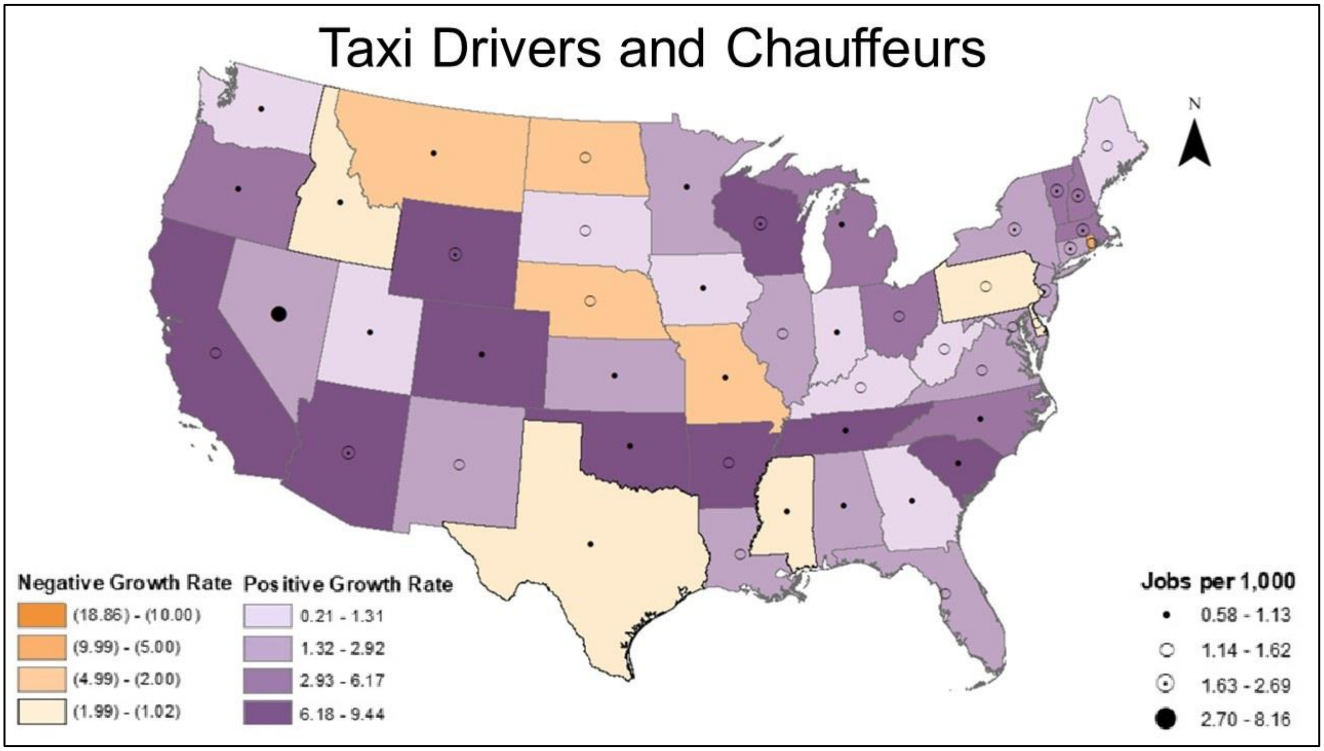
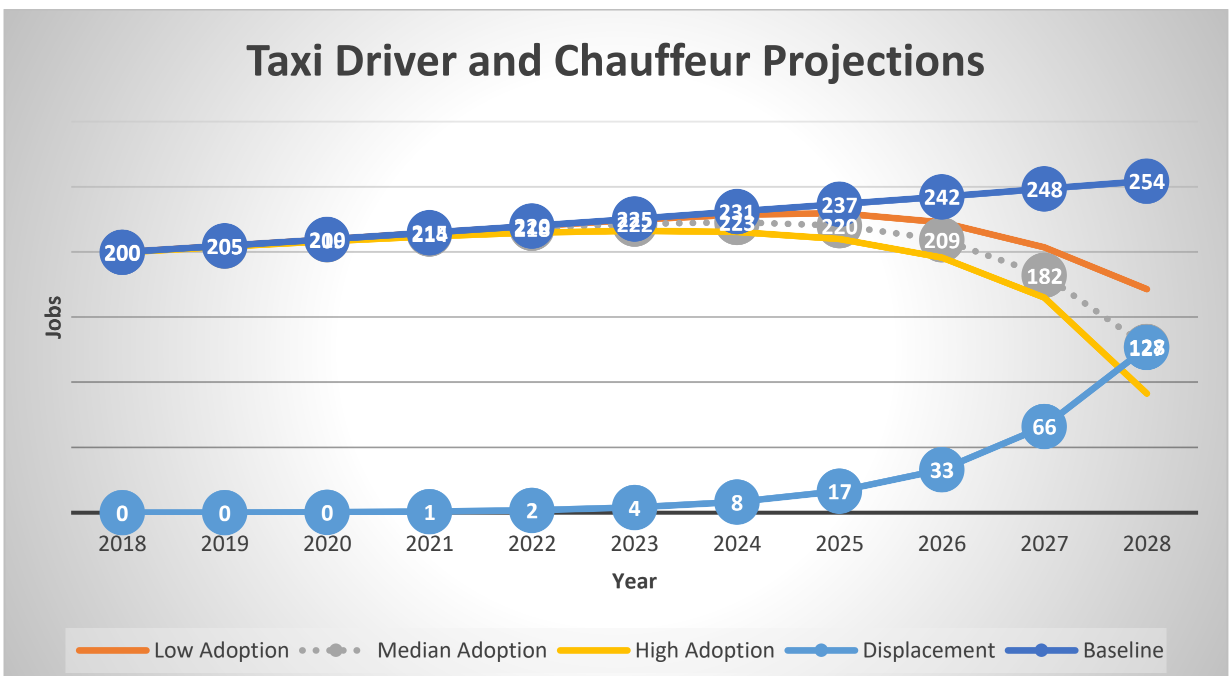


Figure 9: Taxi Driver and Chauffeur Job Projections



We have indicated with a dashed line the scenario that we consider the most likely for <u>taxi drivers</u> based on our qualitative results. Here, that scenario is the <u>gray dashed line</u>.

In contrast to our findings concerning trucking, many participants believed that AVs would displace, not supplement, taxi drivers and chauffeurs in the coming decade. For instance, in response to the moderator's inquiry as to whether an operator would remain in vehicles containing Level 4 or 5 automation, a representative of a major OEM stated:

> *[W]hen it comes to passenger vehicles, including taxi and fleet purposes, I was not envisioning a driver of a level four*.[82]

The interviewee's follow up differed when it came to trucking, suggesting that "there are many other duties that that driver has to worry about." Responding to the same question, another interviewee stated, "Certainly that is the vision of a couple of companies that are working on the technology," following up by saying:

> *I think it will be first deployed at low speed and in very well defined geographic, geo-fenced areas. So, yes, I do see that one happening. And maybe even [in] the relatively short term, with these specialized L4 vehicles that are designed to carry passengers at low speed in dense urban areas*.[83]

Another automotive industry representative put it more bluntly, saying:

> *I see the [taxi] driver being completely displaced. Otherwise it doesn't make economic sense to throw a lot of automation and then still have a driver.*[84]

Nor was this viewpoint limited to participants in the automotive industry. An interviewee specializing in economic development stated:

> *I think [ride-share drivers] have a high likelihood of getting displaced, as well as your taxi drivers.*[85]

The minority view came from the passenger transportation industry, with an interviewee pointing out that as with trucks, taxi drivers and chauffeurs perform specific job-related tasks that cannot necessarily be performed by an AV. The interviewee stated:

> *It's the customer service aspect to [being a chauffeur]; one of the components of our service is the word 'service' and the other word 'experience' . . . you commoditize the service that you're offering if . . . you can just send a device to pick somebody up and take them. Some people want that, but generally not my customer. They're looking for a professional service. Their door's opened and closed for them. A clean vehicle. It's one of the things that's always bugged me about the autonomous vehicle, is who cleans the vehicle after each trip?*[86]

The interviewee went on to point out the importance of non-diving tasks for chauffeurs:

> *Simple things are basically what need to be thought about. We're in a flu epidemic, so you know when people get out of the car we have to wipe it down and kind of sanitize the space because passing along germs, so you think about even that component. So,*

[82] Automotive Industry Representative, Audio Interview, April 4, 2018.
[83] Automotive Industry Representative, Audio Interview, May 2, 2018.
[84] Automotive Industry Representative, Audio Interview, March 1, 2018.
[85] Economic Development Agency Representative, Video Interview, April 3, 2018.
[86] Taxi and Limousine Industry Representative, Audio Interview, February 21, 2018.

the people component, I'm not sure a hundred percent goes away until we solve some of those issues.

BLS's Occupational Outlook supports the interviewee's assertion that customer-service skills are important for taxi drivers and chauffeurs. Specifically, BLS points out that taxi drivers and chauffeurs regularly interact with their customers and have to represent their company positively and ensure passenger satisfaction with their ride.[87]

The interviewee also pointed out those services provided by a human driver versus an AV:

> *A wheelchair vehicle or just a regular taxi that goes to somebody's house because they can't get to a bus stop—those are more individualized services that the drivers are more willing and capable of providing: specialized services instead of just the group transit or group transportation.*

Thus, at least for certain categories of service (i.e., luxury and paratransit), automated vehicles may not displace drivers in the foreseeable future. Additionally, the financial impact of the overall displacement may be mitigated by the fact that, at least for ride-share services, the driver's job may be an avocation for some workers and not their primary source of income. An interviewee pointed out that ride-share service jobs provide supplemental income to drivers. We note that this is not likely the case for all ride-share drivers.

> *So it just strikes me as interesting the different postures, for example Lyft and Uber take, because they are back and forth about benefits to drivers. This is a second mode of income, this is, you know, you can tip, you can do other things. In fact, competition between the two companies involves that.*[88]

However, as we point out above, our projections above do not include ride-share (or ride-hailing) services.[89]

5.2.2. Transit Bus Drivers

In our discussion with interviewees and focus group participants, we generally spoke about "transit circulators" rather than buses and bus driving in general. As such, in undertaking projections, we rely on BLS occupation category "Bus Drivers, Transit and Intercity"[90] rather

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[87] Bureau of Labor Statistics, Taxi Drivers, Ride-Hailing Drivers, and Chauffeurs. Available at https://www.bls.gov/ooh/transportation-and-material-moving/taxi-drivers-and-chauffeurs.htm#tab-4.
[88] Focus Group Participant, California, March 6, 2018.
[89] Additionally, we do not know what proportion of the roughly 1 in 4 drivers who work part time belong to the ride share category, and what proportion consists of other taxi drivers and chauffeurs. However, we believe that part-time drivers belong predominantly to the ride-sharing category. For example, as Hall and Kreuger (2015) find using a survey of Uber's driver partners completed in 2014, fully 80 percent of driver-partners indicated that they were working full- or part-time hours just before they started driving on the Uber platform, with two-thirds reporting working a full-time job. Hall and Kreuger additionally report that 61 percent of driver-partners held a full- or part-time job.
[90] Bureau of Labor Statistics, 53-3021 Bus Drivers, Transit and Intercity. Available at https://www.bls.gov/oes/current/oes533021.htm.

than the broader “Bus Driver” category.[91] The broader categorization additionally includes school and special client bus drivers, a group that in 2017 consisted of more than 500,000 employees, the bulk of the more than 680,000 employees that make up the “Bus Driver” category. Our decision to exclude school and special client bus drivers was driven largely by time limitations, though we do believe that because a substantial fraction of such drivers (at least 40 percent) serves the additional role of monitoring elementary and secondary school students, there are certain practical limitations to the extent that, at least, school bus drivers can be displaced by automated vehicles.

According to BLS, bus drivers must have a commercial driver’s license (CDL) with a passenger (P) endorsement.[92] The CDL can sometimes be earned during on-the-job training. In addition, bus drivers must possess a clean driving record and frequently may be required to pass a background check and meet physical, hearing and vision requirements (see also Table 5 in Appendix 9.1). Bus drivers that do not already have a CDL typically undertake 1 to 3 months of training. The annual median income for a transit bus driver was $43,290 in 2017, which is comparable to long-distance freight truck drivers, who also require a CDL to operate.[93]

How Automated Vehicles Will Change Bus Driving Jobs

As of May 2017, transit bus drivers compose approximately 0.12 percent of all workers in the United States.[94] Figure 10, along with Table 16 in Appendix 9.3, presents the percentage of transit bus drivers per U.S. state. The percent of drivers ranges from 0.02 percent in Rhode Island to 0.37 percent in Hawaii. Using BLS data between 2010 and 2017, we project that the number of transit bus drivers will shrink by 0.40 percent in the coming year. Figure 10, along with Table 17 in Appendix 9.3, displays these projections at the state level, while Figure 11 projects this trend for the U.S. in the coming decade.

Changes in the Number of Jobs: Employing the estimation approach used for our previous “adjusted” counterfactuals, Figure 11 presents the adjusted counterfactual scenario, compared to the linear trendline for transit bus drivers. In the adjusted counterfactual, in 2023, the total numbers of transit bus driver jobs fall from 174,000 to 170,000. This represents a displacement of approximately 4 thousand jobs, or 2.2 percent of the total number of transit bus driver jobs in 2017. In 2028, compared to the linear trendline, the total number of transit bus driver jobs fall from 170,000 to 118,000, a displacement of 52,000 jobs (or 30.6 percent). While not as great an absolute or percentage difference as was the case with taxi driver and chauffeur driving jobs, in percentage terms, this nevertheless represents a substantially more sizeable decline than in either trucking category. Table 17 in Appendix 9.3, displays the total number of projected jobs based on the linear trend and the adjusted counterfactual for 2023 and 2028 at the state level.

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91 Bureau of Labor Statistics, Bus Drivers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/bus-drivers.htm.

92 Bureau of Labor Statistics, Bus Drivers. Available at https://www.bls.gov/ooh/transportation-and-material-moving/bus-drivers.htm#tab-1

93 Table 16 in Appendix 9.3 presents the median wages for transit bus drivers at the state level.

94 Bureau of Labor Statistics, Occupational Employment Statistics. Available at https://www.bls.gov/oes/.

Figure 10: Transit Bus Driver Jobs per 1,000 and Growth (BLS 2010-17)

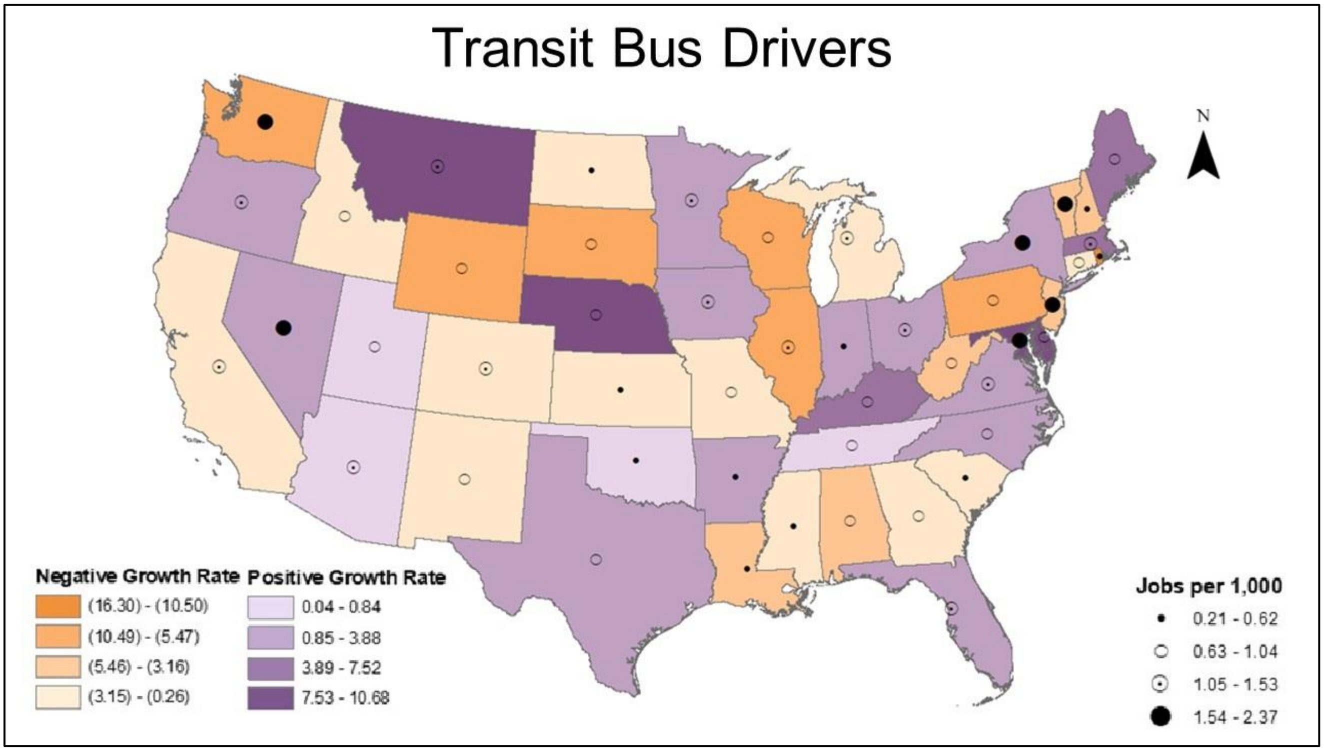
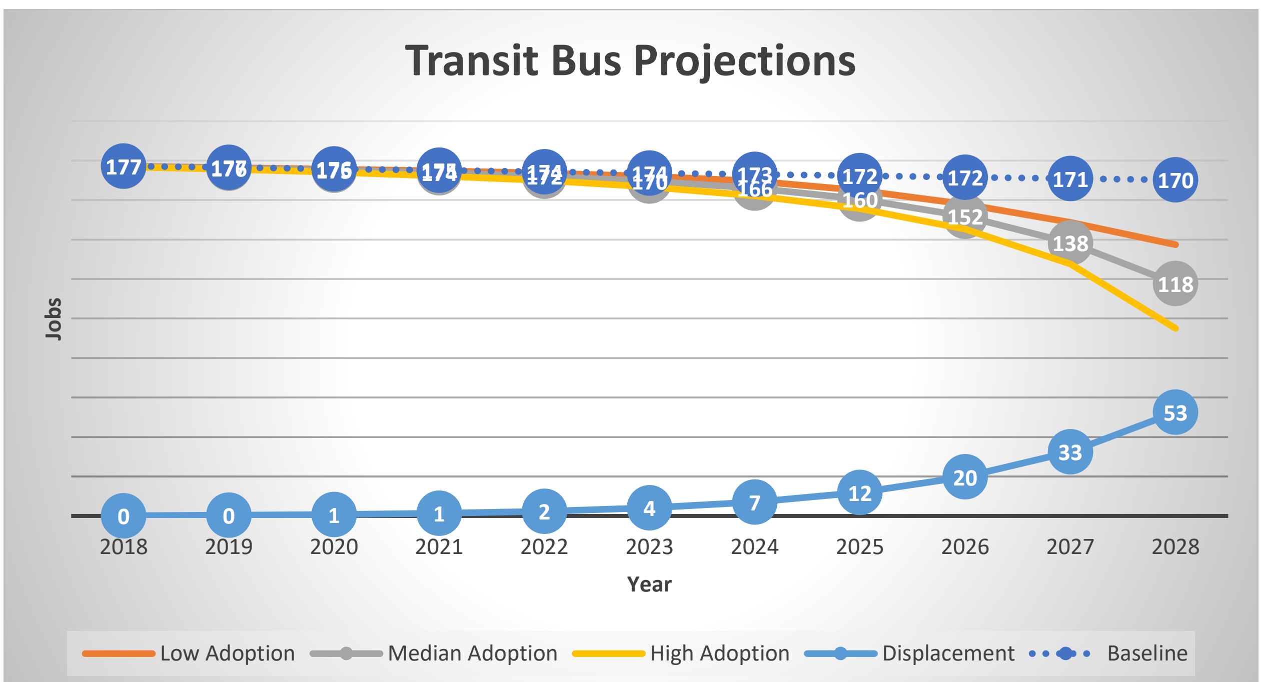


Figure 11: Transit Bus Driver Job Projections



We have indicated with a dashed line the scenario that we consider the most likely based on our qualitative results. Here, that scenario is the <u>blue dashed line</u>.

Though interviewee predictions suggested substantial uptake of automated buses in the coming decade (which guided our projections), many interviewees and focus group participants believed that an individual would continue to occupy an automated bus.[95] The general consensus was that a bus "operator's" duties would change as a result of automated buses. As one interviewee stated:

> *I can, I could see instead of a bus driver, there's a bus ambassador, right.*[96]

The interviewee further noted that:

> *I do think there's opportunities for a different type of person on board. I think the ability for somebody to assist with transit, that again, isn't driving the bus, but assist the person that maybe has limited mobility.*

An interviewee quoted previously as not envisioning a driver in automated taxicabs also stated:

> *When it comes to commercial vehicles, including city buses, I was envisioning a driver or a logistics manager, or a service manager, or whatever you want to call that person sitting at the front.*[97]

A focus group participant pointed out:

> *There's a lot of the bus driver, the person driving the bus is responsible for a lot more things on the bus than just driving the thing down the road, right? Like, they're dealing with fare collection and then specifically, all the [Americans with Disabilities Act] requirements, so there's a lot of federal requirements about vehicles being accessible and then, securing wheel chairs and providing accommodation and things like that.*[98]

Other participants and interviewees expanded upon the notion of a bus ambassador:

> *I think with public transit, you could probably get away from the person driving the vehicle faster than you could getting away from still having a person on the bus dealing with all the various passenger issues and things.*[99]
>
> *The difference being that when you look at [who] some of the users of public transit are, you might still see a need and demand to have a human on that bus . . . even on the higher autonomous vehicles.*
>
> *But you know, your bus driver may be, the skillset needed there may evolve from driving skills to more of customer service and assistance skills.*[100]

A potential barrier for the adoption of automated buses (that influenced the interviewees' prediction for the uptake of AV technology in this context) are the fiscal resources of a city or municipality. As an interviewee pointed out:

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[95] Neither interviewees nor focus group participants were provided information on our projections. Our discussions with them occurred prior to and helped to inform the projections.
[96] Transportation Agency Representative, Audio Interview, March 29, 2018.
[97] Automotive Industry Representative, Audio Interview, April 4, 2018.
[98] Focus Group Participant, Texas, March 5, 2018.
[99] Focus Group Participant, Texas, March 5, 2018.
[100] Economic Development Agency Representative, Video Interview, April 3, 2018.

Frankly what's driving my pessimism in [the public transit market] is the funding available to cities and States and counties at the moment . . . [L]ooking over the last five or 10 years, public funding for those kind of fleet transitions is getting lower and lower and lower. [These] are going to be extremely expensive vehicles and I don't think any city has the resources to just kind of transition completely.[101]

Conversely, a different interviewee mentioned that there are currently automated transit buses in operation:

Well there, I know that they're happening right now on the [Location Redacted]. Where it gets to be widespread adoption, we have a company that just opened and it's a couple of miles away from me that is actually producing the autonomous buses. So, for campus and low-speed shuttle operation with a pass- or with a driver.[102]

Another interviewee who happened to mention the same automated bus operation believed that in such instances, automated buses would indeed be driverless, justifying this belief by stating that "those vehicles operate on very fixed routes."[103] Yet a third interviewee suggested that there were already a number of pilot projects in the automated bus area, lauding their potential to reduce traffic congestion. Similarly, in contrast to a view that automated trucks will be used to resolve a labor shortage rather than to displace drivers, an interviewee said about other vehicle categories discussed in Section 5, "once you're hitting level four, level five autonomy . . . you're not going to have a driver."[104]

Thus, while our discussions with interviewees and the ensuing projections suggest that the outlook for transit bus drivers is not quite as bleak as it is for taxi drivers, we do believe that there is a greater likelihood that our adjusted counterfactual scenario projection may apply to bus drivers as opposed to truck drivers. Moreover, in any event, the duties of a transit bus driver are expected to change from a focus on driving to non-driving responsibilities. Comments from our participants suggest that bus drivers who remain bus operators once automated buses emerge will become bus ambassadors or guides who provide essential customer service and assistance to passengers.

5.3. Other Jobs

In most of our interviews concerning jobs that rely on a vehicle, our goal was to foster a better understanding of the impacts of AVs on jobs that prior research has indicated as facing the greatest risk of displacement.[105] However, in addition to jobs involving delivery and passenger

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[101] Automotive Industry Representative, Audio Interview, April 4, 2018.
[102] Taxi and Limousine Industry Representative, Audio Interview, February 21, 2018.
[103] Automotive Industry Representative, Audio Interview, May 2, 2018.
[104] Insurance Industry Representative, Audio Interview, February 26, 2018.
[105] For instance, Sections 5.1 and 5.2 cover five of seven categories classified as motor vehicle operators by the 2017 DOC Report and comprise approximately 3.4 million of the 3.9 million jobs in these categories. The bulk of the remainder consists of approximately half a million workers classified as School or Special Client Bus Drivers (including approximately 211 thousand elementary and secondary school bus drivers). Due to limitations on time and funding, we did not speak to any interviewees who could substantively inform us concerning this area.

transportation, myriad other jobs include a vehicle as an integral component.[106] These jobs cross numerous industries and trades, for instance, construction, emergency response, farming, forestry, manufacturing, waste disposal, and numerous others. Even though jobs in these fields appear to us as having a lower likelihood of ultimately becoming displaced by AVs, AVs will likely supplement the capabilities of workers and require workers to acquire new skills.

In this section, we briefly expound on our findings from interviews with professionals in emergency response and the U.S. military, who also have substantial expertise in AVs. Although we caution readers from attempting to generalize from these interviews, we nevertheless believe that these interviews yielded important insights about the impact of AVs on a large part of the U.S. workforce.

5.3.1. Emergency Response

The emergency response workforce consists of several professions focused on maintaining public health and safety by responding to emergencies. In 2017, there were almost 1.5 million U.S. workers involved in emergency response, including 15,000 ambulance drivers and attendants, 252,000 emergency medical technicians and paramedics, 320,000 firefighters, 662,000 police and sheriff's patrol officers, and 43,000 hazardous materials removal workers.[107] To perform their jobs, these workers rely on a vast array of vehicles, including two-wheeled vehicles like bicycles, motorcycles and Segways; various sized sedans and sport utility vehicles; and large vehicles like fire engines, whose operation is similar to that of commercial trucks.

Our interviewee indicated that AV technology would likely yield tremendous benefits to worker safety, but would likely not lead to much, if any, workforce displacement over the coming decade. Specifically, the interviewee stated:

> *[Y]ou asked me 'where are we going to be 5 years from now and 10 years from now with [regard to AVs]?' I believe the things that are safety feature oriented only, braking systems, airbags, windshields, . . ., things like that, that will be light years ahead. But as far as the control of the vehicle . . . [being] more autonomous, I don't see that really being . . . implemented . . . the driver's always going to have to drive . . .*
>
> *[The drivers] have to be aware of the totality of circumstances, . . . I mean, you're going into a hostile environment . . . that's not going to be consistent. It's never going to be consistent. And when the officer or the firefighter or whoever [is] in the vehicle sees . . . the threat, whatever it might be, [the individual has to] be able to redirect that vehicle*.[108]

Some of the reasons the interviewee provided for the continued necessity of manual vehicle operation are:

- Emergency response personnel occasionally need to cross medians and travel in the wrong lane of traffic. They must also use their best judgement with regard to when to ignore traffic lights.

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[106] For instance, as we discuss in Section 3, approximately 11.7 million jobs identified by the 2017 DOC Report involve driving as an important, but not primary, component.
[107] Our sum total includes first line supervisors.
[108] Emergency Response Vehicle Expert, Video Interview, April 6, 2018.

- Emergency response vehicles are more prone to encounter situations in which sensors used in autonomous operation are obscured (e.g., by dirt).
- Firefighters need to locate the nearest hydrant to top-off after releasing water at a fire to prevent the remaining water in the engine from shifting around while driving.
- Patrol vehicles must not establish easily verifiable patrol patterns to deter criminals. Additionally, empty, automated patrol vehicles in high crime areas are likely to be vandalized or encounter attempted theft. Conversely, occupied, automated patrol vehicles may lead to driver fatigue due to boredom (i.e., patrolling officer may fall asleep).
- If self-driving, vehicles responding to a crime scene or other emergency may not stop at a location deemed safe or optimal by the vehicle occupant.
- Police officers may need to intentionally crash their vehicle during a pursuit or other emergency.

The interviewee also suggested a few ways in which AVs could assist in emergency response:

- Automated vehicle and more generally “smart car” technology could reduce the number of different systems (e.g., radio, siren, lights, video recording camera, navigation) that an operator needs to be familiar with.
- Automated vehicles could reduce accidents and manpower related to backing up large vehicles like fire engines by automating this function.
- Automated vehicles can improve operator capabilities to access and operate in tight spaces because of better depth perception than that of a human driver.

Despite the potential foreseeable benefits permitted by AVs, there were two hurdles that our interviewee emphasized, one related to vehicle customization, the other concerning training. Emerging innovations in AV technology are mostly focused on the average vehicle, but emergency response departments tend to modify vehicles to suit their specialized needs, which includes, in certain circumstances, overriding safety features. As AV technology becomes more sophisticated, it will become increasingly important for emergency response departments to either work with manufacturers or better train their technicians to enable emergency responders to achieve the desired degree of customization.

The interviewee indicated that “driver training is very inconsistent across the U.S.” Even in the case of fire response, in which the National Fire Protection Association (NFPA) sets consensus standards, because many responders are volunteers, inconsistencies in training are prevalent.[109] An additional hurdle in training is due to the fact that unlike many other drivers, emergency response personnel may need to rotate across various different vehicles with varying levels of technologies. This means that until vehicles that are reliant on an older set of technologies completely fall out of a fleet, drivers who work with that fleet must have operational knowledge of the older, less automated set of technologies. The length of time that this takes

[109] NFPA is a global nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. NFPA delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy. See National Fire Protection Association. About NFPA. Available at https://www.nfpa.org/About-NFPA.

depends on the department, with emergency response departments in less affluent areas likely facing slower vehicle rotation timeframes.

5.3.2. United States Military

The members of the U.S. military work in occupations that are military specific and those that exist in the civilian workplace.[110] In February 2017, BLS estimates indicated that the U.S. military consisted of over 1 million active duty enlisted personnel and more than 233,000 active duty officers.[111] Similar to emergency response personnel, members of the military rely on a variety of ground vehicles that hold varying numbers of personnel or cargo. The military includes transportation vehicles such as the Humvee and larger personnel carriers, fighting vehicles such as the Bradley Fighting Vehicle and self-propelled artillery, as well as myriad cargo carrying vehicles, including tractor-trailers.

As was the case with emergency response, our interviewee did not anticipate that AVs would lead to a declining need for active duty personnel, stressing instead the potential for AVs to enhance the efficacy of various military functions. A core reason for this is the military's need to deal with unstructured environments. As the interviewee pointed out, in such environments:

> *[Personnel are] creating [their] own routes, [they are] not trying to follow a preordained route . . . A priori information does not necessarily guide . . . decision making as much as it does if [one is] following a road network that's established*.[112]

Instead, the interviewee indicated that AVs have the potential to "augment human performance" and that an important task for the military was to understand how to do so without burdening personnel, either "physically or cognitively." The interviewee indicated that in the army, for every individual in a combat or other interpersonal role (e.g., meeting with local leaders and networking with locals, collecting intelligence, etc.), there were approximately three supporting individuals. The goal for AVs in the military would be to augment personnel capabilities to reduce the latter number, allowing active duty personnel to better focus on primary, as opposed to supporting, roles.[113]

At the time of our interview, one area in which the military was actively testing AV technology was in cargo transportation, whereby trucks would be divided into leading trucks occupied by a

[110] BLS classifies active duty enlisted personnel according to broad occupational group and branch of the military. See Bureau of Labor Statistics, Military Careers, What They Do. Available at https://www.bls.gov/ooh/military/military-careers.htm#tab-2.

[111] Enlisted personnel make up about 82 percent of the Armed Forces and carry out military operations, whereas officers manage operations and enlist personnel. Active members of the military serve in the Army, Navy, Air Force, Marine Corps, or Coast Guard. In 2018, Congress authorized active duty strengths of 483,500 for the Army, 327,900 for the Navy, 186,000 for the Marine Corps, and 325,100 for the Air Force. See H.R.2810 - National Defense Authorization Act for Fiscal Year 2018. Available at https://www.congress.gov/bill/115th-congress/house-bill/2810.

[112] Military Vehicle Expert, Audio Interview, February 13, 2018.

[113] We note that, if successful, we envision that such augmentation could lead the U.S. military to step up its activities worldwide, to reduce the number of active personnel relative to a counterfactual without AVs, or both. However, we note that the interviewee hesitated to state that the military could "do as much with fewer people."

human as well as unoccupied follower trucks.[114] Although this could potentially reduce the need for personnel associated with transportation, important questions that remain to be addressed concerned maintenance, sustainment and repair of unoccupied trucks, particularly if transitioned from an uncontested environment (for testing), to a contested one in which security becomes an issue. The interviewee stated that “at that point you may have soldiers in the vehicle for protection of the vehicle, as opposed to the driving function.”

[114] See *Truck Platooning State of the Industry 2018,* at the end of this report for more details on truck platooning and potential impacts.

6. (Non-Driving) Jobs That Automated Vehicles Will Change

6.1. How Automated Vehicles Will Affect Technology Jobs

At present, well over 100,000 individuals in the U.S. motor vehicle industry work in technology occupations. Globally, the motor vehicle industry spends approximately 98.2 billion U.S. dollars on research and development.[115] As our discussions with experts and stakeholders in the industry indicate, over the next decade, a great deal of this R&D spending and future R&D growth will be associated with automated vehicles. Moreover, technology related jobs associated with AVs are not limited to the motor vehicle industry, with numerous startups and large technology companies like Apple, Alphabet Inc. (Waymo), and Intel investing in research and hiring technology workers to participate in the market for automated vehicles.[116]

Participants suggested that jobs in the technology industry will continue to increase—specifically, they discussed, among other occupations, those in engineering, cybersecurity, robotics, data science/machine learning, social science, and hybrid technicians. In particular, participants indicated that companies in the AV domain have a high demand for cybersecurity, data analytics, and engineering occupations.

Throughout our interviews and focus group discussions, we asked interviewees a variety of questions concerning skillsets required to design and manufacture AVs and related components.[117] We recorded over 30 different job titles or phrases related to occupations in the technology fields.[118] As Table 6 in Appendix 9.2 shows, these job titles and phrases correspond to 18 BLS-based (O*Net) technology occupations.[119] Table 7 in Appendix 9.2 indicates that for the U.S. motor-vehicle industry alone, in 2017, these occupations comprise approximately

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115 Statista, the Statistics Portal. Estimated global automotive research and development spending from 2014 to 2017 (in billion U.S. dollars). Available at https://www.statista.com/statistics/566098/research-development-spending-automotive-industry-worldwide/.

116 Stewart, T. (2017). 263 Self-Driving Car Startups to Watch. Available at https://blog.cometlabs.io/263-self-driving-car-startups-to-watch-8a9976dc62b0; Marsden, D. (2017). The Competitive Landscape for Automated Driving Systems: Major Players, Partners & Acquisitions. Available at https://www.slideshare.net/slideshow/embed_code/key/g1gUuJuoW48GMc.

117 A question of particular interest was: "We would like to discuss the skillsets necessary for automobile component manufacturing? To be more specific, can you discuss the functions, skills, and education levels for employees in the following roles in your organization . . ." following which we offered the interviewee the option to suggest and discuss different roles or guided the interviewee through a set of generic job categories that we had decided on based on prior research.

118 The phrases are, in alphabetical order: Analysts; AV Engineers and Testers; Computer Engineers; Computer Numerical Controlled (CNC) Operator; computer science; Control Systems Engineers; cybersecurity; Data Analysts; Design (e.g., interior of cars); Design Engineers; DSRC Engineers; Electrical Engineers; Emissions; Engineers; Hardware Engineers; IT; IT infrastructure; machine learning/big data/AI; manufacturing; materials engineer; mechanical, electrical; Product Planners; Programmers; Researchers; Robotics; signal processing; Software Engineers; Systems Engineer; Technicians; Test Drivers; Tool and Die Operators; UX, AI, certification, emissions, advanced design; work on sensors, radar, and AVs.

119 For each job title or phrase, we used BLS and O*Net job descriptions to associate an appropriate 5- or 6-digit Occupation Code. For instance, we associated the term "Systems Engineer" to Occupation Codes 15-1199 and 17-2141. For concision, in Table 6, except in the case of Commercial and Industrial Designers, we aggregate all 6-digit Occupation Codes to 5-digit codes (i.e., 15-1190 and 17-2140 for Systems Engineers).

118,000 workers.[120] In the motor vehicle industry, the median income for these occupations was $62,763, ranging from approximately $37,000 for Computer Control Programmers and Operators to more than $100,000 for Computer Hardware Engineers and Computer and Information Systems Managers.[121]

Table 8 in Appendix 9.2 corresponds to Table 7, but for the U.S. as a whole. According to Table 8, there were approximately 5.5 million technology workers in the U.S. associated with participant job titles or phrases. For the U.S., the median income for workers in these technology occupations was $86,439, ranging from approximately $41,000 for Computer Control Programmers and Operators to $139,000 for Computer and Information Systems Managers. Thus, on average, U.S. technology workers earn more than their counterparts in the motor vehicle industry and are much more highly compensated than workers in driving occupations discussed in Section 5.

As participants noted, the automotive and AV technology workforce is predicted to grow in the U.S. and also around the world.

> *We're opening a new company in [Location Redacted]. We anticipate over a thousand people. We're currently around 200 and some. But, then we've got this whole new move, well over a thousand. Where's our workforce?*
>
> *This is measured in thousands of engineers. They just announced an AI center in [Location Redacted]. And, I mean, that's hundreds that are [going to] be here just on the AI that will be formed there. The workforce will continue to grow in [Location Redacted], for us, and in other parts of the world. And then the back end, in [Location Redacted], of course, will continue to blossom. And that's just the design phase of it. We haven't even gotten to the manufacturing piece of it.*[122]

Extensive growth was expected in particular technology-related occupations. Areas of greatest needs included software and other areas of engineering, cybersecurity, and data science.

6.1.1. Engineers

Engineering jobs were the most commonly noted type of positions that were critical for the automated vehicle workforce and were expected to increase substantially in the coming years. Interviewees and focus group participants noted a range of different, but often related, types of engineers that were critical for the workforce related to automated vehicles. Software engineers were most often reported by participants as one of the jobs that would be substantially increased in the future as a result of automated vehicles.

Other specific types of engineers critical to the automated vehicle workforce noted by participants included: design engineers, dedicated short-range communication (DSRC)

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[120] The motor vehicle sector consists of North American Industry Classification System (NAICS) Codes 336100 (Motor Vehicle Manufacturing), 336200 (Motor Vehicle Body and Trailer Manufacturing), and 336300 (Motor Vehicle Parts Manufacturing).
[121] The median across occupations was calculated as a job number weighted average of median incomes for individual occupations.
[122] Focus Group Participant, Michigan, April 12, 2018.

engineers,[123] systems engineers, mechanical engineers, electrical engineers, computer engineers, AV engineers, control system engineers, emissions engineers, hardware engineers, and materials engineers.

Participants noted significant increases in the need for engineers as companies in the automated vehicle industry continued development and expansion. When asked how many engineers they would need, one interviewee noted:

> *As a corporation, I would have at least a dozen in each one of the [engineering] categories, because you want them to work at short-term, mid-term, and long-term type developments.*[124]

Others noted significant increases in engineers with autonomy experience will be needed in the next few years.

> *Just for people focused on autonomy, we're sitting at about 80 engineers [currently]. I can see that going up by 30, 40 percent over the next three years, based on the expansion and all the additional activities we've got going on.*
>
> *We have ramped up our AV lab out there. I think a year and a half ago it was about 20, 25 people and now we have over 100 and it's taken over an adjacent building to our R&D facility only for the AV group. We are hiring a ton of AV engineers and testers, and I know our competitors are as well. So, at this point, you know, we are desperately seeking people who have schooling in this, and, you know, that schooling just hasn't been around very long.*[125]

6.1.2. Other Technology Areas of Need

Participants suggested that jobs in the technology industry will continue to increase. In addition to the focus on engineering noted above, they discussed occupations in cybersecurity, data science, social science, and hybrid technicians. In particular, participants indicated that companies in the AV domain have a high demand for cybersecurity and engineering occupations. One participant stated:

> *My company has a [Location Redacted] team that is solely focused on embedded security for connected and automated vehicles. We have five people now. I need to hire 20. That is a reflection of the demand and the necessity.*[126]

Another participant similarly stated:

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[123] DSRC consists of electromagnetic spectrum in the 5.9 GHz band licensed for Intelligent Transportation Systems (ITS). Specifically, DSRC involves vehicle-to-vehicle and vehicle-to-infrastructure communications and is viewed by many in the automotive industry as crucial for *connected,* but not necessarily automated, vehicles. See Federal Communications Commission, Dedicated Short Range Communications (DSRC) Service. Available at https://www.fcc.gov/wireless/bureau-divisions/mobility-division/dedicated-short-range-communications-dsrc-service.

[124] Automotive Industry Representative, Audio Interview, February 8, 2018.

[125] Military Vehicle Expert, Audio Interview, February 13, 2018.

[126] Focus Group Participant, Michigan, April 12, 2018.

From a cyber perspective . . . We have really low talent, low numbers of people with the skill set that we're looking for. And I can't necessarily wait for my company- four to six years to get people through a program. I need to train them up quicker and faster. So, it's taking the existing workforce, and retraining and re-educating. However, as universities start pushing out more talent with the appropriate skill set, industry can then be more selective on who they're picking.[127]

Data scientists and machine learning experts were also in high demand. Participants noted the complexity of data arising from automated vehicles and the need to be able to quickly and efficiently analyze this data, as well as communicate it to others. One participant noted that in the next five years his company could easily double the number of machine learning experts they have on staff.

6.1.3. Shortages of Workers and Challenges of Keeping Employees

Across the interviews and focus groups, participants noted the challenges of finding and hiring engineers and related types of employees who had skills in the automated vehicle area. Participants reported that there are not enough people going into these areas but there also aren't enough senior level people in these fields currently. There are significant shortages in the automated vehicle workforce in these areas.

I think everybody can reliably say we're thousands, tens of thousands, likely short of meeting that talent gap in those fields.[128]

Across a range of organizations included in this study, interviewees noted that it is often hard to hire as many workers as are needed who have the necessary technology related skills. Often this means they spend considerable time and resources trying to find and recruit individuals with the right training and experience. As one participant noted:

I'm trying to get a DSRC engineer. I've been waiting for the right engineer for nearly nine months . . . I pay a premium from a salary standpoint. So these guys are getting money. It's just that there's, there's not too many of them out there. And, I have five more that I've got to hire and it might be the same type of scenario.[129]

They also noted the challenges of keeping employees once they were hired. Given the shortage of employees with these skills, other companies were often trying to hire other companies' employees. And, this was not just a public-sector challenge. An interviewee from the military also noted challenges.

What there is right now in the community is a great deal of competition. So, on a routine basis, we have headhunters calling our folks because there are demands in the auto industry or the transportation industry for the same skills. So, they're always trying to cherry pick our people for other job opportunities. I think it's the global shortage of people who are skilled in autonomy and autonomous systems and the fact that we've

[127] Focus Group Participant, Michigan, April 12, 2018.
[128] Economic Development Agency Representative, Video Interview, April 3, 2018.
[129] Automotive Industry Representative, Audio Interview, February 8, 2018.

been doing it for so many years . . . we have a fairly high performing team, so they are very desirable to other entities, so we are always under risk of losing a lot of talent through this recruiting activity.

Our biggest threat is not from a lack of people. Our biggest threat is from the aggressive recruiting of the other segments . . . non-military segments that are trying to hire our people away.[130]

To help compensate for this challenge, several participants noted, including our military interviewee, that they try to create a pipeline of talent.

We have to continue to bring in junior folks and continue to train them, and bring them along in case we do need people. So, I think that's the pressure we're under. As of right now, we have a very healthy team with significant number of folks and we're in a very good place from that stand point. But, as we go forward, and these programs continue to grow and expand, we will always be looking for more and more talent and building our own pipeline.

There is just not enough skill talent to fill that void, which is why we have to grow our own and create our own training. But I think that that's only going to increase exponentially for us.[131]

6.1.4. Data Proliferation and Analysis Needs Related to Automated Vehicles

A topic that emerged from the interviews and focus group discussions was the massive amounts of data that are being generated and will increasingly be generated from automated vehicles. This data proliferation is resulting in increased need for not only data analysts, but workers who are skilled in machine learning and data analytics more generally.

The scale of what we're talking about data wise, you know, today's vehicle maybe it puts out many megabytes of data per day. The automated vehicle when it's fully deployed will put out terabytes. You can't hire seven million more data analysts. To fix the problem, you have to find better methods. You can't just throw more analysts at the problem. You have to actually create new tools and methodologies to analyze this large amount of data. [132]

As this participant noted, the amount of data being generated will necessitate more workers but also new tools and methodologies for analyzing the massive quantities of data that are being generated. This may represent an instance where universities can be proactive in designing new tools and methodologies to handle these quantities of data and to also train students in this burgeoning area.

[130] Military Vehicle Expert, Audio Interview, February 13, 2018.
[131] Military Vehicle Expert, Audio Interview, February 13, 2018.
[132] Automotive Industry Representative, Audio Interview, May 2, 2018.

6.1.5. Emerging Areas of Need: Cross-Functional and Multidisciplinary Workers

Given the complexities associated with automated vehicles, participants noted that employees need to have a range of skills, rather than just one specific domain specialization. Many companies face challenges in hiring employees that are proficient in multiple engineering domains—which may be a necessity when it comes to AV innovation. For example, participants at our Michigan-based focus group stated:[133]

> *We always say, "code beats paper," and, so, if you come in, you can pass the coding tests, and you can execute, then you've proven your value. The other thing that we've also seen from an engineering curriculum perspective is that often the skill sets that we're looking for are well beyond what would ever be taught in an academic institution today. Even a very renowned academic institution would still be behind for what skills we actually need immediately for autonomous vehicles. I think that's another thing, it's driving opportunity for, again, that emerging space.*

Another participant stated:

> *Now our group, is made up of civil engineers, systems engineers, communications, so it requires a bachelor['s] of engineering in something, but it's a much more diverse set of people and eventually looking for somebody that has a passion about transportation but isn't just a civil engineer anymore.*

Other participants articulated the complex skillsets and combinations of skills that are in high demand in the AV industry by stating that they need employees with experience in:

> *A bunch of other specific engineering disciplines that are already kind of coming up through some of the STEM initiatives. There are some specific things that we do look for right now, I mean, a lot of object-oriented programming skills are very important to us. Certainly anything with respect to computer vision is very important skill set to us. But there are deeper, verticals that, I mean we can go on and talk about the inner workings of an autonomous vehicle system, but that gets pretty specific in those engineering disciplines.*

In addition, interviewees and focus group participants expressed a strong demand for individuals that have experience and expertise in multiple disciplines outside of traditional engineering domains—including social scientists, hybrid-technicians, and people with data science skills. For example, participants at the Michigan-based focus group stated:

> *I think there's going to be a stronger place for the sort of social scientist in that area because translating technologies across global markets is a big, big deal. So, when you, for example, sit in front of an auto presentation where they're breaking down the various standards from a global perspective, we tend to think in our bubble here in [Location Redacted] and maybe arguably nationally.*

[133] Various Focus Group Participants, Michigan, April 12, 2018.

Others stated:

> *So that opens up a whole other class of technicians that there's no marketplace for right now. So, I think the buzz term that tends to be used the most is multidisciplinary cross-functional individuals. Which requires a level of brain-computing which is automatically going to wipe out, I think a lot of availability of talent because . . . how are we going to genetically engineer that herd of unicorns to be able to show up and do the 60 things that you need them to do. Or the 130 if you look at the job posting for that person.*

Similarly, another participant stated:

> *So we actually need folks that go deeper into that [data safety] skill set. That is, methodologies on how to actually produce safe, executable code, and then an entire process will surround that.*

Interviewees noted the need for specialists who understand the integration of the myriad technologies making up the AV ecosystem. Different interviewees noted:

> *You also need somebody who understands holistically how they're supposed to come together and operate.*[134]

> *Workers will have to be very dynamic, in responding to the needs of this field because it's going to be pulling, you know, components from multiple disciplines together for the skillsets that they're going to need to be successful in this field.*[135]

As an example of the latter quote, the interviewee noted how a new automated cybersecurity-type position combined coding skills with cybersecurity training and infused these with the knowledge of automobiles and impacts on infrastructure.

As these quotes illustrate, workers for the automated vehicle industry will need to be able to function across areas and disciplines. This will require retraining and education for those already in the workforce, as well as a focus on multi- and interdisciplinary skills among colleges and universities who are training the future workforce. At least in the near term, the complexity of training and backgrounds may make it challenging to find individuals to fill these type of positions, particularly given that many of these skills are already ones in high demand in the field of automation.

6.2. Changing Needs for Other (non-Driving) Occupations

Aside from tech industry occupations, the experts in our study anticipated growth in other job categories as well as the emergence of entirely new occupations. However, some participants discussed potential ramifications of AV diffusion that could put some existing fields in jeopardy of experiencing job losses.

Myriad occupations across several industries are anticipated to be impacted by AVs, with changes expected to non-driving jobs in the motor vehicle industry, occupations in the public sector or supported by the public sector (i.e., infrastructure), and service professions ranging

[134] Trucking Industry Representative, Audio Interview, 5PM EST, February 5, 2018.
[135] Economic Development Agency Representative, Video Interview, April 3, 2018.

from customer support to legal practice, as well as many others. As we discuss in greater depth in this section, several core implications arise for different job categories:

- In spite of experts' general consensus that, in the long run, AVs could lead to a decline in the need to repair vehicles damaged in road accidents, in the foreseeable future, the complexity of AVs entails a rise in demand for maintenance and repair services. However, this complexity also implies that the skillsets associated with these occupations will become more demanding as well.
- The need to remotely serve private AV passengers or monitor AV contents will generate substantial labor demand for customer service and related professionals. Such jobs were viewed by participants as a more local and possibly healthier alternative to driving jobs that may face declines in the future. Therefore, when thinking about potential net loses/gains in the overall workforce—emergent service jobs must be considered as a possible growth industry.
- Construction/trade professions may be in strong demand as well—particularly because of the aging workforces in those domains as well as the increasing need for those positions pertaining to retrofitting and infrastructure development for CAVs, in particular. As such, trade unions, e.g., electrician's union, and other trade associations could aim to increase younger generations' interests in these professions by highlighting the potential opportunities that CAV diffusion could create for these occupations.

Table 3 indicates that existing and new occupations will require skills that are specific to AVs or skills that are not presently commonly held by employees in these occupations.

Table 3: Changing Skill Requirements Caused by AVs

Occupation	Skills
Mechanic/Maintenance Technicians	Diagnose, calibrate, maintain, and repair AV sensors and other equipment
Dispatcher/Remote Guides	Customer service; troubleshooting AV sensor and equipment malfunctions
Infrastructure Construction and Management (more relevant for CAVs than AVs in general)	Understand needs of Intelligent Transportation Systems architecture and design, including installing conduit, pulling fiber, and installing sensors; calibrating sensors and other equipment
Legal Professionals	Automobile technology policy & regulation and liability

6.2.1. Maintenance and Repair

Despite AVs' potential to improve safety, and consequently diminish the need for vehicle repair caused by road accidents, at least in the foreseeable future, participants anticipate a major increase in demand for vehicle repair and maintenance industry professions. For example, one focus group participant stated:

One is the maintenance industry, even just as basic as washing the vehicle, ensuring that the sensors are clean or in good operating order, so that might be something that would evolve.[136]

Another participant stated:

The vehicle might be autonomous, but it's still a vehicle. It still needs repairs and things of a mechanical nature, as well as, now it needs software updates and everything else too. So there are more jobs to support that vehicle- [but] They might not be the job of the driver in the vehicle . . . [137]

Another participant added in response:

Yeah, so, I see there being at least an equal, if not an increase in what supports these [AVs] but, not a decrease in the workforce surrounding the entire transportation network. But certain areas of that are definitely going to shift.

Participants conveyed a need/growing demand for mechanics and service technicians. One executive from a large Original Equipment Manufacturer (OEM) stated:[138]

I think we're starting to see that we're understaffed with good qualified mechanics and technicians. And that's today. So let's say we're in a need of 10 percent right now. But as this technology evolves and gets more complex, that means that skillset is going to change as well and therefore the demand is also going to be up. So that 10 percent is going to quickly evolve to like 20 percent. Yeah, right now, there's not enough technicians and people of mechanical competence that can fulfill all the needs of every OEM dealership right now.[139]

Though many expected that mechanics and service technicians will be in high demand, the skillsets associated with these occupations will become more complex as well. For instance, another interviewee stated:

[Mechanics] spend a lot of time learning about engine maintenance and repair, and transmission maintenance and repair, and suspension maintenance and repair ... And those kind of typical automotive type components. But now if you're talking about an autonomous system, now you have radar sensors, you have LiDARs, you have possibly different camera systems, visual, near IR, far IR, you have different sensors, and then not only the repair, but the calibration is necessary. So, you can have a lot of different electrical mechanical requirements for these other systems that will be coming as we start to go to more complex systems.[140]

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[136] Focus Group Participant, California, March 6, 2018.
[137] Focus Group Participant, Michigan, April 12, 2018.
[138] An Original Equipment Manufacturer (OEM) is a company that produces parts and equipment that may be marketed by a downstream manufacturing firm. In the auto industry, the term OEM is also often used to refer to automobile manufacturers.
[139] Automotive Industry Representative, Audio Interview, February 8, 2018.
[140] Military Vehicle Expert, Audio Interview, February 13, 2018.

Similarly, another interviewee stated:

> *Mechanics and technicians, I believe that they will change. The sensors on the vehicle will need to be treated with special care and will need to be repaired in a way that we know that they function properly after the repair. And so, right now, typically, mechanics . . . are already becoming more and more reliant on [a] computer, and networks, for analyzing what's going on in the vehicle. But, they also . . . they will need to be able to query the sensors and query the central brain of the AV and make sure that they're functioning as designed, whether . . . whether they've been replaced, repaired, or even just updated with a new software level. So, definitely technicians. So, yes, I think there will be specific needs on training dealer repair technicians and body shop technicians, and probably others that I haven't thought about.*[141]

In addition, another interviewee articulated a similar point about the current deficiency in skilled mechanics and service technicians that are capable of working with AVs. However, the interviewee was more concerned with attitudes towards working in the auto-industry as opposed to focusing on a potential skills gap. For example, the interviewee stated:

> *The vehicle repair ecosystems are in pretty good shape. And the reason for the technician shortfall doesn't have anything to do with skillset as much as it does that it's just been, you know, a working in automobile . . . Less than one percent of the population in a recent study said that they are interested in or had contemplated working in the auto, you know, the car dealership. You know there is a stigma, working in the auto industry that is alive and well. And that's carried over both just generally to the technicians, as well as the grease monkey kind of stereotype that I mentioned earlier, which also turns people off.*[142]

6.2.2. Customer Service Occupations

Participants anticipate that a number of customer service/concierge related occupations and skills that are either largely absent or only ancillary to an existing occupation will arise because of AVs. A prime example of this is the emergence of vehicle concierges as well as other customer service positions, such as remote vehicle assistants:

> *It comes back to protecting jobs versus protecting workers and there is going to be . . . roughly the same number of people catering to passengers. They will probably no longer be behind the wheel, but there's customer service, there's directions. The bus drivers we haven't talked a lot about, but the bus drivers do a lot more than just ride/drive the bus; they de-escalate conflicts, they give directions, they understand when someone needs help getting on the bus, and they will need more customer servicey skills. Some bus drivers are very much at that and some people drive buses because they don't really want to talk to people and then you'll have a fork in the road for career paths, for those*

[141] Automotive Industry Representative, Audio Interview, May 2, 2018.
[142] Automotive Industry Representative, Audio Interview, April 3, 2018.

type of drivers. So we'll protect the job of the concierge . . . but the person who is a driver and that's all they're good at, that worker will probably not be productive.[143]

Regarding other emergent service job categories, such as a diverse set of dispatchers, remote vehicle assistants, and individuals tasked as "safety monitors"—several consistent themes emerged in both the interview and focus group data. For instances, participants stated:

> *Whether it's dispatching or keeping them monitored. Because I envision we've got 10 trucks out there, but who's monitoring [them]? How are we monitoring [the truck] on the screen? And you know, it's just like an air traffic controller. There are going to be people like that, that are going to be doing that . . . We have, on [electronic logging device], I can see where all my trucks are right now, in the state of [Location Redacted]. All of mine have that right now.*[144]

Whereas another participant stated:

> *Well, we have a central dispatch area that's like 100 for all 367 locations and 17,000, or 20,000 drivers. But that's more over the road, so it's like 10,000. It's like half. And then you've got the local management at each of those locations that are responsible for their, you know, driver management. And then you have a . . . our central dispatchers don't do the safety monitoring. We have a department of like 10 that watches all the videos and assigns managers to review with the drivers.*[145]

Another finding that was consistent with the focus group data was related to customer service positions and remote vehicle assistants. Specifically, one interviewee stated:

> *Remote vehicle assistance—so, similar to like GM's On-Star that everyone's probably familiar with. Actually, you know, the GM AV Cruise that they announced is going to be deployed in San Francisco next year. It's the first vehicle announced to be deployed without a steering wheel or brake pedals.*
>
> *And it'll be in a ride-sharing service. They're planning on using their current On-Star assistance to provide a way for an occupant in the vehicle to communicate with someone if they have a question, if something, you know, if something goes wrong like anything that, you know, they want to ask about the vehicle, they can have it real-time and send communication with someone. And that type of plan is not unique to GM, a lot of companies that are planning on rolling out an AV are thinking of this. You can see it also in the California DMV Regulations that were finalized earlier this year. They actually require a two-way communication link for certain types of AVs, so there's a whole new opportunity right there.*[146]

In addition, other customer service related activities could include:

> *People that will have to be able to work on the vehicles and trouble-shoot the vehicles and provide roadside assistance to the vehicles and then people that are responsible for*

[143] Focus Group Participant, California, March 6, 2018.
[144] Focus Group Participant, Texas, March 5, 2018.
[145] Focus Group Participant, Texas, March 5, 2018.
[146] Automotive Industry Representative, Audio Interview, March 21, 2018.

doing the education and teaching and training. There might be a bigger need for customer service, because now it's just about how many vehicles can I put on the road and you know how do I do a better job interacting with people that are, you know, just having challenges? And, ordering a vehicle or not happy with the vehicle service or those kinds of things.[147]

And also:

I think there will be some [customer service jobs] that will be added. And frankly, I don't know that we could think of them all. I could see instead of a bus driver, there's a bus ambassador. So, I think there's different job classifications that will pop [up] as this industry evolves.[148]

As these results illustrate, there is a range of customer service related jobs which will evolve as AVs enter the market and become mainstreamed into society. Some of these will serve as a natural pathway for displaced drivers willing to undertake additional training to acquire the requisite skills for these occupations.

6.2.3. Assembly Workers/Manufacturing Jobs

Experts involved in the interview portion of our study discussed both the potential for an increase in demand in the short-term, and perhaps a decline in demand in the long-term, for assembly workers and manufacturing jobs. For example, a participant stated:

[A]s far as actually assembling a vehicle, I don't think that changes because you go into an autonomous vehicle. Now I think we'll still see impacts as we continue to automate even further in our factories. So you know, a lot of our manufacturing decline, there's a lot of manufacturing jobs over the last 10 to 20 years we're not going to get back, and it's not because they moved to a different country, or anything like that. It's just that we've gotten more efficient at the manufacturing process.[149]

Another interviewee discussed how the increasing complexity of AV systems could require more assembly workers:

Moderator: *So, what you just said maybe indicates that there may be a need for more assembly workers.*

Participant: *Right . . . Because now you've got to install the LiDAR, and, you know, how much more time does that take versus the other things that they were doing? So does that add another worker to the line?*[150]

In a separate interview another participant similarly stated:

[147] Taxi and Limousine Industry Representative, Audio Interview, February 21, 2018.
[148] Transportation Agency Representative, Audio Interview, March 29, 2018.
[149] Economic Development Agency Representative, Video Interview, April 3, 2018.
[150] Trucking Industry Representative, Audio Interview, 3:30PM EST, February 5, 2018.

Well, you're basically adding complexity to the vehicle, so, there will be more assembly operations.[151]

Whereas another participant stated:

I can just make an educated guess that the number of workforce members we'd need for a production line may need to increase due to the additional components that are required on autonomous vehicles.[152]

6.2.4. Construction/General Trades

Other occupational domains that could face increasing demand are in the construction and general trades fields. For instance, referring to retrofitting roadways for Intelligent Transportation Systems (ITS) sensors that may be used in vehicle-to-infrastructure communication by CAVs, primarily, an interviewee with experience in infrastructure development stated:

I think the big question here is, when you talk retrofitting [a road with ITS] it's making me think, we have enough people now to do it, but we don't have enough young people coming into the field to continue to do it.

Being in the field for 18 years, I don't see a lot of new individuals coming into being an electrician, being [a] signal tech, being a laborer in general. All these individuals sort of over the last 15 years really pushed to go to college, and trade schools really just fell to the wayside. So just being in the industry, in the last 10 years, and looking at the labor force, they're getting older. There's not a lot of new, young individuals coming in.[153]

The interviewee indicated that retrofitting existing roads throughout the U.S. could be a substantial undertaking that demands significant labor resources. Referring, again, to the needs of ITS, the interviewee stated:

[E]ven if you [have] 1 mile, you could have your conduit system, and your handholds would have to go in. You'd have stream poles . . . in order to put your radios. Then you have to pull your wire, then you have to pull your fiber. Just that alone, if you were to put three weeks in there at five people . . . Trying to think what else you'd have, you'd have cabinets, conduit, pulling wire, pulling fiber, putting your hardware, your programming, your poles, your cameras . . . Five people a mile, three weeks . . . in a rural area . . . six to eight weeks in a dense urban area.

The interviewee also discussed contractors retrofitting or building new road infrastructure needing separate teams of individuals who specialize in ITS, which entails various information technology skills, including for instance, how to calibrate and troubleshoot sensors.

However, at least indirectly, other participants were less optimistic about the need for additional labor in the construction industry because of limited public resources to retrofit existing infrastructure. For instance, one interviewee was skeptical that their home state would seek to

[151] Automotive Industry Representative, Audio Interview, March 1, 2018.
[152] Automotive Industry Representative, Audio Interview, March 21, 2018.
[153] Construction Industry Representative, Video Interview, April 9, 2018.

provide ubiquitous ITS and noted that half the roads in the state were gravel.[154] As we noted at the beginning of this section, these type jobs are more relevant for discussions of the CAV workforce than strictly the AV workforce.

6.2.5. Lawyers/Lobbyists

AV advancement and diffusion could be largely predicated on regulation, government policies, laws, and new sets of insurance and contractual agreements. As such, some experts foresee an increase in the demand for corporate lawyers—particularly those with experience working in the government and/or on privacy related issues. For instance, a corporate lawyer from a large OEM stated:

> *We never used to have lawyers who specifically dealt with, say, data privacy or, inhouse lawyers that dealt with regulatory law, and now I think we're moving a lot of those functions internal because we're using those kinds of lawyers more than we used to and it makes more financial sense to hire one rather than to be billed by a firm.*
>
> *I'm sure there were privacy lawyers 10 years ago, but probably not as many as there are today. And, so we particularly look for people who might have worked in the government. So, if you were the chief counsel, or an FCC commissioner, within the FTC. I know [Company Redacted] hired one of the lawyers from the legal team at NHTSA.*
>
> *When I say lawyer it's not about defending ourselves at all costs, it's more about making sure that there's a lawyer in the room as we're designing the systems so that we can make sure we're in compliance with federal laws here as well as have a design system that's compliant with international law, with the EU laws; they're a lot stronger when it comes to privacy, and we're building that into the system from the get go.*[155]

In addition, companies may also increase the number of lobbyists that they employ—as well as hire lobbyists that are specifically focused on AV policy and regulation—at both the state and federal levels. The interviewee also stated:

> *When you ask about competitors, my guess is that either our competitors and or trade associations like the auto alliance and global manufacturers, et cetera, my guess is that they are probably going to be ramping up hiring of state and federal level lobbyists.*
>
> *It's really hard to cover all 50 states. You can't be a registered lobbyist and an expert and maintain your contacts in 50 state capitals. And until we have federal preemption, and frankly even after that, because states are going to retain the right to do a lot of AV related law making, such as licensing and traffic laws, et cetera, I think it's going to be really even more important than it was in the past to stay up to date on those regulations at the state level.*
>
> *And, I don't foresee that we will be ramping up much more than maybe one or two people in the next 10 years on that, but it would be my strong assumption that bigger*

[154] Transportation Agency Representative, Audio Interview, March 29, 2018.
[155] Automotive Industry Representative, Audio Interview, April 4, 2018.

companies like GM and Ford, and certainly our trade associations, will be looking to ramp up those kinds of jobs to make sure that they're serving their members well.[156]

Another area in which increasing demand for lawyers may emerge relates to meeting federal safety standards. As one interviewee indicated, companies that take on additional liability for meeting standards that arise due to AV technology may create additional opportunities for lawyers who understand how that technology is regulated.[157] Another interviewee suggested that lawyers working to address AV liability issues need to understand the technology:

[T]he lawyer that should work on AV or CAV needs to have some technical understanding of the way that the vehicle functions in order to be able to identify risk . . . defend the company when their product or service goes awry.[158]

6.2.6. Occupations That May Decline

Participants discussed their concern for healthcare related fields with specific reference to urgent care facilities—under the assumption that the widespread diffusion of AVs could drastically reduce the number of accidents, and subsequent injuries, that occur as a result of human drive error. For instance, a focus group participant stated:

I was talking about [AVs] with somebody from the healthcare field, and a fact that they're worried about is if accidents go away or are reduced or the severity of accidents go away. They were concerned that this may drive down the need for those types of services—[such as] physical therapists and all the collateral industries.[159]

Although the experts in our study did not think that AV diffusion would hinder demand for police officers, other municipality workers, such as parking attendants, could be less in demand. An interviewee specializing in real estate suggested that urban parking would become substantially less scarce and that parking structures would become underutilized because of a future decline in car ownership.[160] Another interviewee stated:

The police officer with the traffic ticket, you know, my last count, there's still lots of things for police officers to do.

I think parking enforcement is already being reduced by automation. And we're seeing it already with, you know, parts and systems that are basically alerting you when your meter's out of money and you didn't charge it up. At the same time, it gives a notice as to where exactly your car is, so you don't need a person that just drives around all day and looks for a meter that says expired. So, I think that impact is already being felt . . . people that have those jobs, I think are already being phased out.[161]

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[156] Automotive Industry Representative, Audio Interview, April 4, 2018.
[157] Transportation Agency Representative, Audio Interview, March 29, 2018.
[158] Automotive Industry Representative, Audio Interview, May 2, 2018.
[159] Focus Group Participant, California, March 6, 2018.
[160] Real Estate Industry Representative, Audio Interview, January 25, 2018.
[161] Transportation Agency Representative, Audio Interview, March 29, 2018.

7. Training Needs and the Future of Education in the Era of Automated Vehicles

The advent of automated vehicles will yield substantial opportunities for educational and training activities by a range of organizations and industries. The results of this study indicate that educational efforts will need to be multidimensional as different elements of the workforce need to be targeted with different tailored education and training outreach efforts. In some instances, there are already existing gaps in the available workforce due to a lack of specific training and/or retraining activities. These gaps are expected to widen unless education and training activities are developed across a range of the automated vehicle workforce.

Industries and educational entities have to quickly get up to speed on what are the needed skills for jobs arising in the new automated vehicle transportation era. Interviewees stressed the rapidly changing aspects of the workforce due to AVs and the need for educational organizations to be adaptable and innovative in thinking about this fast-changing terrain. They need to be forward thinking as the technology continues to evolve as new job titles and classifications that require skillsets that are not known today are going to be needed in the next two to three years. This will require continual updating of skills as technologies evolve and/or the training of workers in new areas that did not exist previously.

In reality, no one knows what reskilling will look like in the future and the challenges of moving forward with reskilling. Some segments of the workforce may not be able or willing to be reskilled. As technologies continue to advance, it may be that workers who are on the wrong side of the digital divide may be less able to easily and effectively learn new technology skills needed to perform work duties; historically, older adults, individuals living in rural areas, and those with lower levels of education and income are the individuals who tend to be on the wrong side of the digital divide. This may result in perpetuating and/or exacerbating inequalities. Tailoring training to different generational and technology proficient cohorts will help ensure that particular groups of workers can more easily learn the skills they need to continue in the workforce. Future research is needed to ascertain the impacts of AVs on reskilling rates, worker wages, and how these technology developments affect changes in the economy and labor market over time. Making training relevant and applicable to this changing knowledge and application content is critical to ensure workforce demands can be met and inequalities are not perpetuated and/or exacerbated.

7.1. Training the Technology Workforce

While some educational and training efforts will need to be very specific and targeted (for those with certificate and associate type degrees), those with higher education and training will need to be broadly trained. This is particularly the case in engineering for AVs, as they need to be able to think broadly about the nature of the product or service that they are working on due to the complex nature of AV systems and the interdependency of the multiple systems needed for AVs to operate successfully. Participants noted that engineers need to have a combination of classic mechanical and/or electrical engineering skills as well as computer science engineering skills. Combining physics, mathematics, computer programming, and data architecture expert knowledge will be critical for training those with higher level degrees (PhDs in particular). Working closely with AV industry partners will help educational entities to tailor their educational and training programs so that they remain relevant and on-point with the advancing technological developments in AVs. Interviewees saw this work as mainly training students who would enter the workforce, rather than retraining activities.

For workers in the AV industry who are defining specifications and advanced development of AVs, advanced degrees (master's degrees and PhDs) are needed. Several participants noted that it is a challenge to find senior level employees in these areas. Creating a pipeline of workers in these areas will be critical to the future of these industries. More than half of the technical workforce has PhDs. About 25 percent have master's degree, and the other 25 percent have bachelor's degrees. One interviewee even noted that a significant share of technicians now have bachelor's degrees.

7.2. Augmenting Skills Through Certificates and On-the-Job Training

In addition to the tailoring of advanced degrees noted above, our results find that certificate programs will be critical for a large segment of the AV workforce. Certificate programs will be one way to quickly give people skills[162] they need to obtain jobs for those new to the field or adjust to some specific aspects of automation for those already in the field who need to be retrained. These will be most needed for skills that can be acquired in a short period of time, and primarily through community colleges. Interviewees noted that being able to acquire these credentials will be critical for enhancing the skills of those already working in the automobile repair and service technician industries, for example.

Related to this, participants noted that credentials should be industry standard and "portable," which will help workers who move to other jobs. Credentials were also thought to be beneficial for truckers to help enhance public trust in AVs, with the idea being that the public might perceive AV trucks as safer if they knew that drivers had extra training related to AV truck use and safety. Getting industry partners involved in determining needed certificates will be beneficial for colleges and vocational schools who want to create certificate programs. And vice versa—companies need colleges and vocational school partners to ensure training programs are available to help maintain the workforce pipeline.

Larger organizations, in particular larger trucking companies, were noted to have their own new driver training programs and in-service training programs for drivers. They are trying to stay ahead in the latest technologies by making sure their drivers know about the latest systems. Some examples included: collision avoidance, driver awareness and safety systems, and the business process. It was noted that the smaller trucking companies, with just a few trucks, were relying on training provided by the truck dealers. There is a need to assess the ecosystems of smaller trucking operations to determine how to properly help these truckers get proper orientation about how to use advanced safety and higher automation systems. This may be one area to target in future educational efforts as new technologies are deployed in trucking.

[162] Though one of the goals of this study was to identify specific skillsets needed for the future, participants had trouble identifying specific skillsets. Future research will be needed with AV industry participants who are not as senior level as the ones in the current study, who have a better sense of the types of work skills involved in both driving and non-driving work activities.

Participants noted a need for industry to work with government to examine overall training frameworks for truckers. It may be that training frameworks need to change as AV technologies become more pervasive, suggesting that CDL testing might also change to reflect this. In addition, automobile technician training modifications may already be occurring through national association efforts but also to a lesser degree at the dealership level.

7.3. A Multi-Institutional, Flexible Approach to Trade Education

There was a clear consensus among participants that it will take a multi-institutional approach to advance the workforce in the AV era. Industries, communities, and educational organizations need to partner together to develop training programs targeted to increasing training for specific groups of workers. Interviewees gave examples of industries working with K-12 school systems to make students aware of opportunities in STEM areas, as well as AVs more specifically. Developing curriculum in concert was also another way to advance the training and educational activities in this area.

Opportunities for vocational and community colleges were noted as a way to help build the workforce. Participants noted that there are many people who do not want to or are not ready to go to a four-year traditional college. Vocational and community colleges, where they can obtain associates degrees or certificates for a technical area or system related to AVs would be highly marketable and fill a large niche in the AV industry. Certificates show, in particular, that workers have met a certain baseline of standards and skills.

Some auto companies and manufacturers have partnered with community colleges and vocational schools to start programs where people can enter programs relatively inexpensively to earn an associate degree in a practical specialty. Students who earn a certain grade in the program are guaranteed a full-time job with the auto company after graduation. This was noted as one way to help fill jobs where there is a big shortfall of existing employees. New technology developers should work with OEMs to showcase the latest technologies, training opportunities, and types of jobs that will be available to excite students and draw interest to these programs.

There may also be opportunities to recruit people straight out of high school, particularly if they have coding experience; then, give them additional training within the organization so they can start in their careers rather than going to community or four-year colleges. Having multi-week or month boot camps could help them acquire the skills on the job, so that they can be useful from the beginning of the job.

7.4. Honing the Skills of Postsecondary Degree Holders

As we noted in section 6.1.5 above, employers want workers who are broadly trained, particularly in relation to engineering skills. Though this is desired by employers, there is also a need for workers to have specific skills. Some participants noted that when they get workers straight out of college they still have to train them, as many of the four-year degree programs are too general for the work that is needed in AVs at this time. Thus, it would seem that companies in the AV industries may want to think about developing their own training programs or partnering with other AV companies to develop training programs that can benefit all the companies in this arena. This will require substantial cooperation among companies and a willingness to identify key skills that are needed for workers beyond those acquired during the four-year college experience. Sharing intelligence across industries and companies could be challenging but also very rewarding for the future of the workforce.

New opportunities exist for colleges and universities to expand current offerings, particularly around the AI and cybersecurity areas. This will only increase as vehicles become more connected. One area of expansion could be on the topic of AI and vehicle design. Participants noted the opportunity for new classes specifically on the topic of AI and vehicle design. There is also a need for standard protocols for how to share data across interdependent systems.

7.5. Community Outreach

In addition to the training and educational opportunities surrounding the specifics of AVs, participants noted that additional educational efforts are needed to explain to varying stakeholders and others what AVs are and what they are not. For example, drivers have to understand the product in order to use the system and explain differences in levels of automation. Consistent with prior research, focus group participants did not believe that consumers were ready to adopt automated vehicles.[163] Public awareness campaigns will be needed to help ensure trust in AVs, so that different groups will be willing to use them. Thus, marketing, public relations, and communication professionals will be needed for these efforts.

In summary, substantial and multifaceted education and training efforts will be needed to transition the workforce and public for automated vehicles. Participants generally believed that it was important for educators to stress both general knowledge and specific skills, suggesting the need for workers who can specialize and yet have sufficient depth of knowledge to retrain. All focus group participants were asked “In relation to preparing future workers for the automated vehicle workforce, should educators focus more on general knowledge so that future workers are prepared to perform a variety of jobs, or should they use educational approaches that stress skills to do a particular job well (e.g., through certificate programs)?” Of the 32 respondents, only one indicated general knowledge, while 18 indicated that both general knowledge and specific skills were equally important. For example, one participant from the Texas focus group stated:

> *In Texas, we have the Texas Workforce Commission, and they have regulations and accreditation[s], and there is a[n] [existing] curriculum. It's very hard to add additional content to the curriculum. But one thing we can do is add badges, micro credentials, certification, [and] retraining activities. Things [so] that any student can actually create their own degree in addition to the major and add those skills that they would need.*

[163] All focus group participants were asked, “On a scale of 1 to 4, with 1 indicating strong disagreement, 2 indicating disagreement, 3 indicating agreement, and 4 indicating strong agreement, indicate your level of agreement with the statement: consumers are not yet willing to adopt AVs.” With 32 out of 33 participants responding, the average level of agreement was 2.69, with no participant strongly disagreeing.

A variety of approaches and opportunities exist within this realm. Multiple entities are needed to partner together to make the training as relevant and applicable as possible to constituent groups. As fast as technology is evolving, the education and training efforts will need to expand quickly and continue over time. Continual updating and retraining will be needed as technology evolves.

8. Conclusion

In Section 5, using interviewee predictions about the uptake of automated vehicles in different vehicle segments together with public employment data, we found that in the next decade, of the approximately 3.5 million jobs that were subject to our analysis, at most, only a few hundred thousand were likely to be displaced, and mostly toward the end of the decade as uptake of automated vehicles surges. In particular, the outlook for the trucking industry appears to be more positive than earlier reports suggested. Individuals will still be needed in trucks; thus, AVs will supplement, rather than substitute, truck operators over the next decade. The taxi outlook, however, is less positive. These results suggest that focusing on the workforce as a whole is problematic for gauging the impacts of AVs; a more nuanced perspective is needed as there are likely to be different impacts across different sectors of the workforce.

Relatedly, we asked focus group participants the two following questions:

Q. 1. How do you think that automated vehicles will affect the size of the U.S. workforce?
Q. 2. Do you expect the size of your organization's workforce to increase, stay the same, or decrease in the next 2, 5, and 10 years as a result of automated vehicles?

As Table 4 shows, in response to Q. 1, the majority of the 30 respondents expected the US workforce size to stay the same (47 percent) or increase (37 percent). Similarly, in 2 and 5 years, no one believed that automated vehicles would diminish the size of their organization's workforce, with 69 percent of participants saying that automated vehicles would increase it in 2 years, and 72 percent of participants saying that automated vehicles would increase it in 5 years.

Consistent with our projections, looking ahead to 10 years, 12 percent of participants did indicate that they believed that automated vehicles would decrease the size of their organization's workforce. Nevertheless, even then, 49 percent of participants indicated that automated vehicles would increase the size of their organization's workforce and 39 percent indicated that their organization's workforce would remain the same.

Table 4: Focus Group Participants' Projections about AV Impacts on Workforce

	Increase	**Stay the Same**	**Decrease**	**Participants**
Size of US Workforce	37%	47%	16%	30
Organization's workforce: 2 Year Projections	69%	31%	0%	32
Organization's workforce: 5 Year Projections	72%	28%	0%	32
Organization's workforce: 10 Year Projections	49%	39%	12%	33

Based on our findings, the employment outlook that results from automated vehicles is far more optimistic than previous studies (DOC, 2017; Stick Shift, 2017) would have us believe. This said, a relatively positive employment outlook is *not* a reason for complacency. Our findings indicate, that even if they do not engender a substantial change in the number of jobs, automated vehicles entail a tremendous adjustment to the way that workers in many industries do their jobs. In the long run, our research suggests that these changes will be beneficial for workers (and society at large). On average, these changes should permit workers to become more productive at what they do and enable many workers to perform their job more safely. However, in the near term, like many automated processes and technologies before them, automated vehicles entail a shift that needs to be understood so that stakeholders, including governmental entities, can work together to smooth what could otherwise be a bumpy transition.

A number of natural directions that could inform stakeholders arise from our research. Researchers and stakeholders must work to understand the needs and desires of workers who will be most affected, particularly those in driving occupations. Throughout our study, some high-level executives and representatives of major stakeholders lauded the benefits of automated vehicles to drivers (or vehicle operators) whereas others were somewhat more cautious about the potential effects. Rather than assume these benefits, stakeholders need to study the workers themselves to understand what leads certain workers to enter their occupations, what these workers' next best alternatives to their current jobs are, and how workers might respond to technology change in their workplace.

Stakeholders might also benefit from additional empirical research seeking to better understand the demand and supply of technology and other non-driving workers. As our research indicates, motor vehicle manufacturers and technology firms are already finding it difficult to attract or retain certain technology workers and as automated vehicles begin to proliferate, maintenance and certain other occupations will need to evolve and expand. In Section 8, we honed in on what educators and other stakeholders might do to address technology needs, but more research can be undertaken to better inform educators. For instance, with respect to maintenance professionals, researchers can work to better understand existing business structures (i.e., where vehicles are maintained) and the roles of maintenance technicians in these businesses and how these business' hiring and training needs will change as we see more automated vehicles on the road.

Finally, in this report, we only briefly touched on regulation of automated vehicles (see, for instance, Section 9.5 of the Appendix), noting that existing legislation concerning AVs has not focused on workforce issues. However, our conversations with interviewees and focus group participants highlighted how regulation can lead to major implications for the workforce. For instance, as we learned during our study, representatives in the trucking industry believe that restrictions on the age at which a CDL holder can drive a freight truck across state lines have contributed to a truck driver shortage by diminishing career opportunities for workers at an age when many workers make long term career decisions. More can be done to understand, not just how potential future laws pertaining to automated vehicles and the workforce can impact labor markets, but also how existing and anticipated regulations can alter the pace of transition to automated vehicles in different segments of society.

Understanding the impacts of AVs on the workforce is in the infancy stage given the early phases of AV scaling and deployment. As AVs continue to evolve and be deployed across society, additional research will be needed to better ascertain the workforce impacts of AVs and how these impacts change over time and for varying groups in society.

9. Appendix

9.1. State CDL Information

Table 5: State CDL Requirement Websites

State	URL
Alabama	http://dps.alabama.gov/Home/wfContent.aspx?ID=30&PLH1=plhHome-DriverLicense
Alaska	http://doa.alaska.gov/dmv/akol/cdl/
Arizona	https://www.azdot.gov/motor-vehicles/driver-services/commercial-driver-license
Arkansas	https://www.dfa.arkansas.gov/driver-services/commercial-drivers-license-help-desk/
California	https://www.dmv.ca.gov/portal/dmv/detail/commercial/commercial
Colorado	https://www.colorado.gov/pacific/dmv/cdl-general-information
Connecticut	http://www.ct.gov/dmv/cwp/view.asp?a=805&q=526724
Delaware	https://www.dmv.de.gov/services/driver_services/drivers_license/dr_lic_cdl.shtml
DC	https://dmv.dc.gov/service/obtain-commercial-driver-license
Florida	http://www.flhsmv.gov/ddl/cdl.html
Georgia	https://dds.georgia.gov/cdl-apply-commercial-license
Hawaii	http://www.hawaiicounty.gov/finance-cdl-general-info
Idaho	https://trucking.idaho.gov/commercial-drivers-license-cdl/
Illinois	http://www.cyberdriveillinois.com/departments/drivers/drivers_license/CDL/home.html
Indiana	https://www.in.gov/bmv/2529.htm
Iowa	https://iowadot.gov/mvd/cdl/commercial-driver-s-licenses
Kansas	https://www.ksrevenue.org/dovcdl.html
Kentucky	https://drive.ky.gov/driver-licensing/Pages/Commercial-Drivers-License-Information.aspx
Louisiana	https://www.expresslane.org/Pages/default.aspx
Maine	http://www.maine.gov/sos/bmv/licenses/commercialexam.html
Maryland	http://www.mva.maryland.gov/drivers/apply/cdl/commercial.htm
Massachusetts	https://www.mass.gov/commercial-drivers-licenses-cdl
Michigan	https://www.michigan.gov/sos/0,4670,7-127-1627_8669_53324---,00.html
Minnesota	https://dps.mn.gov/divisions/dvs/Pages/dvs-content-detail.aspx?pageID=666
Mississippi	https://www.dps.state.ms.us/driver-services/new-drivers-license/
Missouri	http://dor.mo.gov/drivers/commercial/

State	URL
Montana	https://dojmt.gov/driving/commercial-driver-licensing/
Nebraska	https://dmv.nebraska.gov/cdl/cdl
Nevada	http://www.dmvnv.com/cdl.htm
New Hampshire	https://www.nh.gov/safety/divisions/dmv/driver-licensing/commercial/apply.htm
New Jersey	http://www.state.nj.us/mvc/drivertopics/cdl.htm
New Mexico	http://www.mvd.newmexico.gov/commercial-drivers-licenses.aspx
New York	https://dmv.ny.gov/org/get-cdl
North Carolina	https://www.ncdot.gov/dmv/driver/commercial/
North Dakota	http://www.dot.nd.gov/divisions/driverslicense/cdlrequirements.htm
Ohio	http://www.bmv.ohio.gov/dl-cdl-testing.aspx
Oklahoma	https://www.ok.gov/dps/Obtain_an_Oklahoma_Commercial_Driver_License/CDL_Written_Test.html
Oregon	http://www.oregon.gov/ODOT/DMV/Pages/DriverID/CDLget.aspx
Pennsylvania	http://www.dmv.pa.gov/Driver-Services/Commercial-Driver/Pages/default.aspx
Rhode Island	http://www.dmv.ri.gov/licenses/commercial/
South Carolina	http://www.scdmvonline.com/Driver-Services/Commercial-Licenses/Testing
South Dakota	https://dps.sd.gov/driver-licensing/commercial-drivers-license
Tennessee	https://www.tn.gov/safety/driver-services/commercial-driver-license.html
Texas	https://www.dps.texas.gov/DriverLicense/CommercialLicense.htm
Utah	https://dld.utah.gov/licensingid-cards/commercial-driver-license-cdl/
Vermont	http://dmv.vermont.gov/commercial-services/licenses
Virginia	https://www.dmv.virginia.gov/drivers/#applyingcdl.asp
Washington	http://www.dol.wa.gov/driverslicense/cdl.html
West Virginia	https://transportation.wv.gov/DMV/Motor-Carriers/CDL/Pages/default.aspx
Wisconsin	http://wisconsindot.gov/Pages/dmv/com-drv-vehs/cdl-how-aply/cdloverview.aspx
Wyoming	http://www.dot.state.wy.us/home/driver_license_records/License-Commercial.html

9.2. Technology Occupations

Table 6: BLS/O*Net to Participant Job/“Phrases” Crosswalk

BLS/O*Net Job Category	BLS/O*Net Code	Jobs/“Phrases” Discussed by Participants
Computer and Information Systems Managers	11-3020	“Cybersecurity”
Computer and Information Research Scientists	15-1110	Computer Engineer, “Computer science,” “IT Infrastructure,” “Machine learning/big data/AI,” Software Engineer
Computer and Information Analysts	15-1120	“Cybersecurity,” Data Analyst Software Engineer
Software Developers and Programmers	15-1130	Programmer, Software Engineer
Miscellaneous Computer Occupations	15-1190	Data Analyst, “IT,” Software Engineer, Systems Engineer
Computer Hardware Engineers	17-2060	Computer Engineer, Hardware Engineer
Electrical and Electronics Engineers	17-2070	AV Engineers and Testers, Electrical Engineer, Mechanical Engineer, “work on sensors, radar, and AVs”
Environmental Engineers	17-2080	“Emissions”
Industrial Engineers, Including Health and Safety	17-2110	AV Engineers and Testers, Product Planner, Safety Monitor, Test Driver
Materials Engineers	17-2130	Materials Engineer
Mechanical Engineers	17-2140	Design Engineer, Mechanical Engineer, Systems Engineer
Miscellaneous Engineers	17-2190	Design Engineer, “Design (e.g., Interior of cars),” “Manufacturing”
Engineering Technicians, Except Drafters	17-3020	Control Systems Engineers, Product Planners, Robotics, Signal Processing, Technicians
Commercial and Industrial Designers	27-1021	“Design (e.g., Interior of cars),” UX
Misc. Electrical/Electronic Equip. Mechanics, Installers, & Rep.	49-2090	“Work on sensors, radar, and AVs”

BLS/O*Net **Job Category**	**BLS/O*Net Code**	**Jobs/“Phrases” Discussed by Participants**
Computer Control Programmers and Operators	51-4010	Computer Numerical Controlled (CNC) Operators, “Manufacturing”
Machinists	51-4040	Tool and Die Operators
Tool and Die Makers	51-4110	Tool and Die Operators

Table 7: Technology Jobs in the Motor Vehicle Sector (BLS 2017)[164]

BLS/O*Net Job Category	Number of Jobs	Median Wages
Computer and Information Systems Managers	610	$112,110
Computer and Information Analysts	1,450	$82,769
Computer and Information Research Scientists	--[a]	--[a]
Software Developers and Programmers	2,080	$84,431
Miscellaneous Computer Occupations	340	$62,040
Computer Hardware Engineers	70	$106,220
Electrical and Electronics Engineers	2,820	$84,341
Environmental Engineers	190	$92,549
Industrial Engineers, Including Health and Safety	24,340	$82,084
Materials Engineers	640	$78,510
Mechanical Engineers	17,070	$82,002
Miscellaneous Engineers	2,870	$80,039
Engineering Technicians, Except Drafters	10,640	$50,213
Commercial and Industrial Designers	1,800	$63,461
Misc. Electrical/Electronic Equip. Mechanics, Installers, & Repairers	1,750	$41,647
Computer Control Programmers and Operators	13,380	$37,343
Machinists	22,260	$41,917
Tool and Die Makers	16,100	$59,133
Total	**118,410**	**$62,763**

a. BLS recorded no jobs in this category in the motor vehicle sector in 2017.

[164] The motor vehicle sector consists of North American Industry Classification System (NAICS) Codes 336100 (Motor Vehicle Manufacturing), 336200 (Motor Vehicle Body and Trailer Manufacturing), and 336300 (Motor Vehicle Parts Manufacturing).

Table 8: Technology Jobs in the United States (BLS 2017)

BLS/O*Net Job Category	Number of Jobs	Median Wages
Computer and Information Systems Managers	365,690	$139,220
Computer and Information Analysts	687,210	$89,280
Computer and Information Research Scientists	27,920	$114,520
Software Developers and Programmers	1,617,400	$97,770
Miscellaneous Computer Occupations	315,830	$88,510
Computer Hardware Engineers	66,770	$115,120
Electrical and Electronics Engineers	318,300	$97,970
Environmental Engineers	52,640	$86,800
Industrial Engineers, Including Health and Safety	291,660	$86,090
Materials Engineers	27,200	$94,610
Mechanical Engineers	291,290	$85,880
Miscellaneous Engineers	131,500	$97,250
Engineering Technicians, Except Drafters	427,140	$58,170
Commercial and Industrial Designers	31,250	$65,970
Misc. Electrical and Electronic Equip. Mechanics, Installers, and Repairers	244,120	$51,630
Computer Control Programmers and Operators	168,450	$40,680
Machinists	378,320	$42,600
Tool and Die Makers	73,510	$52,480
Total	**5,516,200**	**$86,439**

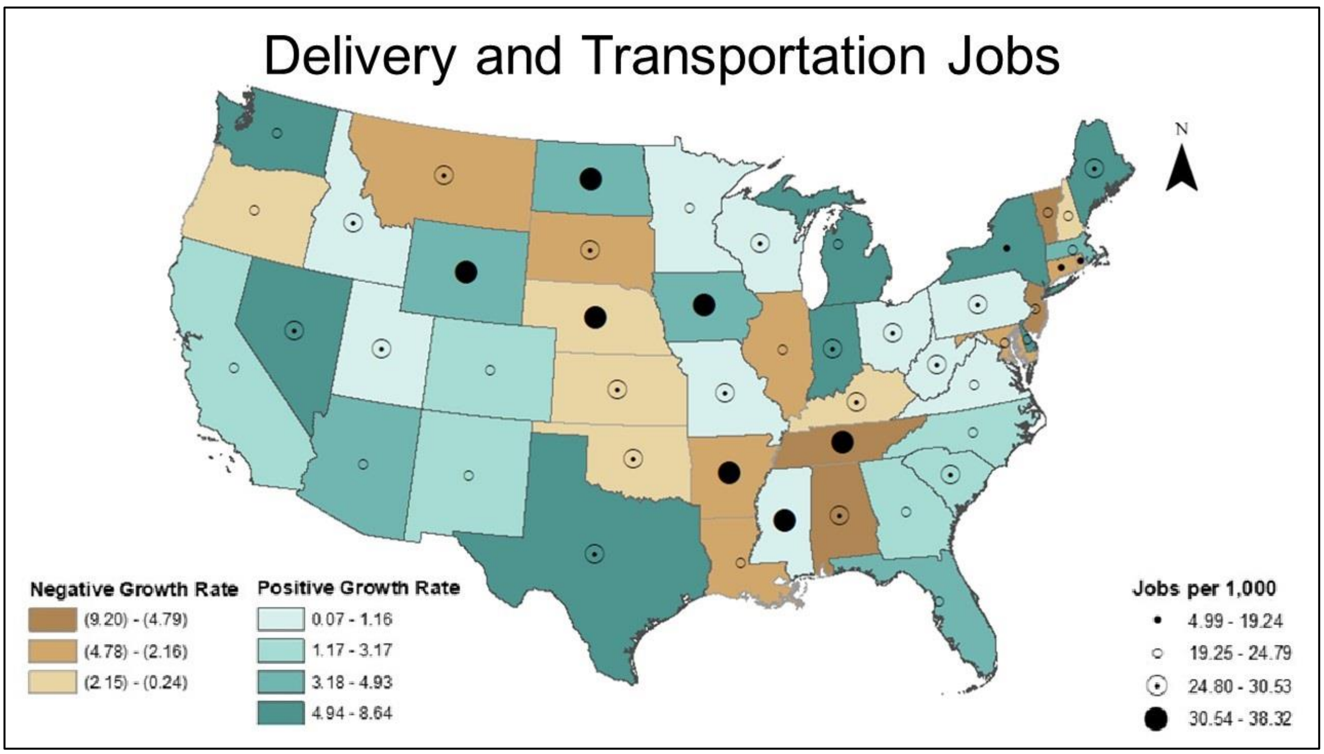
9.3. Economic Appendix

9.3.1. Projection Methodology

In this Appendix, we describe the procedure used to construct our projections of how automated vehicles could impact different segments of the product delivery and passenger transportation labor force.

Baseline Projection: To perform a baseline projection that does not account for the prospective impact of AVs, we obtained eight years (2010-2017) of annual, state-level BLS data on five different job categories: Heavy and Tractor-Trailer Truck Drivers (which we refer to as Long-Distance Freight Drivers); Light Truck and Delivery Service Drivers; Driver/Sales Workers; Taxi Drivers and Chauffeurs; and Bus Drivers, Transit and Intercity (which we refer to as Transit Bus Drivers). Consistent with our discussion in Section 5.1, we combined data for Light Truck and Delivery Service Drivers together with Driver/Sales Workers (which we refer to as Delivery Drivers). Figure 12 displays projected growth in the coming year as well as the percent of drivers in these categories combined at the state level.

Figure 12: Delivery and Transportation Jobs per 1,000 and Growth (BLS 2010-17)[165]



[165] This figure represents jobs and growth for delivery and passenger transportation jobs focused on in Sections 5.1 and 5.2 in this report. It does not include state level data for certain delivery and transportation jobs categorized by BLS.

Because of the small number of observations, our baseline projection is based on log-linear regressions of jobs in each category on an intercept and year. The coefficient on year informs our linear projection in Figure 6, Figure 7, Figure 9, and Figure 11 as well as the "No AV" columns in Table 10, Table 13, Table 15, and Table 17.

"Adjusted" Counterfactual Projection: To conduct projections that account for the potential job losses resulting from the emergence of AVs, we estimate the adoption of AV technologies over time. An outline of the procedure we use is as follows. First, we use interviewee responses to calculate estimated adoption rates at given time periods. Second, we use these estimated adoption rates to create a set of simulated panel data. Third, we use the simulated data to estimate the adoption trend for that specific set of data. Finally, we repeat these steps to estimate a distribution of trend lines for each job category.

To conduct projections, we first associated each of the interviewee responses to a job classification. Specifically, we associated parcel and other delivery vehicles with Delivery Drivers; transit circulators with Bus Drivers, Transit and Intercity; long haul trucks with Heavy and Tractor-Trailer Truck Drivers; and taxicabs/limousines with Taxi Drivers and Chauffeurs. As an example response relating to taxi drivers and chauffeurs, an interviewee might state that he or she believed that in 10 years, 25 percent of taxicabs/limousines on the road would be equipped with Level 4 automation. Interviewees were primarily asked for 5- and 10-year responses for each category (in a few instances, interviewees were asked for 2-year responses).

In order to account for the variability of interviewee responses, rather than naïvely rely on mean responses for each year and job/vehicle category, we employed a Monte Carlo routine with Bootstrapping to forecast AV adoption rates for each job classifications.[166] The Monte Carlo method revolves around repeatedly estimating a model using simulated data, with parameters of the data either assigned by the researcher or calibrated based on external information. Herein, the parameters are derived from the responses of the interviewed industry experts. Green (2002) provides an overview of Monte Carlo routines in Appendix E; bootstrapping is described in Appendix E.4.

For each repetition of this Monte Carlo routine, we created a panel of simulated data. To form the data set, 1,000 observations were assigned a propensity to adopt Level 4 AVs, drawn randomly from a uniform [0,1] distribution. These data were then transformed into a 10-year panel.[167] Thresholds for adoption were calculated using a Bootstrapping routine that drew, with replacement, 20 draws from the population of responses on the estimated adoption of Level 4 AVs 2, 5 and, 10 years in the future. The means of these Bootstrapped sampling distributions serve as adoption thresholds for the given years (2, 5, and 10). Then, for each of the 1,000

[166] The naïve approach that uses the average adoption figures provided by respondents for each category would not incorporate the variability of response in the estimation of AV adoption, allow for estimation of adoption rates in time periods for which we do not have survey responses, or employ an established model of technology diffusion.

[167] We transformed data into a panel by copying each observation (identified by ID) 9 times and then assigning observations a "time" in order from 1 to 10. Thus, each ID would have 10 records with an identical propensity to adopt and each record corresponds to a single year.

observations, if the observation's randomly drawn propensity to adopt fell below the threshold, that observation was designated as having adopted at that time-period.[168] We use the panel of data generated from the Monte Carlo routine to conduct a "survival analysis" that forms the crux of our projections.

For each repetition of the Monte Carlo routine, we follow the general approach to modeling the diffusion of technologies as outlined in Georski (2000). We model the rate of AV adoption for a given repetition of the Monte Carlo routine using a Gompertz diffusion curve. Link and Scott (2003) provide a description of the survival- and hazard-functions for Gompertz diffusion model. The Gompertz model is a diffusion model that assumes a monotonically increasing hazard rate.[169] In the initial time-period there is some probability that a given person will adopt a technology. This probability increases monotonically in each successive time-period. The statistical model of the Gompertz curve estimates both the initial propensity to adopt and the increase in this probability over time.[170] Using each repetition of the Monte Carlo routine, we estimate the parameters of the Gompertz curve.

We repeated the process of data set formulation, threshold calculation, and estimation 100 times for each job category. We then used the means of the set of estimated coefficients from the Monte Carlo repetitions as the parameters for the Gompertz diffusion curve to form projections of AV adoption and potential job displacement for each job category.[171] Cumulative adoption of AVs at any time-period can be calculated as the percentage of observations that has already adopted in the past added to the hazard rate in the current time-period multiplied by the remaining population that hasn't adopted. Figure 13 displays the projections of AV adoption for each job category as well as for passenger cars.

We approximate the sampling distribution of our estimated adoption trends using the bootstrapping method previously described. We approximated the 90% confidence intervals of the forecasts using the precentile method. That is, we use the 5th and 95th percentile of adoption from the repeated estimations as the upper and lower bounds for the confidence interval for each year. Lam and Veall (2002) provide a description for how one may calculate these bounds in their comparison of the relative performance of methods for estimating standard errors.

Our estimations of displaced jobs are calculated assuming a 1-to-1 relationship between AV adoption and replacement of jobs. This means that 20% adoption of AVs is estimated to replace 20% of the jobs in a given job category relative to the baseline of the projection. This may lead to an overestimation of job displacement if AVs do not replace jobs at a 1-to-1 rate.

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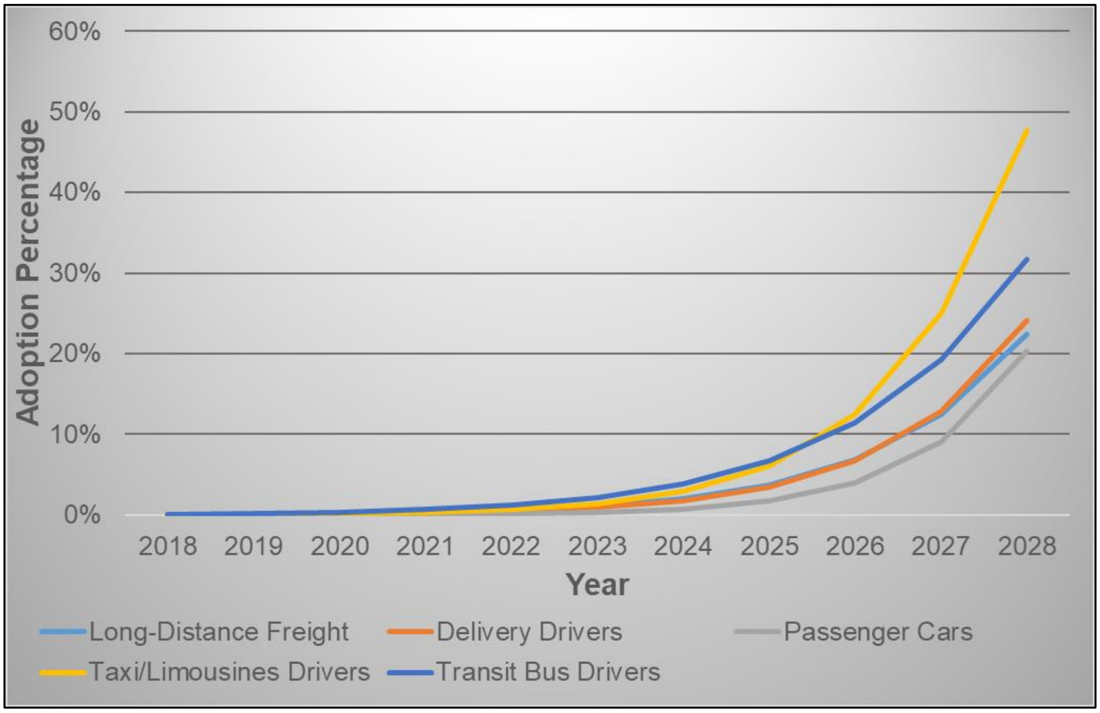
[168] For instance, if an ID's (see footnote 167) randomly assigned propensity was 0.01 and the adoption threshold in year 2 was 0.015 then the observation would have adopted AV technology in year 2. We repeated this for each observation for years 2, 5, and 10.

[169] More precisely, the Gompertz diffusion model is a form of survival analysis in which maximum-likelihood estimation is used to estimate the hazard rate (i.e., probability of adoption at a given time) for the data.

[170] The Gompertz specification estimates two specific parameters: one that determines the hazard rate at time period 0 and one that determines the increase in the hazard rate from one time period to the next.

[171] We note that to smooth over idiosyncrasies inherent in baseline state projections, our estimates of job displacement are relative to the nationwide baseline trend (no AV counterfactual).

Figure 13: Projected AV Adoption by Job/Vehicle Category



9.3.2. State Data Tables

Table 9: Long-Distance Freight Trucking Statistics by State (BLS 2017)[172]

State	Total Jobs	Jobs per 1,000	Growth Rate	Median Income
Alabama	30,720	15.977	1.26%	$38,390
Alaska	2,640	8.304	-3.09%	$54,270
Arizona	23,030	8.519	1.03%	$42,320
Arkansas	32,640	27.198	1.48%	$37,930
California	137,930	8.262	2.37%	$43,970
Colorado	21,990	8.604	1.69%	$45,370
Connecticut	12,940	7.822	2.67%	$47,280
Delaware	4,110	9.291	3.12%	$41,150
DC	510	0.718	-3.68%	$49,340
Florida	85,390	10.143	4.07%	$38,240
Georgia	56,450	13.118	3.09%	$41,770
Hawaii	3,290	5.198	0.96%	$46,880
Idaho	11,810	17.226	1.15%	$39,680
Illinois	70,920	11.964	1.80%	$47,040
Indiana	51,830	17.171	1.43%	$44,570
Iowa	38,110	24.819	1.52%	$40,280
Kansas	20,410	14.905	0.35%	$41,130
Kentucky	25,210	13.433	0.38%	$41,330
Louisiana	21,190	11.140	-1.06%	$39,800
Maine	8,800	14.693	-0.97%	$38,060
Maryland	23,640	8.872	2.67%	$45,590
Massachusetts	25,790	7.309	3.00%	$49,050
Michigan	55,560	12.994	2.67%	$40,020
Minnesota	35,420	12.481	2.09%	$45,180
Mississippi	22,570	20.161	1.67%	$38,060
Missouri	43,600	15.633	1.25%	$42,350

[172] Data for Total Jobs, Jobs per 1,000, and Median Income obtained from Bureau of Labor Statistics, Occupational Employment Statistics. Available at https://www.bls.gov/oes/.

State	Total Jobs	Jobs per 1,000	Growth Rate	Median Income
Montana	6,420	13.943	1.37%	$43,400
Nebraska	26,540	27.358	0.51%	$40,610
Nevada	11,630	8.877	4.36%	$49,270
New Hampshire	6,320	9.731	0.48%	$43,450
New Jersey	45,650	11.391	2.08%	$47,110
New Mexico	9,940	12.411	2.98%	$40,780
New York	58,870	6.393	2.60%	$45,540
North Carolina	55,430	12.897	3.52%	$41,070
North Dakota	11,000	26.388	5.41%	$51,850
Ohio	74,310	13.836	2.64%	$41,790
Oklahoma	24,680	15.692	1.35%	$41,370
Oregon	23,290	12.723	1.38%	$44,400
Pennsylvania	80,810	13.977	2.83%	$44,800
Rhode Island	3,220	6.766	2.87%	$46,260
South Carolina	27,610	13.740	4.84%	$39,850
South Dakota	7,820	18.634	0.77%	$38,550
Tennessee	60,350	20.698	1.22%	$39,640
Texas	182,370	15.337	5.57%	$40,360
Utah	23,500	16.658	4.66%	$44,430
Vermont	3,370	11.053	-1.87%	$42,040
Virginia	41,150	10.857	2.40%	$40,350
Washington	32,030	10.052	2.77%	$45,530
West Virginia	11,010	15.992	-0.67%	$36,840
Wisconsin	48,400	17.132	2.11%	$41,900
Wyoming	5,910	22.046	1.01%	$48,250

Table 10: Long-Distance Freight Trucking Projections by State

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Alabama	33,038	32,699	35,532	27,565
Alaska	2,839	2,810	3,054	2,369
Arizona	24,768	24,514	26,637	20,665
Arkansas	35,103	34,743	37,752	29,288
California	148,339	146,817	159,534	123,766
Colorado	23,650	23,407	25,434	19,732
Connecticut	13,917	13,774	14,967	11,611
Delaware	4,420	4,375	4,754	3,688
DC	548	543	590	458
Florida	91,834	90,892	98,765	76,622
Georgia	60,710	60,087	65,292	50,653
Hawaii	3,538	3,502	3,805	2,952
Idaho	12,701	12,571	13,660	10,597
Illinois	76,272	75,490	82,028	63,637
Indiana	55,742	55,170	59,948	46,508
Iowa	40,986	40,566	44,079	34,197
Kansas	21,950	21,725	23,607	18,314
Kentucky	27,113	26,834	29,159	22,621
Louisiana	22,789	22,555	24,509	19,014
Maine	9,464	9,367	10,178	7,896
Maryland	25,424	25,163	27,343	21,212
Massachusetts	27,736	27,452	29,830	23,142
Michigan	59,753	59,140	64,262	49,855
Minnesota	38,093	37,702	40,968	31,783
Mississippi	24,273	24,024	26,105	20,252
Missouri	46,890	46,409	50,429	39,123
Montana	6,905	6,834	7,426	5,761

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Nebraska	28,543	28,250	30,697	23,815
Nevada	12,508	12,379	13,452	10,436
New Hampshire	6,797	6,727	7,310	5,671
New Jersey	49,095	48,591	52,800	40,962
New Mexico	10,690	10,580	11,497	8,919
New York	63,313	62,663	68,091	52,825
North Carolina	59,613	59,002	64,112	49,738
North Dakota	11,830	11,709	12,723	9,870
Ohio	79,918	79,098	85,949	66,679
Oklahoma	26,543	26,270	28,546	22,146
Oregon	25,048	24,791	26,938	20,898
Pennsylvania	86,909	86,017	93,467	72,512
Rhode Island	3,463	3,427	3,724	2,889
South Carolina	29,694	29,389	31,935	24,775
South Dakota	8,410	8,324	9,045	7,017
Tennessee	64,905	64,239	69,803	54,153
Texas	196,133	194,121	210,935	163,643
Utah	25,274	25,014	27,181	21,087
Vermont	3,624	3,587	3,898	3,024
Virginia	44,256	43,801	47,595	36,924
Washington	34,447	34,094	37,047	28,741
West Virginia	11,841	11,719	12,735	9,879
Wisconsin	8,744	8,654	9,403	7,295
Wyoming	52,053	51,519	55,981	43,430

Table 11: Delivery Driver Statistics by State (BLS 2017)[173]

State	Total Jobs	Jobs per 1,000	Growth Rate
Alabama	18,120	9.424	-0.83%
Alaska	2,460	7.746	-4.49%
Arizona	23,430	8.665	2.31%
Arkansas	10,110	8.424	-0.11%
California	144,450	8.652	2.14%
Colorado	26,320	10.299	2.83%
Connecticut	13,590	8.209	-0.91%
Delaware	3,920	8.878	1.60%
DC	2,240	3.152	7.10%
Florida	82,790	9.833	3.39%
Georgia	41,350	9.607	0.79%
Hawaii	6,320	9.972	4.27%
Idaho	6,360	9.270	0.46%
Illinois	59,360	10.014	2.63%
Indiana	29,640	9.820	2.12%
Iowa	12,480	8.125	0.42%
Kansas	12,360	9.022	0.85%
Kentucky	19,190	10.225	0.74%
Louisiana	18,840	9.901	0.59%
Maine	6,470	10.798	3.78%
Maryland	27,580	10.353	1.82%
Massachusetts	30,500	8.644	2.26%
Michigan	40,140	9.386	2.87%
Minnesota	25,590	9.018	1.79%
Mississippi	11,160	9.974	0.81%
Missouri	26,240	9.412	2.25%

[173] Data for Total Jobs and Jobs per 1,000 obtained from Bureau of Labor Statistics, Occupational Employment Statistics. Available at https://www.bls.gov/oes/.

State	Total Jobs	Jobs per 1,000	Growth Rate
Montana	5,210	11.321	0.66%
Nebraska	7,570	7.803	0.22%
Nevada	10,670	8.147	2.98%
New Hampshire	6,560	10.080	1.01%
New Jersey	37,680	9.404	2.42%
New Mexico	7,160	8.936	1.33%
New York	68,730	7.465	1.86%
North Carolina	41,040	9.548	1.27%
North Dakota	4,250	10.213	0.93%
Ohio	58,240	10.844	2.08%
Oklahoma	13,670	8.691	1.76%
Oregon	15,620	8.532	0.42%
Pennsylvania	53,710	9.289	-0.40%
Rhode Island	5,210	10.937	2.16%
South Carolina	20,910	10.410	2.60%
South Dakota	4,200	10.012	1.11%
Tennessee	26,420	9.062	-0.75%
Texas	109,500	9.209	4.69%
Utah	10,800	7.657	1.05%
Vermont	2,860	9.388	-0.35%
Virginia	32,330	8.529	1.25%
Washington	26,750	8.397	3.74%
West Virginia	7,440	10.808	0.59%
Wisconsin	23,590	8.349	-0.37%
Wyoming	3,140	11.721	2.35%

Table 12: Delivery Driver Disambiguation (BLS 2017)

State	Light Truck Jobs	Light Truck Median Income	Driver/Sales Jobs	Driver/Sales Median Income
Alabama	12,930	$25,790	5,190	$31,710
Alaska	1,860	$41,050	600	$26,850
Arizona	14,830	$32,390	8,600	$25,220
Arkansas	6,720	$27,320	3,390	$21,880
California	103,760	$34,140	40,690	$30,880
Colorado	17,780	$35,410	8,540	$24,550
Connecticut	10,270	$35,220	3,320	$25,080
Delaware	2,330	$32,100	1,590	$19,490
DC	1,740	$25,740	500	$26,630
Florida	54,000	$29,840	28,790	$20,950
Georgia	25,390	$32,060	15,960	$20,210
Hawaii	4,510	$34,230	1,810	$26,260
Idaho	3,790	$28,230	2,570	$25,470
Illinois	45,550	$33,320	13,810	$19,810
Indiana	18,310	$28,720	11,330	$19,060
Iowa	8,540	$30,650	3,940	$19,600
Kansas	8,450	$31,680	3,910	$28,240
Kentucky	13,850	$30,690	5,340	$19,390
Louisiana	15,050	$29,300	3,790	$20,130
Maine	4,360	$27,930	2,110	$28,160
Maryland	21,260	$34,410	6,320	$22,640
Massachusetts	21,160	$35,820	9,340	$29,320
Michigan	27,290	$31,040	12,850	$20,050
Minnesota	15,550	$35,960	10,040	$23,990
Mississippi	7,180	$27,540	3,980	$20,270
Missouri	16,510	$30,720	9,730	$23,970
Montana	3,700	$30,240	1,510	$25,860

State	Light Truck Jobs	Light Truck Median Income	Driver/Sales Jobs	Driver/Sales Median Income
Nebraska	4,740	$30,260	2,830	$25,850
Nevada	6,870	$32,670	3,800	$30,330
New Hampshire	4,280	$28,290	2,280	$26,780
New Jersey	29,070	$34,550	8,610	$29,510
New Mexico	4,680	$31,670	2,480	$18,920
New York	46,000	$31,450	22,730	$22,060
North Carolina	25,750	$28,790	15,290	$22,940
North Dakota	2,310	$38,420	1,940	$26,340
Ohio	36,610	$29,680	21,630	$19,700
Oklahoma	8,640	$30,670	5,030	$23,810
Oregon	9,190	$33,500	6,430	$29,300
Pennsylvania	35,900	$28,930	17,810	$21,110
Rhode Island	3,660	$29,450	1,550	$23,860
South Carolina	13,780	$27,150	7,130	$19,350
South Dakota	2,840	$28,530	1,360	$29,260
Tennessee	18,320	$32,260	8,100	$20,780
Texas	65,380	$29,840	44,120	$25,000
Utah	7,820	$31,340	2,980	$24,620
Vermont	2,180	$32,040	680	$32,070
Virginia	21,580	$29,080	10,750	$22,310
Washington	18,710	$36,240	8,040	$25,200
West Virginia	4,870	$26,750	2,570	$19,950
Wisconsin	16,290	$29,000	7,300	$28,210
Wyoming	1,530	$34,710	1,610	$26,570

Table 13: Delivery Driver Projections by State

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Alabama	19,383	19,208	20,733	15,728
Alaska	2,631	2,608	2,815	2,135
Arizona	25,063	24,837	26,809	20,337
Arkansas	10,815	10,717	11,568	8,775
California	154,516	153,127	165,284	125,383
Colorado	28,154	27,901	30,116	22,846
Connecticut	14,537	14,406	15,550	11,796
Delaware	4,193	4,155	4,485	3,403
DC	2,396	2,375	2,563	1,944
Florida	88,559	87,763	94,731	71,862
Georgia	44,232	43,834	47,314	35,892
Hawaii	6,760	6,700	7,232	5,486
Idaho	6,803	6,742	7,277	5,520
Illinois	63,497	62,926	67,922	51,525
Indiana	31,706	31,421	33,915	25,728
Iowa	13,350	13,230	14,280	10,833
Kansas	13,221	13,102	14,143	10,729
Kentucky	20,527	20,343	21,958	16,657
Louisiana	20,153	19,972	21,557	16,353
Maine	6,921	6,859	7,403	5,616
Maryland	29,502	29,237	31,558	23,939
Massachusetts	32,625	32,332	34,899	26,474
Michigan	42,937	42,551	45,929	34,842
Minnesota	27,373	27,127	29,281	22,212
Mississippi	11,938	11,830	12,770	9,687
Missouri	28,069	27,816	30,025	22,776
Montana	5,573	5,523	5,961	4,522

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Nebraska	8,098	8,025	8,662	6,571
Nevada	11,414	11,311	12,209	9,262
New Hampshire	7,017	6,954	7,506	5,694
New Jersey	40,306	39,943	43,115	32,706
New Mexico	7,659	7,590	8,193	6,215
New York	73,520	72,859	78,643	59,658
North Carolina	43,900	43,505	46,959	35,623
North Dakota	4,546	4,505	4,863	3,689
Ohio	62,299	61,739	66,640	50,552
Oklahoma	14,623	14,491	15,642	11,866
Oregon	16,709	16,558	17,873	13,558
Pennsylvania	57,453	56,936	61,457	46,620
Rhode Island	5,573	5,523	5,961	4,522
South Carolina	22,367	22,166	23,926	18,150
South Dakota	4,493	4,452	4,806	3,646
Tennessee	28,261	28,007	30,231	22,933
Texas	117,131	116,078	125,293	95,046
Utah	11,553	11,449	12,358	9,374
Vermont	3,059	3,032	3,273	2,482
Virginia	34,583	34,272	36,993	28,063
Washington	28,614	28,357	30,608	23,219
West Virginia	7,958	7,887	8,513	6,458
Wisconsin	25,234	25,007	26,992	20,476
Wyoming	3,359	3,329	3,593	2,726

Table 14: Taxi Driver and Chauffeur Statistics by State (BLS 2017)[174]

State	Total Jobs	Jobs per 1,000	Growth Rate	Median Income
Alabama	1,360	0.708	2.64%	$21,550
Alaska	410	1.298	6.75%	$25,950
Arizona	5,470	2.024	8.17%	$23,400
Arkansas	1,950	1.624	6.47%	$21,130
California	24,370	1.460	8.22%	$28,620
Colorado	2,430	0.949	7.45%	$27,100
Connecticut	3,580	2.164	1.83%	$25,910
Delaware	570	1.276	-1.34%	$25,130
DC	410	0.578	-18.86%	$34,130
Florida	10,080	1.198	2.92%	$23,700
Georgia	3,550	0.826	0.90%	$20,390
Hawaii	1,290	2.037	2.45%	$27,550
Idaho	530	0.773	-1.15%	$20,250
Illinois	7,820	1.319	2.43%	$25,050
Indiana	2,620	0.868	0.64%	$21,860
Iowa	1,500	0.975	1.31%	$23,040
Kansas	1,340	0.979	1.64%	$22,240
Kentucky	2,510	1.339	0.71%	$21,010
Louisiana	2,480	1.303	2.12%	$21,650
Maine	950	1.588	0.33%	$24,370
Maryland	4,300	1.612	2.81%	$26,130
Massachusetts	9,510	2.694	5.15%	$28,180
Michigan	4,840	1.132	4.24%	$22,480
Minnesota	3,210	1.132	2.26%	$27,140
Mississippi	910	0.816	-1.15%	$19,330
Missouri	2,800	1.005	-2.88%	$23,690

[174] Data for Total Jobs, Jobs per 1,000, and Median Income obtained from Bureau of Labor Statistics, Occupational Employment Statistics. Available at https://www.bls.gov/oes/.

State	Total Jobs	Jobs per 1,000	Growth Rate	Median Income
Montana	450	0.968	-3.25%	$23,590
Nebraska	1,370	1.414	-4.56%	$23,030
Nevada	10,700	8.163	1.61%	$26,370
New Hampshire	1,470	2.256	5.00%	$23,630
New Jersey	8,660	2.161	2.70%	$26,970
New Mexico	1,120	1.393	2.72%	$24,260
New York	16,230	1.763	1.84%	$28,940
North Carolina	3,380	0.787	3.90%	$23,610
North Dakota	570	1.378	-3.09%	$27,110
Ohio	7,840	1.460	4.21%	$21,610
Oklahoma	1,560	0.991	9.32%	$20,900
Oregon	1,930	1.053	6.17%	$25,050
Pennsylvania	7,990	1.383	-1.98%	$23,980
Rhode Island	570	1.202	-6.69%	$24,620
South Carolina	1,600	0.797	7.37%	$21,770
South Dakota	500	1.197	0.28%	$24,490
Tennessee	2,690	0.922	7.87%	$22,000
Texas	11,260	0.947	-1.02%	$24,380
Utah	1,510	1.069	1.08%	$23,280
Vermont	630	2.049	4.81%	$24,010
Virginia	5,310	1.400	1.76%	$26,220
Washington	3,450	1.081	0.36%	$28,160
West Virginia	960	1.397	0.21%	$19,740
Wisconsin	5,420	1.918	6.59%	$22,080
Wyoming	520	1.944	9.44%	$23,850

Table 15: Taxi Driver and Chauffeur Projections by State

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Alabama	1,535	1,514	1,732	906
Alaska	463	456	522	273
Arizona	6,172	6,089	6,964	3,644
Arkansas	2,200	2,171	2,483	1,299
California	27,498	27,127	31,028	16,235
Colorado	2,742	2,705	3,094	1,619
Connecticut	4,040	3,985	4,558	2,385
Delaware	643	634	726	380
DC	463	456	522	273
Florida	11,374	11,220	12,834	6,715
Georgia	4,006	3,952	4,520	2,365
Hawaii	1,456	1,436	1,642	859
Idaho	598	590	675	353
Illinois	8,824	8,705	9,956	5,210
Indiana	2,956	2,916	3,336	1,745
Iowa	1,693	1,670	1,910	999
Kansas	1,512	1,492	1,706	893
Kentucky	2,832	2,794	3,196	1,672
Louisiana	2,798	2,761	3,158	1,652
Maine	1,072	1,057	1,210	633
Maryland	4,852	4,786	5,475	2,865
Massachusetts	10,731	10,586	12,108	6,335
Michigan	5,461	5,388	6,162	3,224
Minnesota	3,622	3,573	4,087	2,138
Mississippi	1,027	1,013	1,159	606
Missouri	3,159	3,117	3,565	1,865
Montana	508	501	573	300

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Nebraska	1,546	1,525	1,744	913
Nevada	12,073	11,910	13,623	7,128
New Hampshire	1,659	1,636	1,872	979
New Jersey	9,772	9,640	11,026	5,769
New Mexico	1,264	1,247	1,426	746
New York	18,313	18,066	20,664	10,812
North Carolina	3,814	3,762	4,303	2,252
North Dakota	643	634	726	380
Ohio	8,846	8,727	9,982	5,223
Oklahoma	1,760	1,736	1,986	1,039
Oregon	2,178	2,148	2,457	1,286
Pennsylvania	9,016	8,894	10,173	5,323
Rhode Island	643	634	726	380
South Carolina	1,805	1,781	2,037	1,066
South Dakota	564	557	637	333
Tennessee	3,035	2,994	3,425	1,792
Texas	12,705	12,534	14,336	7,501
Utah	1,704	1,681	1,923	1,006
Vermont	711	701	802	420
Virginia	5,992	5,911	6,761	3,537
Washington	3,893	3,840	4,393	2,298
West Virginia	1,083	1,069	1,222	640
Wisconsin	6,116	6,033	6,901	3,611
Wyoming	587	579	662	346

Table 16: Transit Bus Drivers Statistics by State (BLS 2017)[175]

State	Total Jobs	Jobs per 1,000	Growth Rate	Median Income
Alabama	1,310	0.681	-3.99%	$26,200
Alaska	390	1.219	-4.34%	$50,930
Arizona	3,660	1.355	0.04%	$39,530
Arkansas	310	0.257	2.30%	$28,540
California	23,350	1.398	-1.77%	$43,950
Colorado	3,380	1.321	-1.32%	$38,250
Connecticut	1,550	0.936	-1.55%	$45,880
Delaware	390	0.875	9.28%	$41,800
DC	390	0.547	6.43%	$36,290
Florida	11,590	1.377	2.38%	$31,510
Georgia	3,660	0.850	-0.41%	$31,370
Hawaii	2,320	3.672	-2.04%	$44,730
Idaho	590	0.861	-2.42%	$31,670
Illinois	7,990	1.349	-7.13%	$53,030
Indiana	1,830	0.606	2.18%	$37,140
Iowa	1,750	1.140	1.98%	$33,120
Kansas	610	0.448	-1.76%	$30,530
Kentucky	1,870	0.994	4.98%	$29,460
Louisiana	1,110	0.585	-3.39%	$33,840
Maine	400	0.667	7.52%	$36,870
Maryland	5,310	1.993	10.45%	$38,090
Massachusetts	4,990	1.414	7.05%	$49,820
Michigan	5,090	1.190	-0.26%	$32,700
Minnesota	3,880	1.368	1.59%	$36,400
Mississippi	700	0.622	-1.43%	$27,120
Missouri	2,780	0.997	-1.68%	$40,330

[175] Data for Total Jobs, Jobs per 1,000, and Median Income obtained from Bureau of Labor Statistics, Occupational Employment Statistics. Available at https://www.bls.gov/oes/.

State	Total Jobs	Jobs per 1,000	Growth Rate	Median Income
Montana	560	1.209	10.68%	$32,850
Nebraska	840	0.863	10.27%	$43,350
Nevada	2,740	2.090	1.66%	$29,830
New Hampshire	280	0.425	-3.16%	$42,720
New Jersey	7,350	1.833	-4.44%	$47,840
New Mexico	740	0.918	-0.32%	$29,510
New York	21,830	2.371	2.14%	$65,250
North Carolina	3,870	0.899	1.61%	$30,920
North Dakota	140	0.345	-2.59%	$36,120
Ohio	6,390	1.189	3.88%	$41,970
Oklahoma	940	0.595	0.12%	$24,160
Oregon	2,790	1.527	2.63%	$45,120
Pennsylvania	5,320	0.921	-5.47%	$36,760
Rhode Island	100	0.211	-16.30%	$36,230
South Carolina	830	0.411	-2.18%	$30,190
South Dakota	290	0.686	-6.24%	$30,700
Tennessee	2,560	0.878	0.84%	$36,760
Texas	12,420	1.044	2.16%	$38,380
Utah	960	0.680	0.37%	$33,090
Vermont	520	1.693	-3.63%	$39,390
Virginia	5,150	1.358	1.48%	$39,330
Washington	5,470	1.716	-5.99%	$57,270
West Virginia	600	0.875	-4.88%	$33,910
Wisconsin	2,080	0.738	-7.15%	$46,770
Wyoming	210	0.801	-7.55%	$32,020

Table 17: Transit Bus Drivers Projections by State

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Alabama	1,284	1,256	1,258	860
Alaska	382	374	375	256
Arizona	3,587	3,509	3,515	2,403
Arkansas	304	297	298	204
California	22,884	22,385	22,427	15,329
Colorado	3,313	3,240	3,246	2,219
Connecticut	1,519	1,486	1,489	1,018
Delaware	382	374	375	256
DC	382	374	375	256
Florida	11,359	11,111	11,132	7,609
Georgia	3,587	3,509	3,515	2,403
Hawaii	2,274	2,224	2,228	1,523
Idaho	578	566	567	387
Illinois	7,831	7,660	7,674	5,245
Indiana	1,793	1,754	1,758	1,201
Iowa	1,715	1,678	1,681	1,149
Kansas	598	585	586	400
Kentucky	1,833	1,793	1,796	1,228
Louisiana	1,088	1,064	1,066	729
Maine	392	383	384	263
Maryland	5,204	5,090	5,100	3,486
Massachusetts	4,890	4,784	4,793	3,276
Michigan	4,988	4,880	4,889	3,342
Minnesota	3,803	3,720	3,727	2,547
Mississippi	686	671	672	460
Missouri	2,725	2,665	2,670	1,825
Montana	549	537	538	368

State	2023 Jobs No AVs	2023 Jobs AV Adjusted	2028 Jobs No AVs	2028 Jobs AV Adjusted
Nebraska	823	805	807	551
Nevada	2,685	2,627	2,632	1,799
New Hampshire	274	268	269	184
New Jersey	7,203	7,046	7,060	4,825
New Mexico	725	709	711	486
New York	21,394	20,927	20,967	14,331
North Carolina	3,793	3,710	3,717	2,541
North Dakota	137	134	134	92
Ohio	6,262	6,126	6,138	4,195
Oklahoma	921	901	903	617
Oregon	2,734	2,675	2,680	1,832
Pennsylvania	5,214	5,100	5,110	3,493
Rhode Island	98	96	96	66
South Carolina	813	796	797	545
South Dakota	284	278	279	190
Tennessee	2,509	2,454	2,459	1,681
Texas	12,172	11,906	11,929	8,154
Utah	941	920	922	630
Vermont	510	498	499	341
Virginia	5,047	4,937	4,947	3,381
Washington	5,361	5,244	5,254	3,591
West Virginia	588	575	576	394
Wisconsin	2,038	1,994	1,998	1,366
Wyoming	206	201	202	138

9.4. Automated Vehicles: Society and Technology – A Brief Review

In this section, we place AVs in a broader context by describing how they presently fit into society. We begin with a brief history of the automobile, with a focus on more recent developments, such as that of the electric car and automated vehicles. We then briefly describe AV technologies and approaches to object detection. We conclude this section with a review of studies of social perceptions of AVs, including perceived benefits and concerns.

9.4.1. A Brief History: The Automobile and AVs

Over a 130-year history, the automobile has had a profound impact on the modern era. The early history of the automobile can be divided into a number of periods, initially based on the prevalent means of propulsion, and with later periods being defined by trends in exterior styling, size, and utility preferences (Parissien, 2014).

In the U.S., Charles and Frank Duryea founded the Duryea Motor Wagon Company in 1893 and became the first American automobile manufacturing company. However, Ransom E. Olds and Olds Motor Vehicle Company (later known as Oldsmobile) dominated the era of automobile production, when the Olds Motor Vehicle Company production line started operation in 1902. The Thomas B. Jeffery Company developed the world's second mass-produced automobile and 1,500 Ramblers were built and sold in its first year, representing one-sixth of all existing motorcars in the U.S. The 20th century saw the development and dissemination of mass produced and consumed automobiles, with much of this development being attributed to Henry Ford and technology proliferation (Bailey, Ruyter, Michie, and Tyler, 2010). Throughout the late 19th and early 20th centuries the development of automotive technology was rapid and due, in part, to competition between hundreds of small manufacturers that existed in the U.S. prior to consolidation in the early 1900s (Parissien, 2014).

The emergence of the automobile precipitated a decline in horse-powered transportation and jobs, while giving rise to various new areas of employment. For instance, horse-cars were a common form of urban transport in the U.S. in the late 19th century.[176] Most horse-cars were operated by private companies rather than owned by individuals. Once street cars, and later, mass produced gas-powered automobiles began to displace horse-cars, professions such as horse-car driver, and hackney declined rapidly, while giving way to motor cab operators (McShane and Tarr, 2003). We note that while the spread of the motor car impacted other jobs in horse transportation,[177] it changed the responsibilities of, but did not eliminate, driving occupations.

It was only a decade after the U.S. motor vehicle industry came to be dominated by General Motors, Ford, and Chrysler, that Norman Bel Geddes, in the General Motors Futurama exhibit at the 1939-1940 New York World's Fair, introduced the concept of vehicle automation (Bel

[176] In January 1887, there were 20,392 cars and 98,659 horses in the U.S. (McShane and Tarr, 2003).
[177] Other occupations, such as blacksmiths and stable hands also declined due to the spread of the automobile, whereas occupations in industries, such as the roadside motel and fast food, that served the "motoring public," grew in number (Autor 2015).

Geddes, 1940). Indeed, AVs have a considerable history in the U.S. Shladover (1990, 2016, 2017) delineates four waves of AV development in the U.S.

The first wave of research and developments with regard to automated road vehicles was undertaken by General Motors and RCA Sarnoff Laboratory (Radio Corporation of America) in the 1950s (Bender, 1991). Using test tracks, General Motors and RCA developed and demonstrated automatic control of steering and longitudinal spacing of automobiles for what they called the "Electronic Highway." Major federal government involvement in roadway automation began with the New Transportation Systems Research Act of 1966. The Act instructed the U.S. Departments of Housing and Urban Development and Commerce to study new systems for urban transportation (Shladover, 1990). The "New Systems Study" led to the creation of a series of reports by the Stanford Research Institute and General Research Corporation. A summary report in 1968 entitled "Tomorrow's Transportation: New Systems for the Urban Future," recommended development of six new urban transportation systems. Specifically, one system called "dual mode," was essentially the automated roadway using vehicles that could operate in either a manual or an automated mode.

A second wave of research and development stemmed from the Ohio State University from 1964 to 1980 (Fenton & Mayhan, 1991). The program included studies on headway[178] safety policy,[179] studies of longitudinal (acceleration and deceleration) and lateral (steering) control of individual vehicles, and studies of automated traffic on a typical urban highway network. During this time, the DOT Transportation Systems Center (TSC) conducted an economic evaluation of dual mode from 1971 to 1973. The primary recommendation from the evaluation was that dual mode systems be developed for both transit and private (automotive) vehicles. The Urban Mass Transit Administration (UMTA) initiated studies of three different dual mode transit (bus and pallet[180]) systems in 1973 (Shladover, 1990). However, the program never moved beyond the initial concept development phase and dual mode lost favor in the transportation industry.

The founding of the Partners for Advanced Transit and Highways (PATH) Program by the California Department of Transportation (Caltrans) and the University of California in 1986 initiated a third wave of research and development (Shladover, 1990). This work reached a highpoint with the research and demonstration work of the National Automated Highway Systems Consortium (NAHSC) from 1994 to 1998; it continued until 2003 (Rillings, 1997) as Caltrans and PATH conducted joint demonstrations of automated bus and truck platoons.

Finally, the current, fourth wave, began with the Defense Advanced Research Projects Agency (DARPA) Challenges from 2004 to 2007 and the subsequent work at Google (Shladover, 2017). In its challenges, which involved prizes for teams whose AVs could complete designated routes or tasks, DARPA sought to "leverage American ingenuity to accelerate the development of autonomous vehicle technologies that can be applied to military requirements."[181] Google, in

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[178] Headway refers to the measurement of the distance or time between vehicles in a transportation system.
[179] Headway safety policy involves the specification of a minimum acceptable headway under normal operating conditions.
[180] A pallet is a large container to move materials.
[181] Defense Advanced Research Projects Agency, Prize Challenges. Available at https://www.darpa.mil/work-with-us/public/prizes.

October 2010, announced its work on autonomous vehicles, with its self-driving cars having logged over 140,000 miles by the time of the announcement.[182] As of February 2018, Waymo's (Alphabet Inc. AV subsidiary) self-driving cars have logged over 5,000,000 miles.[183]

9.4.2. AV Technologies & Object Detection

Automated vehicles rely on different sensors to make judgements about objects and the external environments of the vehicle on behalf of the driver (Asvadi, Garrote, Premebida, Peixoto, & J. Nunes, 2017; Patole, Torlak, Wang, & Ali, 2017; Sanchez, 2015). Global positioning systems combined with detailed maps and landmark registration via real time sensors can provide accurate localization as of the last mapping. Real time sensors for object detection and registration include a combination of cameras, ultrasound or sonar, radar (radio wave detection and ranging), and LiDAR (light detection and ranging).

In particular, radar provides the ability for an automated vehicle to see long distances ahead in poor visibility conditions to help avoid collisions (Patole et al., 2017), and can measure the subtle frequency shift of microwaves reflected from a moving object according to its speed (Doppler shift), enabling path prediction. LiDAR measures distance to an object using a pulsed laser light (Herman & Ismail, 2017; Sanchez, 2015; Woodside Capital Partners, 2016), whose higher frequency provides finer detail for object recognition and advanced driver assistance systems (ADAS).[184] Unlike active sensors such as radar and LiDAR, camera technologies acquire data in a passive way (Sun, Bebis, and Miller, 2006).[185] Cameras are essential in providing many of the ADAS applications for object detection, including forward collision warning, pedestrian detection, traffic signal detection, lane departure warning, headway monitoring, blind spot detection, parking assist, and intelligent headlight control (Herman & Ismail, 2017). Multi-spectral imaging, for example visible and infrared, can provide information about the material properties of obstacles via their thermal differences, such as distinguishing between a concrete block and a garbage bag of leaves.

One of the main barriers of object detection technology in an automated vehicle is cost. For example, Google spent approximately $200,000 to build its 2014 automated vehicle (Herman & Ismail, 2017). Google's vehicle employed various sensor technologies, including a sonar device, stereo camera, laser, radar, and LiDAR. Of the sensors, the LiDAR (a Velodyne 64-beam laser) was the most expensive at a price of $80,000 (Herman & Ismail, 2017; Woodside Capital Partners, 2016). In contrast, Tesla's business model and goal is to lower the manufacturing costs and costs of goods sold to assure business sustainability (Bilbeisi & Kesse, 2017; Herman & Ismail, 2017). Therefore, Tesla does not embed a LiDAR sensor; instead, Tesla automated

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[182] Google, Official Blog, What we're driving at, October 9, 2010. Available at https://googleblog.blogspot.com/2010/10/what-were-driving-at.html?m=1.

[183] Waymo, Official website, On the Road. Available at https://waymo.com/ontheroad/.

[184] Differences in laser light return times and its wavelengths are used to make digital three dimensional (3-D) representations of the object. Major characteristics of LiDAR sensors are their wide field of view (FOV), precise distance measurement, object recognition at long ranges, and night-vision capability (Asvadi et al., 2017).

[185] At present, there are three types of camera used in the development of AVs: single camera (monocular vision), dual camera (stereo vision), and specialized camera (built in camera).

driving (referred to as "autopilot") presently combines a forward looking camera, radar, and 360 degree sonar sensors with real-time traffic updates in the model S automated vehicle (Bilbeisi & Kesse, 2017).[186]

Reliable and accurate object detection relies on fusing sensor data from radar output and other outputs such as LiDAR, camera vision, and ultrasound. LiDAR and vision sensors provide enhanced object discrimination capabilities and reduce computation costs by delivering faster response (Herman & Ismail, 2017; Patole et al., 2017; Woodside Capital Partners, 2016). Independent observations from each sensor must be combined to increase their reliability. Moreover, because it is a line of sight technology, LiDAR is more sensitive to environmental factors such as snow, fog, dust, and rain. Radar, on the other hand, offers superior speed measurements, relying on the Doppler effect as opposed to the amount of illumination measurement in LiDAR.

All measurements are synchronized to a common clock time stamp when multiple sensors are in operation (Asvadi et al., 2017). Observations from individual sensors are typically combined to form global sensor data (Asvadi et al., 2017; Herman & Ismail, 2017), often referred to as sensor fusion. Sensor fusion improves reliability by providing multiple measurements of the same object or condition, enhancing the ability to eliminate faulty data. Artificial intelligence and machine learning algorithms process the global sensor data for the automated vehicle to detect an object and take necessary action.

9.4.3. Social Perceptions of AVs

Most social science studies concerning AVs focus on social perceptions of AVs. Researchers have consistently found that individuals express concerns over AVs related to trust, liability, costs, and vehicle control (Benleulmi & Blecker, 2017; Casley, Jardim, & Quartulli, 2013; Howard & Dai, 2014; Kohl, Mostafa, Böhm, & Krcmar, 2017; Lipson & Kurman, 2016). The key barriers across studies relate to respondents' perceptions of the risk of AVs being unsafe and the risk of the vehicle malfunctioning (Benleulmi & Blecker, 2017; Casley et al., 2013). For instance, Casley et al. (2013) asked survey respondents to rank safety, cost, and law in terms of influencing their perceptions of AVs. The majority of respondents (82 percent) indicated that safety is the most influential factor, followed by law (11 percent), and cost (7 percent).

Findings from Benleulmi & Blecker (2017) as well as Howard & Dai (2014) also reveal that lack of vehicle control and higher percieved risks are significatly related to lack of trust in AVs. Kohl et al. (2017) examine tweets from Twitter users regarding AVs. Users tweet about risks of self-driving cars almost three times more often than about the benefits of AVs. Among the different risk-related tweets, the majority expressed concern about AV safety, distrust of companies manufacturing AVs, and fear of hackers writing viruses to take control of an AV. In terms of cost, respondents from Casley et al.'s (2013) study believed that each AV feature would cost more

[186] The estimated cost of a stereo forward looking camera system is $250, long range radar sensors is $150, and 360 degree sonar sensors is $200 (Woodside Capital Partners, 2016).

than $5,000. Yet, participants were willing to pay approximatley $1,000 for each feature on average.

However, individuals also believe that AVs have potential for positive social impact, including greater efficiency, reduced environmental impact, increased safety, amenities for multitasking, and convenience (Casley et al., 2013; Howard & Dai, 2014). For example, the majority of participants in the Casley et al. (2013) study indicated a greater likelihood to purchase an AV if the vehicle were more efficient in terms of fuel and time to destination. Findings from Howard & Dai (2014) provide support that amenities, such as opportunities to multitask, convenience, and reduced travel times increased respondents' willingness to purchase AVs. Furthermore, the analysis of tweets indicates that saving time is the greatest perceived benefit of AVs (Kohl et al., 2017). Researchers also note that AVs may potentially address issues of equity by permitting economically disadvantaged groups access to flexible, convenient, and speedy travel (Howard & Dai, 2014). High end CAVs can also benefit surrounding vehicles by communicating their additional sensor information, enhancing safety around them. This will likely be used to market the high margin features as providing societal benefit in addition to added personal safety.

Given the demographic age shift in the U.S. population, attention is beginning to focus on how AVs might impact the lives of older adults and those with disabilities and health impairments. Recent research has focused on factors affecting different generational cohorts' acceptance of and willingness to use AVs (Huang et al., 2018; Kadylak et al., 2018; Lee et al., 2017; Ward et al. 2017). Trust, knowledge, and perceived risks and benefits were shown to be related to AV acceptance in general (Ward et al., 2017). Lee et al. (2017) found age to be negatively related to perceptions of AVs (i.e., older generational cohorts were less likely to report interest in using AVs or have favorable perceptions of AVs). Huang and colleagues (2018), in a statewide survey of Michigan residents, found that individuals in the Silent Generation (born before 1945) perceived fewer benefits and more concerns compared to younger generational cohorts. Kadylak et al. (2018), using a nationally representative sample of individuals aged 65 and older, find that only 19 percent of respondents report that they were willing to use AVs in the future.

Researchers have also focused specifically on the potential social benefits of AVs for older adults (i.e., those aged 65 and older). Kadylak et al. (2018) found that health status and limitations in activities of daily living (IADLs) were related to older adults' willingness to use AVs in the future; this suggests that for those who have health limitations, AVs could enhance their quality of life and ability to function in society. In spite of higher crash rates, older drivers are not uniformly unsafe and their ability to continue driving is important to maintain independence (Son et al., 2015; Souders & Charness, 2016). Son and colleagues' (2015) single blind experiment research examined 26 younger (i.e., age 25 to 35) and 26 older (i.e., age 55 to 65) adults' acceptance of safety assistance systems after driving a vehicle equipped with Advanced Driver Assistance Systems (ADAS; effectively, a level 1 AV). Specifically, older adults were asked about their acceptance of forward collision warning (FCW) and lane departure warning (LDW) systems. Older drivers had higher acceptance of the LDW than younger drivers. In addition, older drivers rated the assistance system higher and had more positive attitudes toward safety assistance systems than younger drivers. Survey results of older adults in Florida reveal that older adults who reported higher levels of ease of new technology use had increased general comfort with and willingness to use AVs, greater expectation of AV related benefits, reduced AV concerns, increased familiarity with AVs, and greater willingness to use AVs (Souders & Charness, 2016).

Three findings are of particular interest from these prior studies. First, respondents' age positively predicted willingness to use ADAS, providing support that AVs could help older drivers. Second, a greater level of trust in AVs significantly predicted a higher level of AV acceptance. Third, health status and limitations in activities of daily living (IADLs) are related to older adults' willingness to adopt AVs in the future.

Individual perceptions, while important, are not the only driving force setting the pace of adoption of AVs. Shladover (1990, 2016, 2017) notes broader considerations related to the social impacts of AVs. First, state and local transportation agency budgets are rarely sufficient and do not have adequate funding to cover the basic responsibilities, such as maintenance of the current infrastructure. Thus, investing in new infrastructure systems to support AVs is difficult (Lipson & Kurman, 2016). Also, each accident has the potential to become a major tort liability case. An injury-producing accident resulting from an AV on an automated roadway poses multiple legal questions unless policies are implemented in advance. In the following section, we explore policies and regulations concerning AVs.

9.5. Regulation of Automated Vehicles

We anticipate that government policy and regulation of AVs will have tremendous impacts on how AVs affect the workforce. To date, existing legislation concerning AVs has not focused on workforce issues; the primary foci have been on issues such as safe operation and testing of AVs as well as accident liability. However, delays in AV deployment in certain industries caused by differences in legislation across states or general unpreparedness for AV deployment by a locality or state will likely influence the workforce transition time horizon. For instance, municipal and state regulations will likely affect the general preparedness of infrastructure to handle AVs and subsequent adoption of AVs in these localities. Similarly, differences in legislation across states can impact interstate commerce, which will influence business and labor dynamics, including where certain businesses locate and expand, where workers chose to live, and how goods are delivered between states. With regard to the last point, standardization throughout the U.S. may be necessary for driverless interstate commerce. The timeline of such standardization is likely to be intertwined with labor changes in industries like long-haul delivery.

According to the National Conference of State Legislatures (NCSL), in 2017, 33 states introduced AV legislation, with 20 states having done so in 2016. Additionally, 21 states have passed legislation related to AVs.[187] Most of the state level legislation is geared towards allowing and regulating the testing and use of AVs within specific conditions. However, the scope and specificity of each bill varies widely across states. For example, Nevada passed a series of bills (e.g., SB 140, in 2011; SB 313, in 2013; AB 69, in 2017) which define testing conditions, affords the DMV some regulatory power, and specifies the use of emerging

[187] See NCSL, Autonomous Vehicles, Self-Driving Vehicles Enacted Legislation. Available at http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

technologies on state highway systems (e.g., driver-assisted platooning technology).[188] In addition, the legislation passed in Nevada specifies detailed laws regarding liability and insurance issues, as well as monetary fines that are put in place to reprimand those who violate AV laws. Other states, such as Pennsylvania, have passed legislation (e.g., SB 1267) which allocates funding towards updating municipality transportation systems with connected and AV technology.[189] The Pennsylvania legislation (SB 1267) allows a maximum of $40 million per fiscal year that can be allocated towards state automated driving system (ADS) municipality projects.

Federal legislation has also recently passed in the U.S. House of Representatives (HR 3388, SELF Drive Act)[190] and the U.S. Senate (AV START Act)[191] regarding AV testing, safety evaluations, law enforcement, as well as privacy and cybersecurity. Both pieces of pending legislation set forth specific privacy and cybersecurity guidelines that auto manufacturers must follow to import or sell AVs in the U.S. The legislation that passed in the House, for example, requires that manufacturers have a written plan for withholding and deidentifying information about AV passengers and owners. In addition, both federal acts use ADS terminology, as defined by the SAE international standards, that is consistent with the language used to discuss ADS technology in recent state level legislation.[192]

At the time of writing, NCSL served as an up to date reference for federal and state legislation concerning AVs in the U.S. Nevertheless, although somewhat dated by the rapid pace of legislation concerning AVs, two existing reports offer useful overviews of AV policy and regulations, the RAND Corporation's report, *Autonomous vehicle technology: A guide for policymakers* (2014 RAND Report) and the Graham Environmental Sustainable Institute report, *Automated, Connected, and Electric Vehicles: An Assessment of Emerging Transportation Technologies and a Policy Roadmap for More Sustainable Transportation* (Underwood et al., 2014).

The 2014 RAND Report provides an overview of regulations concerning AVs at both the state and federal level and assesses policy risks and concerns associated with AV regulation. As part of their research, the authors interviewed approximately 30 stakeholders, including automobile manufacturers, technology firms, communications providers, and representatives of various regulatory bodies.

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[188] See Nevada Senate Bill No. 140, Chapter 523, p. 3646, 76th Session (2011); Nevada Senate Bill No. 313, Chapter 376, p. 2008, 77th Session (2013); Nevada Assembly Bill 69, Chapter 608, p. 4464, 79th Session (2017). Bills can be found at the Nevada Legislature, Nevada Law Library. Available at https://www.leg.state.nv.us/law1.cfm.

[189] See Pennsylvania Senate Bill No. 1267, 2016 P.L. 861, No. 101. Available at http://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2016&sessInd=0&act=101.

[190] Safety Ensuring Lives Future Deployment and Research In Vehicle Evolution Act. H.R. 3388 – 115th Congress (2017-2018). Available at https://www.congress.gov/bill/115th-congress/house-bill/3388.

[191] American Vision for Safer Transportation through Advancement of Revolutionary Technologies Act. S. 1885 – 115th Congress (2017-2018). Available at https://www.congress.gov/bill/115th-congress/senate-bill/1885.

[192] Federal agencies also play a role in policymaking concerning AVs. For instance, in September 2017, the National Highway and Transportation Safety Administration (NHTSA) released new federal guidance for AVs. In its report, *Automated Driving Systems: A Vision for Safety*, the NHTSA lays out priority safety design elements for the automotive industry and other stakeholders considering best practices.

At the time of writing, four states and the District of Columbia had passed legislation authorizing AV testing (RAND, 2014, p. 41) and at least fourteen others had introduced and, in some instances, passed related legislation. The authors categorize legislation according to, among other things, laws concerning:

- Definitions of the meaning of AV or autonomous technology.
- Compliance regulations and certification concerning safety of the operation of the vehicle.
- Limitations on original manufacturer liability.
- Insurance requirements for testing an AV.

The authors devote substantial discussion to safety regulations concerning automobiles generally to help draw insight for future regulations of AVs and to help form expectations. In particular, the authors undertake a historical case study of air-bag regulation to highlight that expectations regarding technology adoption and deployment need to be modest. For instance, there were forty years between the first air-bag patents and regulations requiring airbags in all cars (RAND, 2014, p. 103).

Policies and regulations are likely to be critical in setting the pace of adoption. For instance, whereas the authors find that the existing liability regimes that they examine do not present unusual liability concerns for owners or drivers of AVs, expected increases in manufacturer liability may lead to inefficient delays in AV adoption (RAND, 2014, p. 132). Stakeholders expressed concern that a plethora of conflicting state laws could likewise hamper AV deployment (RAND, 2014, p. 81).

Underwood et al. (2014) present a policy roadmap to advance sustainable transportation based on an assessment of innovations in connected, automated, and electric vehicle technologies. The authors view innovations, such as AVs, as a means to mitigate transportation problems like roadway congestion as well as fatalities and injuries from road accidents.[193] The authors offer various policy recommendations concerning AVs (Underwood et al., 2014, p. 42):

- Avoid legislation restricting AV testing.
- Existing auto liability law provides sufficient incentives to automakers and others to safely test and produce AVs.
- Remove restrictions, such as on cell phone use while driving, on drivers of existing cars that have automatic braking, lane keeping, and other safety features to incentivize

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[193] Underwood et al. (2014) used a modified Delphi methodology, incorporating four phases. First, 23 experts were selected through an anonymous election process based on identification of top experts by several automotive engineering and robotics experts. These 23 experts included industry leaders from public, private, non-profit, and academic domains – all of whom had expertise with automation or sustainable mobility. They received a series of three iteratively refined surveys to identify their perspectives on CAVs. A fourth survey, identical to the third survey, was administered to attendees of the Automated Vehicle Systems Symposium in 2014 (N=250 respondents), in an outreach effort to the scientific and engineering communities involved in developing and researching CAV systems. The authors predicted that the first market introduction of full autonomous vehicles would be at least a decade away (Underwood et al., 2014, p. 39), with a median forecast of 2030 and an interquartile range of ten years between 2025 and 2035. The intent of this study was to 'map out a vision and to define a roadmap for arriving at the long-term future of sustainable automotive transportation' (Underwood, 2014:16).

drivers to add these features and require these technologies for new state and local vehicles as they are added to government fleets.
- Provide flexibility and incentives for insurance companies that provide discounts for drivers of increasingly autonomous cars.

Neither the 2014 RAND Report, nor Underwood et al. (2014), discuss workforce implications. Moreover, to our knowledge, as of the end of 2017, neither federal nor state policies explicitly consider the potential impact that AVs could have on the labor force. Nevertheless, it is evident that delays in AV deployment in certain industries caused by differences in legislation across states will influence the workforce transition time horizon. Safety, liability, and other regulations and standards can similarly influence when commercial entities are able and willing to deploy AVs without a driver, a critical point that must be reached before transportation industry employees are displaced by AVs on a large scale. In this report, we have taken a more in-depth look at research aimed at projecting the potential impacts that AVs might have on various sectors of the U.S. labor force.

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Truck Platooning State of the Industry 2018

Date: June 16, 2018

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Introduction

The evolution and application of connected and automated vehicle (CAV) technology to Class 8 heavy duty tractor-trailers has the potential to improve safety, improve fuel efficiency, reduce emissions, improve operational efficiency, thus reducing overall operational cost. While past and ongoing research has generally focused on technology development, economic benefits and operations aspects, the impact of CAV on the transportation workforce is far less researched. In January 2018, the American Center for Mobility initiated a workforce study to study the impact of these technologies. The study is being led by Michigan State and Texas A&M Transportation Institute. In freight, the application of new technologies to enable truck platooning – a formation of two or more trucks traveling in close proximity – is one area receiving attention from commercial operators, technology developers and public agencies. This technical memorandum will summarize existing automation research and testing efforts and the current understanding of the readiness of truck platooning technology.

Fundamentals of Truck Platooning

What is Truck Platooning?

Truck platooning is a formation of commercial trucks traveling safely and closely together while at high speeds. Technologies that enable platooning including global position systems (GPS), forward looking sensors, such as camera, radar and/or LiDAR, and vehicle to vehicle (V2V) communications. These technologies work in conjunction to automatically and precisely control the lateral motion (e.g., steering) and/or longitudinal vehicle motion (e.g., brake and throttle/gas pedals).

Enabling Technologies

Over the past decade, commercial vehicle manufacturers and suppliers have developed many of the foundational technologies required for Level 1 and Level 2 automation applications. Truck platooning depends on three technologies: connected braking, Forward Collision Avoidance and Mitigation (FCAM), and disc brakes. This section briefly introduces each technology and its role in truck platooning.

Forward Collision Avoidance and Mitigation (FCAM)

FCAM systems are radar-based systems that enhance the human reaction in an emergency braking event. Similar to Adaptive Cruise Control, which is present in many consumer passenger vehicles on the road today, FCAM use radar to adjust the speed of the truck to match the speed of preceding vehicles. In order to integrate FCAM systems, truck tractors require Electronic Stability Control (ESC) and Anti-Lock Braking Systems (ABS). NHTSA recently issued a final rule for FMVSS 136 requiring ESC systems for Class 7 and 8 heavy vehicles. Consequently, U.S. manufacturers will begin installing ESC on new commercial truck tractors and busses beginning in 2017.

Connected Braking

Connected braking refers to a link between a leading and following truck such that the following trucks braking (and acceleration) is synchronized with the lead truck to provide automated longitudinal control of the follower truck. Secure vehicle-to-vehicle (V2V) communication between lead and following trucks is enabled via 5.9 GHz Dedicated Short Range Communications (DSRC), which has been allocated for traffic safety use. This electronic coupling enables the following vehicle to react much quicker to braking action by the lead truck, compared to both manual driving response and automated braking without V2V.

Disc Brakes

Disc brakes are considered to have superior performance to the more common drum brakes. Disc brakes allow for shorter stopping distance and greater reliability due to reduced overheating and the associated decrease in wear. While disc brakes are increasingly available on new trucks, they are still uncommon due to higher costs and fleet turnover rate.

Truck Platooning Automation Levels

Truck platooning can occur at various levels of automation, corresponding to the SAE automation levels introduced above, as follows:

- *Level 1 (L1) truck platooning* extends radar, camera, GPS, and V2V communications-based, cooperative ACC to provide precise automated longitudinal vehicle control in order to maintain a tight formation of vehicles with short following distances. A manually driven truck (L0) leads a platoon, while the driver(s) of the L1 following truck(s) control the steering of their vehicle. L1 platooning systems require FCAM technology, which enables the following vehicle(s) to follow the lead vehicle safely at high speeds at distances ranging from 10 m – 50 m in order to achieve fuel savings, enhanced mobility, and associated emissions reductions for platooning vehicles. In order to maintain the safety and integrity of the platoon, the vehicles must be sequenced such that the vehicle with the highest braking capability, typically the one with the heaviest load, is at the rear of the platoon, while the one with lowest braking capability, typically the lightest load, leads the platoon. L1 platooning is often referred to as Driver Assisted Truck Platooning (DAPT).

- *Level 2 (L2) truck platooning* builds upon the L1 system by adding technology to electronically control the steering of the following truck(s) in addition to the acceleration and braking. This provides automated lateral and longitudinal vehicle control to maintain a tight lateral formation of vehicles with short following distances. In L2 platooning, a manually driven truck (L0) leads a platoon, while the L2 following truck(s) have their steering, braking and acceleration automatically controlled, while monitored by the drivers in their vehicles. L2 truck platooning systems can be designed to evolve the more capable and complex Level 3 (conditional automation) and Level 4 (high automation) systems. L2 platooning systems automation may increase these benefits while reducing driver workload and increasing safety.

- Level 3 *(L3)* conditional automation and Level 4 (L4) high automation truck platooning systems would expand upon the operating system in Level 2 with more capable and complex automation systems. Higher-level truck platooning systems have not yet been deployed on public roads. For the remainder of this document, Levels 3 through 5 are referred to as highly automated vehicles and Automated Driving Systems (ADS)

Automation

Truck platooning relies on automated vehicle technologies, but early systems have some fundamental distinctions from highly automated vehicles, or automated driving systems (ADS). Truck platooning realizes automated lateral and/or longitudinal vehicle control through the integration of vehicle-to-vehicle (V2V) and forward-looking sensors (e.g. camera and/or radar). Platooning can occur at different levels of automation as noted above, but early systems are expected to be Level 1 and Level 2 automation. As such, a driver is required to remain engaged in the driving task. ADS fall into SAE Levels 3 – 5 and range from systems that perform all aspects of the driving task under some circumstances with the human driver remaining ready to take back control, to systems that can safely operate without a human driver under all conditions and at all times. These systems will generally utilize all enabling technologies and sensors mentioned above, in addition to scanning LiDAR sensors, additional cameras and radar sensors, higher end processors with Graphics Processing Units (GPU), digital maps, and artificial intelligence, significantly increasing the complexity and capability of the system.

Connectivity

Platooning requires V2V connectivity, but currently implementations do not require local connectivity between the vehicle to infrastructure (V2I or I2V). V2V enables trucks to transmit brake and throttle commands among the platoon and to operate more safely at short headways.. However, connectivity via onboard telematics systems to a back-office operation is a common component of platooning concepts to support platoon management.

Potential Benefits of Truck Platooning

Truck platooning may increase the efficiency of truck freight movement and provide other widespread benefits. Level 1 truck platooning has demonstrated the potential for significant fuel savings, enhanced mobility and associated emissions reductions from platooning vehicles. Stakeholders who stand to benefit from truck platooning include (*1*):

- infrastructure operators
- commercial vehicle operators
- truck drivers
- general public

Broadly, the categories of benefits of truck platooning include safety, mobility, economic and environmental benefits. These benefits are summarized in this section. Additionally, other indirect benefits may include improved quality of life or improved air quality due to reduced congestion. In Table 1, the potential benefits are cross-walked with the stakeholder groups who would receive those benefits.

Table 1. Summary of Truck Platooning Benefits and Stakeholders

Stakeholder	Benefit Category			
	Safety	Mobility	Economic	Environ-mental
Infrastructure Operators	✓	✓		
Commercial vehicle operators	✓	✓	✓	
Truck drivers	✓	✓		
General public	✓	✓	✓	✓

Safety Benefits

Collisions between trucks and cars could be greatly reduced through reduction in driver-related crashes. By reducing the number of drivers making decisions, the incidence of driver error decreases, thus increasing roadway safety for others through the potential of reduced crashes. Early commercial truck platooning systems will require FCAM systems and disc brakes (Peloton Plan, 2017). These system will provide incremental safety benefits when the truck is platooning and when the truck is not platooning by requiring these safety systems to be installed on the platoon-capable truck.

Mobility Benefits

The FCAM and improved braking involved in truck platooning is expected to reduce the risk of collision and increase roadway safety. This will positively impact mobility due to a decrease in incident-related congestion. Further, platooning systems are expected to improve mobility with high market penetration and use rates, under specific traffic condition. At a 30-50 percent market penetration rate and with all trucks forming two-truck platoons, highway throughput increases by 6-8 percent in nearly congested conditions (Kuhn 2017).

Economic Benefits

Research suggests that truck platooning can provide 5–20 percent fuel savings, as well as increased highway throughput. This can decrease transportation costs for operators and result in reduced prices for consumers. Several factors will likely affect fuel economy in a real-world platooning scenario (*2*):

- Headway between trucks
- Number of trucks and position of the truck within the platoon
- Truck geometry (“nosed” cabs versus “cab-over”)
- Lateral offset of the trucks
- Operating speed
- Vehicle weight.

Commercial vehicle operators may experience substantial economic benefits; these potential benefits have been part of the transportation dialogue since 2001. As noted by Shladover (2001), heavy truck costs and usage make the economic return of an investment in automation equipment more attractive for a truck than for a passenger car (*3*). In addition, the installation of automation equipment on a commercial truck is likely to be easier than on a car. Heavy trucks are more attractive for automation due to factors including a less constrained space for equipment, smaller order quantities, shorter lead time from design to production, the use of a standardized communications network, and other electronic engine and brake controls (*4*). Automated trucks could result in significant changes in driving duty cycles and pay rates for drivers. For example, in a highly automated truck, a driver could travel long distances while resting and still earn payment (*5*).

Environmental Benefits

Platooning can reduce drag on platooning trucks, increasing fuel efficiency and reducing emissions of carbon monoxide and other pollutants. While numerous projects have measured reductions in fuel consumption associated with platooning, most stop short of measuring associated emissions reductions, instead citing correlations between fuel consumption and emissions. Daimler advertises a 5 % reduction in in carbon dioxide (CO_2) with their Highway Pilot System.

Other Benefits

Truck platooning may offer additional indirect benefits such as improved quality of life for drivers due to reduced stress and workload, for all motorists due to reduced congestion, and to the general public due to improved air quality due to reduced congestion and emissions.

Potential Challenges to Truck Platooning

While the technological aspects of truck platooning are well developed, deployment efforts must address several challenges. The benefits achieved from automated truck platooning will likely vary based on the implementation and use of the technology. These exist at the public agency, commercial vehicle operator, driver, and technological levels. Examples include:

- Adoption by commercial vehicle operators due to cost/return on investment; uncertainty of technology; misunderstanding over risks of lower level DATP systems versus highly automated system; complexity or suitability of integration into current operations; and logistics systems; incremental safety benefits over new safety technologies; and proactively protecting against workforce impacts for more highly automated systems.
- Acceptance by drivers due to understanding and trust of the safety and reliability of L1-L5 automated systems; acceptance due to displacement concerns; issues related to unintentional misuse of system;
- Technological challenges for lower levels of platooning include achieving standardization and interoperability across manufacturers in the absence V2V and AV regulations or Federal research initiatives; implementation of engineering solutions to ensure driver engagement for L1 and L2, and adequate, timely transfer of control from human to machine for L3 systems   For highly automated systems, commercialization of LiDAR and new sensing, processing and AI technologies at a commercially viable price point; protections against malicious misuse of the systems; ensuring proper sequencing of vehicles within a platoon to ensure safety;
- Public Agency challenges include proactively addressing changes to policies and procedures related to operations, certification, compliance, permitting, licensing, and emergency response to address changes associated with the technology.

Impact on the Workforce

The impact of truck platooning on the workforce depends substantially on the platooning concept, specifically the inclusion of Level 4 or Level 5 trucks within the platoon. Implementation of a two-truck Level 1 platooning system is expected to occur in 2018, with the evolution to three-truck platoons and Level 2 systems occurring the next five years. By definition, these early systems require each vehicle in the platoon to have a driver engaged in the driving task at all times. While these systems may reduce driver stress or workload, they will not replace the driver for any portion of a trip. Thus, truck platooning is not expected to impact the workforce in early implementation. However, successful commercialization of platooning concepts involving Level 4 and 5 vehicles will result in workforce impacts in the future.

Existing Truck Platooning Deployment and Research

Truck platooning emerged as early as the 1990s. In 1999, Germany conducted platooning operations on public roadways. Public entities in Germany, Japan, and the U.S. sponsored continued testing in the ensuing years.

In recent years, private sector technology development has sparked renewed interest in truck platooning. In 2017, most manufacturers made FCAM and ACC standard on the Class 8 truck tractors (*6*) which lays the groundwork for commercializing Level 1 platooning applications. Drive Assistive Truck Platooning (DATP), equivalent to SAE Level 1 automation is expected to enter the market in 2018.

In the U.S. and Canada, the public and private sectors are currently testing two and three truck platoons using Level 1 and Level 2 systems. Public sector agencies and research institutions are also involved in truck platooning research and demonstration projects.

State officials are identifying freight routes that could support truck platooning both within states and along multi-state corridors such as the Florida Turnpike, Ohio Turnpike, and Interstate 10 (in California, Arizona, New Mexico, and Texas). As of early 2018, 16 states have supported demonstrations and/or testing of truck platooning (*7*). A map of these states is shown in Figure 1.

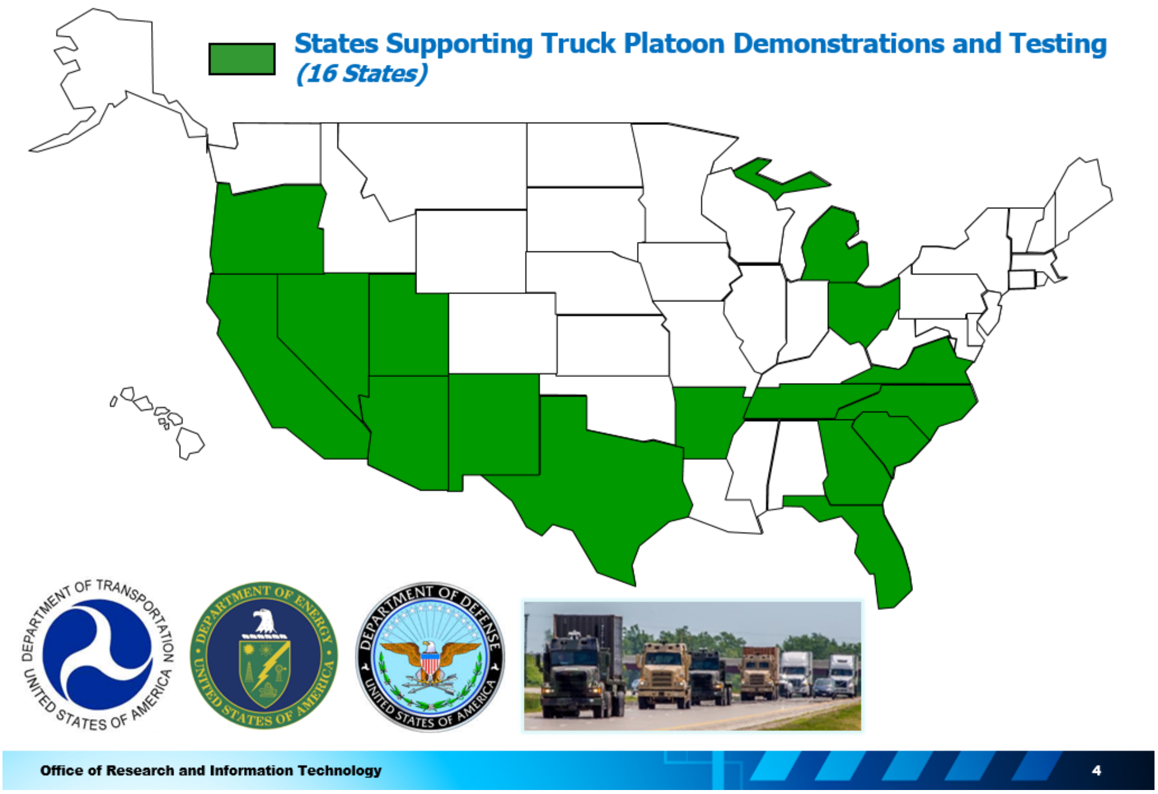

Figure 1. U.S. Public Sector Truck Platooning Activity

Source: Loftus, TRB 2018 (*8*).

In 2016, the Netherlands led the European Truck Platooning Challenge, a cross-border demonstration of automated truck platooning on public roads. Six platoons were arranged with participation from DAF Trucks, Daimler Trucks, IVECO, MAN Truck & Bus, Scania, and Volvo Group (*9*).

The European Automobile Manufacturers Association (ACEA) predicts that driving “across Europe on motorways (thus crossing national borders) with multi-brand platoons, without needing any specific exemptions” should be possible by 2023. Figure 2 presents ACEA’s Platooning Roadmap timeline for Europe.

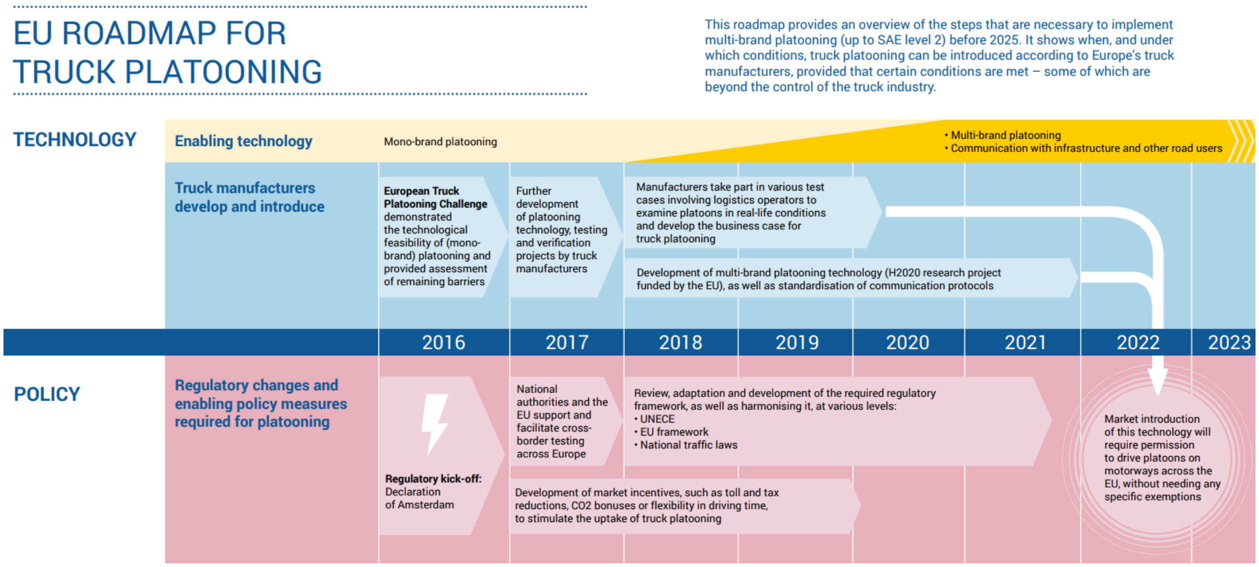

Figure 2. ACEA’s Platooning Roadmap

Source: ACEA, http://www.acea.be/uploads/publications/Platooning_roadmap.pdf

Current deployment tests and demonstrations vary in configuration and level of automation. Table 2 highlights summarizes a selection of existing platooning research projects and pilot programs. Additional project details are provided in Appendix 1.

Table 2. Current and On-Going U.S. and International Platooning Projects.

Project and Timeframe	Location	Automation Level	Partners	System Level	Other Information
Peloton	Utah	Level 1 DATP	CR England and North American Council for Freight Efficiency	Prototype	2013
	I-80, Reno, Nevada	Level 1	Nevada DOT	Prototype	2014
	ITS World Congress, Detroit, Michigan	Level 1	DENSO, Meritor WABCO	Prototype	2014
Volvo	California	Level 1 CACC (emulated DATP)	Caltrans, UC-Berkeley PATH		

Project and Timeframe	Location	Automation Level	Partners	System Level	Other Information
TxDOT, TTI and Navistar 2015-2019 (10)	Texas, USA	Level 2, Two Truck Platoons	TxDOT, TTI, Navistar, Ricardo, Great Dane, Denso, Bendix, TRW Lytx, , US Army TARDEC and Argonne National Labs		Navistar is working with the Texas Department of Transportation (TxDOT) and the Texas A&M Transportation Institute on a multi-phase project to support the introduction of deployed truck platoons in Texas. TxDOT, TTI and Navistar plan to test a truck platooning concept though a feasibility planning study and proof-of-concept demonstration. Unique in the U.S., this work focuses on Level 2 platooning rather than Level 1 DATP.
FHWA, EAR Platooning Demonstration 2014–2017 (11)	Los Angeles and Washington, D.C. regions, USA	Level 1, Three-Truck CACC (emulated DATP)	Caltrans-PATH-Volvo		Three specially equipped tractor semi-trailers demonstrated cooperative adaptive cruise control, only one element of the platooning algorithm, and followed at gaps indicative of platooning systems, but did not include a the platooning software required for safe and reliable platoon operation. The testing emulated platooning. Two demonstrations were conducted, to test three-truck platoons to demonstrate potential to: • Improve Fuel Economy • Reduce Emissions • Improve Road-Use Efficiency • Reduce Driver Workload • Maintain Level of Safety.

Project and Timeframe	Location	Automation Level	Partners	System Level	Other Information
Florida Platooning Study 2017–2018)	Florida, USA	L1 Two-truck DATP	Florida DOT and Florida Department of Highway Safety and Motor Vehicles		The Florida Department of Transportation, in consultation with the Department of Highway Safety and Motor Vehicles, has been authorized by Florida statute (316.0896-Driver assistive truck platooning technology pilot project) to study the use and safe operation of driver-assistive truck platooning technology. The study includes provisions for companies to perform testing on specific portions of the Florida Interstate network. Currently Peloton is the only company testing in FL
Auburn	Auburn, Alabama	L1 Two-truck DATP	USDOT		Energy Saving, safety
Connected Vehicle Pooled Fund Study: I-10 Coalition	Arizona, California, New Mexico, Texas	To be determined	Arizona DOT, Caltrans, New Mexico DOT, and Texas DOT		Concept of Operations study led by the Arizona DOT looking at connected freight operations and technologies from Ports of Los Angeles and Long Beach to Port of Houston and Beaumont. Project is examining innovative freight technologies like truck parking systems, public-private partnerships, and border ITS.
UK Platooning Trial 2017- 2019 (12)	UK	TBD	London Department for Transport, Highways England		A trial project was launched to test truck platooning and understand the potential benefits of the technology. A €8.1 million investment will support planning, initial road trial, operator trial and analysis phases.
COMPANION 2016	Spain	L1	Volkswagen Group Research, Sweden's Royal Institute of		The main focus of the project is how a single vehicle operating in a platoon should be efficiently controlled without

Project and Timeframe	Location	Automation Level	Partners	System Level	Other Information
			Technology (KTH), Germany's Oldenburger Institut für Informatik (OFFIS), Science & Technology (Netherlands), IDIADA Automotive Technology (Spain), Transportes Cerezuela in Spain		jeopardizing safety. Longitudinal movement is automatically controlled while lateral movement is manual. The control architecture has been developed based on distributed control, meaning that each vehicle is responsible for its own control based on information from onboard sensors like radar, cameras, etc., and information exchange between the vehicles in the platoon via V2V communication

Appendix: 1 Truck Platooning Project Information

US Private Sector Activities

Daimler—Freightliner

In May 2015, Nevada licensed two Freightliner trucks to operate autonomously on public roads (*13*). The trucks were equipped with Daimler's Highway Pilot system that constantly monitors the driving environment through a network of cameras and sensors to maintain speed, following distance and manage stop and go traffic. Since the initial commercial implantation of this system only combines lane centering technology with L1 platooning capability, the following vehicle(s) cannot automatically control steering during lane change or merging maneuvers. Lane change and merging maneuvers are preformed manually by the driver(s) of the following vehicle(s), who can also override the system at any time (*14*). Although Daimler's initial implementation of their Highway Pilot system offers limited lateral control capabilities compared to other L2 platooning implementations, it reduces the safety engineering challenges, and thus potential hazards and risks, associated with more complex L2 and highly automated systems.

Peloton

Peloton Technology was formed in 2012 to deliver a commercial driver assisted platooning system for the long-haul trucking industry. The Peloton system utilizes L1 automation to control the acceleration and braking of the following vehicle in a two-truck platoon to maintain speed and gap. Peloton requires telematics connectivity to their proprietary back-end system, which performs operational, safety and business functions, most notably to regulate system operation based upon location, traffic and environmental conditions. Peloton is a key partner in an Auburn University-led research project to advance industry readiness of truck platooning, sponsored under the FHWA Exploratory Advanced Research program from 2013 to 2015. Also at the federal research level, NREL subjected two trucks equipped with the Peloton System trucks to extensive fuel efficiency testing in spring 2014. Additional tests, demonstrations and pilots of the System include: fuel efficiency testing in collaboration with CR England and the North American Council for Freight Efficiency in Utah in November 2013; a Nevada DOT-backed live demonstration on I-80 outside Reno in May 2014; successful forward collision avoidance testing in Summer 2014; a demonstration in partnership with DENSO and Meritor WABCO at the ITS World Congress in Detroit in September 2014; and a current data-only fleet pilot. With over 12,000 platooning miles traveled to date, the System is scheduled for further demonstrations and fleet pilots in 2015.

Volvo, FHWA and Caltrans –FHWA Exploratory Advanced Research Project: Partially Automated Three-Truck Platooning (2014–2017) (See US Public Sector Activities)

Volvo is working with the FHWA and Caltrans on an Exploratory Advanced Research Project to test system performance and driver acceptance of a three truck CACC string at various settings, driver acceptance of human-machine-interfaces, and fuel efficiency. As part of the research, two demonstrations were conducted in the Los Angeles and Washington, D.C. regions. It is believed that the system tested in the FHWA project was an extension of a near-term commercially available 2-truck CACC or platooning system for Volvo trucks.

Navistar-International, Texas DOT and Texas A&M Transportation Institute Level 2 Truck Platooning (2015-2018) (See US Public Sector Activities)

Navistar is working with the Texas Department of Transportation (TxDOT) and the Texas A&M Transportation Institute (TTI) on a multi-phase project to support the introduction of deployed truck platoons in Texas. TxDOT, TTI and Navistar plan to test a truck platooning concept though a feasibility planning study and proof-of-concept demonstration. Unique in the U.S., this work focuses on Level 2 platooning rather than Level 1 DATP (*15*).

US Public Sector Activities

TxDOT – TTI Commercial Truck Platooning – Level 2 Automation Project (2015-2019)

The Texas Department of Transportation is sponsoring a research project on Level 2 commercial truck platooning. TTI is leading the research effort with subcontractor Ricardo and a number of public and private sector in-kind partners, including Navistar, Great Dane, DENSO, ZF-TRW, Bendix, Lytx, National Renewable Energy Laboratory, and US Army TARDEC.

The Phase 1 Feasibility Study focused on deployment of two or more platooning vehicles on specific corridors within Texas within 5 to 10 years. In addition to developing and integrating a Proof-of-Concept (POC) system into two Class 8 tractors with 48 ft. trailers, the TTI team documented lessons learned from past platooning projects; identified potential regulatory or legislative roadblocks to introducing platooning into commercial fleet operations; and explored potential implementation scenarios given the existing infrastructure and operational environment. The research team concluded that platooning technology is "ready for commercialization and that it provides value in specific roadway, fleet, and operating conditions." Specific areas of focus were:

1. Defining performance measures for evaluating truck platooning system alternatives.
2. Identifying potential candidate locations where truck platooning may be beneficial.
3. Identifying organizational issues.

In July 2016, the Phase 2 POC Demonstration of a L2 partially automated 2-vehicle platooning system was conducted on a closed course. Ongoing research aims to develop the concept of operations and requirements for the design and vehicle system; enhance system functionality and reliability; and develop the Phase 3 implementation plan and deployment guidance. In Phase 3, partners intend to deploy the commercial truck-platooning application with a commercial vehicle operator in Texas and perform an evaluation.

FHWA-Auburn University Platooning - FHWA Exploratory Advanced Research Project: Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near-Term Deployment (2013–2017)

Funded by the Federal Highway Administration (FHWA) Exploratory Advanced Research Program and in the second of two phases, this Auburn University project has investigated L1 driver assisted truck platooning systems that controls throttle and braking to provide a two-truck platooning system. Consistent with other efforts, they accomplished this by integrating V2V communications and adaptive cruise control (ACC) in order to safety achieve longitudinal control with close following distances (*16*).

Auburn University (project lead) is partnered with Peloton Technology (only involved in Phase 1), Peterbilt Trucks, Meritor-WABCO, and the American Transportation Research Institute and are performing research to identify the key questions that must be answered prior to market introduction of heavy truck DATP. A significant portion of the Phase 1 research involved fuel economy studies through modeling and controlled vehicle testing. FHWA-Caltrans platooning -

FHWA Exploratory Advanced Research Project: Partially Automated Three-Truck Platooning (2014–2017)

A FHWA-Caltrans-PATH-Volvo team used three specially equipped tractor semi-trailers and demonstrated cooperative adaptive cruise control to test system performance and driver acceptance at various settings, driver acceptance of human-machine-interfaces, and fuel efficiency. The project opted to test a three-truck CACC string the emulated a three truck platoon, but didn't include the formal driver-initiated and acknowledged joining and leaving policies typical of commercial vehicle platooning systems. As part of the research, two demonstrations were conducted in the Los Angeles and Washington, D.C. regions. The purpose was to test three-truck platoons to demonstrate potential to (*17*):

- Improve Fuel Economy
- Reduce Emissions
- Improve Road-Use Efficiency
- Reduce Driver Workload
- Maintain Level of Safety.

Florida Platooning Study (2017–2018)

The Florida Department of Transportation, in consultation with the Department of Highway Safety and Motor Vehicles, has been authorized by statute (Florida Statutes 316.0896-Assistive truck platooning technology pilot project) to study the use and safe operation of driver-assistive truck platooning technology. The purpose is to develop a pilot project to test vehicles that are equipped to operate using driver-assistive truck platooning technology. Additionally, the study is performing research to inform policy and planning activities, and is analyzing the impact of two truck platoons on the Florida infrastructure.

Connected Vehicle Pooled Fund Study: I-10 Coalition

This is a pooled-fund study led by the Arizona DOT with support from Caltrans, New Mexico DOT, and Texas DOT. The project is to prepare a concept of operations (ConOps) for future connected vehicle operations along the western I-10 freight corridor. The partners seek to enhance safe and efficient freight movement through public- and private-sector collaboration as well as integration and coordination of existing corridor infrastructure.

The ConOps will create a framework for future improvements in technology, governmental policies, and procedures so that shippers and carriers can thrive by doing business along the I-10 corridor. The ConOps will also determine stakeholder interests and needs, possible solutions for those needs, and barriers to implementation for those solutions. For freight stakeholders along the I-10 corridor, the connected freight corridor could involve a number of individual technologies, information systems, or operational programs that could improve freight movement and efficiency.

The I-10 ConOps connects user needs with technical specifications so that the states in the coalition can guide the development and deployment of a connected freight corridor. The ConOps documents system concepts, operational scenarios, and the rationale behind key decisions affecting its design and deployment. It also incorporates the U.S. Department of Transportation's Connected Vehicle Reference Implementation Architecture, the department's framework for the integration and standardization of connected vehicle technologies.

University of California at Berkeley Platooning of Trucks/Buses (1993–2011)

The Partners for Advanced Transportation Technology (PATH) first tested the longitudinal control of a four-car platoon at 4 m separation at highway speeds in 1994. More recently, the PATH platooning research has focused on heavy trucks, mainly because of the potential for energy saving associated with aerodynamic drag reductions. The PATH experiments on truck platoons have shown the technical feasibility of driving two trucks at a gap of 3 m (9.8 ft.) and three trucks at a gap of 4 m (13.1 ft.) between trucks using L1 automation. A study of crash safety was completed using modeling and simulation, which showed the advantages of a platoon rather than individual AVs. The PATH research stated, “The gaps between platoons would be long enough to ensure that even in the worst crash hazard condition, with maximum deceleration; a following platoon would be able to stop without hitting the last vehicle of the forward platoon” (*18*).

International Activities - Europe

UK Platooning Trial (2017-2019)

In 2017, the London Department for Transport and Highways England launched a trial project to test truck platooning and understand the potential benefits of the technology. A €8.1 million investment will support planning, initial road trial, operator trial and analysis phases scheduled to occur from September 2017 and 2019 (*19*).

European Truck Platooning Challenge (2015–2016)

The Netherlands launched the European Truck Platooning Challenge during its 2016 presidency of the Council of the European Union (*20*). The purpose was to accelerate deployment of platooning by stimulating public sector regulatory authorities across Europe to consider permitting and other regulatory steps needed for deployment, creating a “borderless” environment for truck platooning. The challenge used tractor-trailer combinations. In April 2016, two- and three-truck platoons from six different truck makers arrived in Rotterdam, operating DATP Level 1 platooning on public roads from Sweden, Denmark, Germany, Belgium, and the Netherlands.

Partners included Dutch Rijkswaterstaat and other European Union road operators, DAF Trucks, Daimler Trucks, IVECO, MAN Truck & Bus, Scania, and Volvo Group. Support came from leading EU umbrella bodies representing road authorities, European vehicle and driver registration authorities, vehicle manufacturers, automotive suppliers, freight haulers, and shippers.

COMPANION (2014–2017)

Partners include Volkswagen Group Research, Sweden’s Royal Institute of Technology (KTH), Germany’s Oldenburger Institut für Informatik (OFFIS), Science & Technology (Netherlands), IDIADA Automotive Technology (Spain) in Spain and the Spanish haulage company Transportes Cerezuela. The main focus of the project is how a single vehicle operating in a platoon should be efficiently controlled without jeopardizing safety. Longitudinal movement is automatically controlled while lateral movement is manual. The control architecture has been developed based on distributed control, meaning that each vehicle is responsible for its own control based on information from onboard sensors like radar, cameras, etc., and information exchange between the vehicles in the platoon via V2V communication (*21*). Testing of the full system was conducted on Spanish roads in 2016.

SARTRE (2009–2012)

A partnership between Volvo Cars, Volvo Trucks and research institutes, SARTRE sought to demonstrate the feasibility of a platooning approach in which convoys are formed with a lead vehicle (a professional driver in a truck) followed closely by several autonomous vehicles in platooning formation. Similar to adaptive cruise control on passenger vehicles, this system functions by matching one vehicle’s movements to the speed, distance and direction of a vehicle

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