



U.S. Department of Transportation



DRIVING AUTOMATION SYSTEMS IN LONG-HAUL TRUCKING AND BUS TRANSIT

Preliminary Analysis
of Potential
Workforce Impacts

Driving Automation Systems in Long-Haul Trucking and Bus Transit: Preliminary Analysis of Potential Workforce Impacts

Report to Congress

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List of Acronyms

Acronym	Meaning
ADA	Americans with Disabilities Act
ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving System
AFL-CIO	American Federation of Labor and Congress of Industrial Organizations
ALPA	Air Line Pilots Association
ASEC CPS	Annual Social and Economic Supplement of the Current Population Survey
ATA	American Trucking Associations
ATM	automated teller machine
ATRI	American Transportation Research Institute
ATU	Amalgamated Transit Union
BLS	Bureau of Labor Statistics
BLS OES	Bureau of Labor Statistics' Occupational Employment Statistics
CACC	cooperative adaptive cruise control
CCJ	Commercial Carrier Journal
CDC	Centers for Disease Control and Prevention
CDL	commercial driver's license
CMV	commercial motor vehicle
DDT	dynamic driving task
DOC	Department of Commerce
DOL	Department of Labor
ELDT	Entry-Level Driver Training
FHWA	Federal Highway Administration

FLSA	Fair Labor Standards Act
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GAO	Government Accountability Office
GVW	gross vehicle weight
GVWR	gross vehicle weight rating
HAV	highly automated vehicle
HHS	Department of Health and Human Services
HMI	human-machine interface
HOS	Hours of Service
JES	Joint Explanatory Statement
LTL	less-than-truckload
MBTA	Massachusetts Bay Transportation Authority
NHTSA	National Highway Traffic Safety Administration
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NTD	National Transit Database
NTTC	National Tank Truck Carriers
ODD	operational design domain
OEM	original equipment manufacturer
OES	Occupational Employment Statistics
OOIDA	Owner-Operator Independent Drivers Association

RFC	Request for Comments
SAE	SAE International
SARTRE	Safe Road Trains for the Environment
SOC	Standard Occupational Classification
STAR	Strategic Transit Automation Research
TAA	Trade Adjustment Assistance
TCAS	traffic collision avoidance system
TRACS	Transit Advisory Committee for Safety
TRB	Transportation Research Board
TRCP	Transit Cooperative Research Program
TTD	Transportation Trades Department
U.S.	United States
U.S. DOT	United States Department of Transportation
VAA	Vehicle Assist and Automation
VIUS	Vehicle Inventory and Use Survey
WARN	Worker Adjustment and Retraining Notification
WIOA	Workforce Innovation and Opportunity Act

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Legislative Request

This report is consistent with the Joint Explanatory Statement (JES) on the Consolidated Appropriations Act, 2018:¹

Of the total amount provided, up to \$1,500,000 shall be for the Secretary of Transportation, in consultation with the Secretary of Labor, to conduct a comprehensive analysis of the impact [of] ADAS and HAV technologies on drivers and operators of commercial motor vehicles, including labor displacement, within one year of enactment of this Act. The analysis shall include stakeholder outreach and examine: (1) reduced situational awareness caused by the operation of these vehicles and options for mitigating such safety risks; (2) visibility, mobility, and safety issues of platooning; and (3) minimum and recommended training requirements. The analysis should also examine labor displacement from the deployment of HAV and ADAS technologies, including: (1) the potential pace of job loss; (2) segments of motor carrier and passenger transportation that could be affected; (3) existing labor market programs that link workers to employment; and (4) recommendations for new public or private sector job training opportunities. The analysis shall not impede or delay any ongoing studies at the Department related to automated vehicles.

¹ Joint Explanatory Statement on the *Consolidated Appropriations Act, 2018*, HR 1625, 115th Cong., 2nd sess., *Congressional Record* 164 (daily ed. March 22, 2018): H 2876, <https://www.congress.gov/crec/2018/03/22/CREC-2018-03-22-bk3.pdf>.

Executive Summary

The 2018 Consolidated Appropriations Act provided funding to the Secretary of Transportation for highly automated vehicle research and development, and requested that the Department, in consultation with the Secretary of Labor, “conduct a comprehensive analysis of the impact of ADAS [Advanced Driver-Assistance Systems] and HAV [Highly Automated Vehicles] technologies on drivers and operators of commercial motor vehicles, including labor displacement.” This report, developed by the United States Department of Transportation in coordination with the Department of Labor, Department of Commerce, and Department of Health and Human Services, analyzes the potential impacts of driving automation systems on the professional driving workforce in two industry segments: long-haul trucking and transit buses.² This report uses SAE International J3016 terminology to refer to levels of automation (see **Figure 1**). It is based primarily on a review of published literature and analysis of existing datasets.

The economic history of the United States includes centuries of innovations that have transformed American life and led to unparalleled prosperity. Innovative technologies foster economic opportunity through the creation of new businesses, products, and services. These innovations have also changed how we work. Labor-saving technologies have improved productivity; reduced occupational injury, sickness, and mortality; and raised wages and living standards. Innovation also influences labor markets by changing the demand for some skills relative to others. Labor markets adjust to such fluctuations via changes in relative wages to balance the supply and demand for labor.

The adoption of driving automation is expected to follow the general contours of this historical experience. However, this report finds that there is vast uncertainty about the more specific questions of how and when driving automation may be adopted in the long-haul trucking and transit bus industry segments, and what the associated impacts on the professional driving workforce may be. As such, this report presents findings based on existing data, stakeholder consultation, and a review of the published literature on technology, labor markets, human factors, and other workforce considerations, rather than making definitive predictions.

While some Level 1 and 2 ADAS technologies are available now on production vehicles, the use of Level 3, 4, and 5 automated driving systems (ADS) on heavy vehicles has been largely limited to demonstrations and pilot projects. A literature review and consultation with industry experts suggests that there is a long time horizon before broad adoption can take place.

² This document generally uses the terms *driving automation* and *driving automation system(s)* to refer broadly to all levels of automation (i.e., Levels 1–5 as defined in SAE International’s Standard J3016). The document also uses the terms *Advanced Driver Assistance Systems (ADAS)* to refer to Levels 0–2 and *Automated Driving Systems (ADS)* to refer to Levels 3–5. Where greater specificity is needed, the authors refer to the relevant levels of automation (e.g., Level 4 and 5). The authors recognize that SAE J3016 distinguishes Levels 3–5 as ADS based on the role that a human driver plays while the system is engaged. This distinction, however, is generally less salient when discussing potential workforce displacement impacts than the presence of a human driver in the vehicle. Per J3016, Levels 0–3 continue to assume the presence of a human driver; despite falling within SAE’s definition of ADS, Level 3 automation assumes that a human driver will be present as the fallback. Automated driving at Levels 4 and 5, by definition, does not require an onboard human driver for fallback performance or to monitor the driving environment, as long as the vehicle remains in its operational design domain.

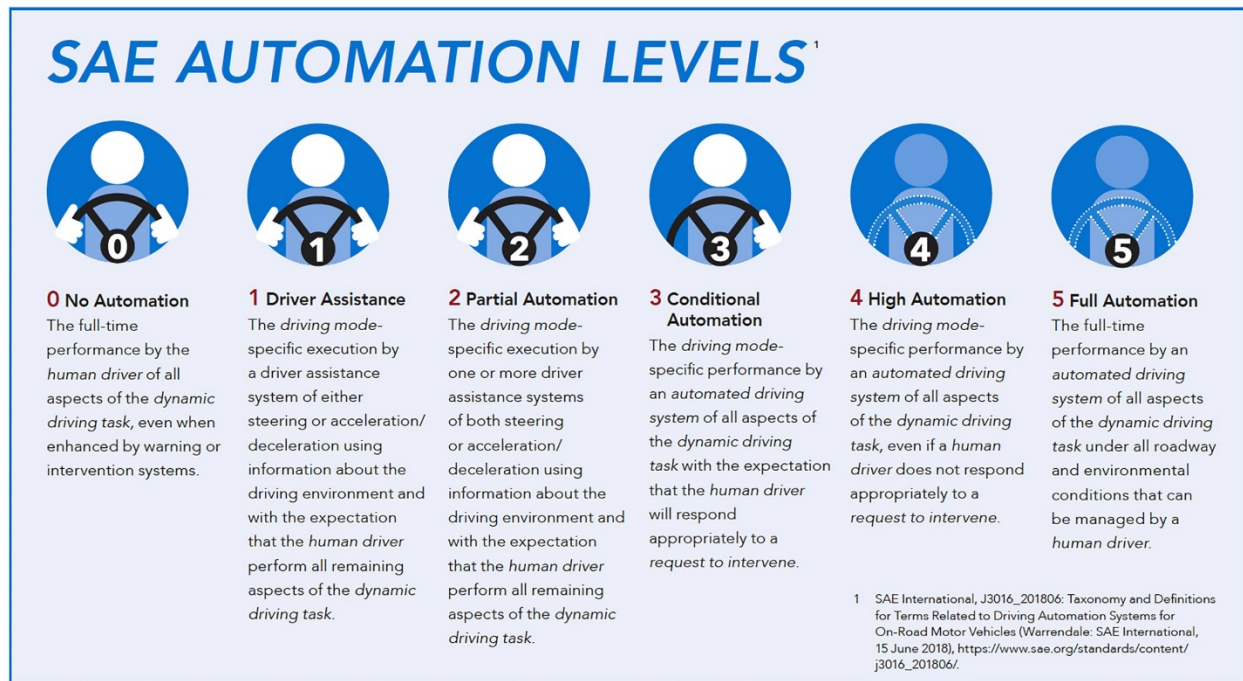


Figure 1. SAE Automation Levels

The introduction of driving automation systems could change professional driving jobs in diverse ways, including job responsibilities, wages, and quality of life. Increased adoption of Level 1, 2, and 3 technologies is unlikely to bring about driver job displacement; Level 1 and 2 systems may also lead to improvements in safety and operations. In the long term, the adoption of Level 4 or 5 ADS may supplant certain driving tasks and reduce the need for human drivers, leading to lower freight costs and productivity improvements, but also to periods of transitional unemployment for some affected workers. If workers experience displacement as a result of automation adoption, existing U.S. Department of Labor (DOL) programs offer retraining and other general career services.

The adoption of automation technologies has historically been associated with some level of job displacement. As described in more detail in this report, however, several factors are expected to mitigate these impacts in the trucking and transit industries:

- *The timeline for development of Level 4 or 5 capabilities is highly uncertain, but widespread adoption is not generally predicted to be imminent.* These technologies are not yet commercially available. Once on the market, they would require a period of testing before they become widely accepted in the trucking and transit industries. Even then, existing conventional vehicles would likely remain in service for many years until the fleet turns over. This means that workers in this field will have time to adapt to the changing environment, whether through additional training, transitioning to related employment opportunities, or other means. Level 1 and 2 driving automation are not expected to cause driver displacement.
- *Natural attrition is likely to absorb a large share of potential job displacement. These labor market adjustments are expected to occur over several decades, although the long-haul trucking segment will likely be affected first.* Truck and transit drivers have relatively older age profiles;

many current drivers will be at or near retirement age within the next decade. This natural turnover in the industry, particularly for trucking, should reduce the number of involuntary job losses.

- *New jobs will be created.* Driving automation systems would be expected to lower freight transportation costs and enhance productivity, leading to greater economic activity and job creation in the transportation and logistics industries, and other business sectors. Just as many employees today work in occupations that were unknown to prior generations—such as unmanned aerial systems, vehicle cybersecurity, or micromobility—future workers may choose from a wider variety of jobs that emerge from technology improvements, including driving automation.
- *Retraining programs are available through DOL and State partners.* Driving automation systems are not the first case of technology-related disruption, nor will they be the last. DOL and its partners offer a range of programs that have a strong track record of helping workers adapt to new technologies and market conditions.

Driving automation systems are not the only factor that will influence the labor market for professional drivers, and there is currently significant uncertainty regarding these systems' capabilities, applications, and adoption. The specific ways in which professional driving jobs will change may vary significantly across market segments and operating environments and will be influenced by contemporaneous changes in related industries.

As technologies mature and business models are better understood, future reexaminations of this topic will provide valuable insight into the impacts of driving automation on the Nation's transportation workforce.

1. Introduction

This report summarizes the potential impacts of driving automation on segments of the professional driving workforce in the United States, based largely on an analysis of published research findings and existing data sources. This section describes the scope, context, and methodology; following sections discuss potential workforce impacts, associated human factors topics, and training resources. The report was developed by the United States Department of Transportation (U.S. DOT) in coordination with the Department of Labor (DOL), Department of Commerce (DOC), and Department of Health and Human Services (HHS).

1.1. Report Scope

The 2018 Consolidated Appropriations Act provided funding to the Secretary of Transportation for highly automated vehicle research and development, and requested that U.S. DOT, in consultation with the Secretary of Labor, “conduct a comprehensive analysis of the impact [of] ADAS [Advanced Driver Assistance Systems] and HAV [Highly Automated Vehicle] technologies on drivers and operators of commercial motor vehicles, including labor displacement.” This report interprets “drivers of commercial motor vehicles” as covering holders of a commercial driver’s license (CDL) for whom driving is their primary job responsibility. The report scope further narrows to two sectors: long-haul trucking and transit buses.³ While other driving occupations will surely be impacted by the introduction of driving automation systems, long-haul trucking and transit both present potential opportunities and fall under the oversight of Federal agencies.⁴ See **Workforce Impacts** for further discussion of these sectors.

1.2. Historical and Economic Context

The economic history of the United States is a centuries-long line of innovations that have transformed American life and led to unparalleled prosperity. Innovative technologies foster economic opportunity through the creation of new businesses, products, and services. These innovations have also changed how we work. Labor-saving technologies have improved productivity; reduced occupational injury, sickness and mortality; and raised wages and living standards.

Innovation also influences labor markets by changing the demand for some skills relative to others. Jobs requiring high-demand skills will experience higher wages, and jobs with skills that are less in demand may see wages stagnate. Some labor-saving technologies completely replace certain human tasks with machines. Labor markets adjust to such fluctuations via changes in relative wages to balance the supply and demand for labor.

Driving automation systems have the potential to alter the labor market for millions of Americans currently working in driving-related occupations. The body of this report profiles the current workforce in this field, explores the types of labor market impacts that may be experienced, and details the potential impacts on working conditions for different business models and levels of driving automation.

³ A CDL is required for heavy trucks (including tractor-trailers) and passenger vehicles that carry at least 16 passengers, including the driver (e.g., motor coaches). See *Workforce Impacts* for more details.

⁴ Any references to levels of automation made in this report reflect definitions stated in “SAE J3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles,” SAE International, updated June 15, 2018, https://www.sae.org/standards/content/j3016_201806.

The ultimate impacts on driving-related occupations, however, are highly uncertain and thus any firm conclusions would be speculative.

As with other technologies that have been deployed in the past, the impacts on the workforce will be different for driving automation systems that *assist* the human driver versus those that *replace* the driver. Drivers will still be required in vehicles equipped with Levels 1, 2, or 3 technologies, but there is the potential for the job to be safer with fewer crashes. In time, the introduction of Level 4 or 5 ADS may remove the need for a driver, although many non-driving responsibilities would remain. Some potential future workers will elect different career paths; some drivers may be displaced and require new jobs. These could include new employment opportunities related to the growing transportation and logistics industry or a transition to completely different industries. As has happened in the past, those transitions to new occupations and industries may result in temporary unemployment. The new jobs these workers obtain may have higher or lower wages than their current positions; however, with retraining they may obtain new skills that are in high demand.

Transportation history also shows that while advanced technologies can emerge quickly, most require time to be commercialized and take root in the relevant industries. For example, various prototype automobiles were produced in the late 19th century, but mass production only began with the introduction of the moving assembly line to build the Ford Model T in 1913. Several more decades passed—and significant infrastructure investments were required—before automobile commuting and motor trucking became firmly established. The introduction of driving automation systems is likewise expected to be gradual, requiring testing of new technologies and the turnover of the existing vehicle fleet. During the transition, some drivers will retire, and other workers will choose different occupations. Natural attrition will likely mitigate potential driver unemployment.

This report provides a summary of the existing literature on these potential impacts as well as information on the current set of job training programs and resources available to affected workers in these industry segments. Driving automation may bring widespread benefits through higher productivity and lower freight costs, which will lead to lower prices and new goods and services for consumers and new workforce opportunities.

1.3. Driving Automation and Heavy Vehicle Research and Development Context

The last 10 years have seen significant advancements in driving automation. SAE Level 1 adaptive cruise control and lane-keeping systems are now commonplace in even entry-level new passenger cars, and Level 2 driver-assistance features that combine speed and directional control are available from several major manufacturers. As these features enter the marketplace, numerous technology companies and vehicle original equipment manufacturers (OEMs) have also been developing and testing far more advanced capabilities. U.S. DOT estimates that more than 80 companies are currently testing automated cars, trucks, and other vehicles.⁵ Test activities are being, will be, or have been conducted in 40 U.S. States plus Washington, DC, and more than half of U.S. States have introduced legislation or allowed testing on public roads via other means (e.g., executive orders). Additionally, several companies and a

⁵ Elaine Chao, “Remarks Prepared for Delivery by U.S. Secretary of Transportation Elaine L. Chao at the UBER Elevate Symposium,” Arlington, VA, June 11, 2019, <https://www.transportation.gov/briefing-room/uber-elevate-symposium>.

few transit agencies now offer rides to members of the public in prototype passenger vehicles. See **Appendix** for a summary of research, development, and commercialization activity in these areas.

The commercial trucking industry has also seen private investment and technology development. Certain segments of the trucking fleet spend the majority of their time on limited-access highways, which represent simpler operating environments than surface streets and constitute a smaller proportion of total lane mileage, making the use of driving automation systems potentially more feasible.⁶ Trucking firms operate in a highly competitive industry, and are receptive to technological innovations that could offer potential reductions in operating costs. Against this backdrop, freight shipments have been steadily increasing while driver retention remains a critical concern among motor carriers.⁷ As driving automation may help firms reduce operating costs and improve retention, it is likely to continue as a research focus for some segments of the trucking industry.

The first phase of adoption of automation is already underway in trucking (see **Appendix** for a summary of industry activity and relevant examples). Many new trucks are available with the same ADAS that have become prevalent in passenger cars and other light-duty vehicles over the last decade, including adaptive cruise control and automatic emergency braking. Looking toward the adoption of ADS in commercial vehicles, technology developers are transporting freight for paying customers while testing driving automation in commercial trucking operations.

Platooning technology, which links a lead truck with little or no driving automation and a following truck that uses automation to maintain a set following distance behind the lead vehicle, is being piloted on public roads in the U.S. and other countries. Allowing trucks to travel closer together offers potential improvements in overall fuel economy. Some experts forecast automation of long-haul, uninterrupted freeway driving in the medium-term, with only last-mile local driving to the delivery or pick-up location requiring a human operator. These studies generally predict a longer horizon for commercial availability of trucks capable of Level 4 automated driving on both local streets and on highways, stating this is likely to be at least a decade away.⁸

Public transportation applications have similarly attracted interest, particularly in the testing of driver-assistance technologies such as automatic emergency braking, as well as numerous pilot tests with a

⁶ "Table HM-260 - Highway Statistics 2018," Highway Policy Information, Federal Highway Administration, updated November 27, 2019, <https://www.fhwa.dot.gov/policyinformation/statistics/2018/hm260.cfm>. Interstates and other freeways and expressways represented approximately 3.5 percent of the Nation's total lane mileage in 2018.

⁷ "Truck Tonnage [TRUCKD11]," U.S. Bureau of Transportation Statistics, accessed May 15, 2019, retrieved from FRED, Federal Reserve Bank of St. Louis, <https://fred.stlouisfed.org/series/TRUCKD11>. The American Trucking Associations' Truck Tonnage Index has risen more than 20 percent over the last five years and more than 50 percent over the last 10 years; Dan Ronan, "Driver Shortage Repeats as Top Concern in ATRI Industry Survey," *Transport Topics*, October 30, 2018, <https://www.ttnews.com/articles/driver-shortage-repeats-top-concern-atri-industry-survey>.

⁸ Steve Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker* (Center for Labor Research and Education, University of California, Berkeley, and Working Partnerships USA, September 2018), 2, <http://driverlessreport.org/files/driverless.pdf>; David Montgomery et al., *America's Workforce and the Self-Driving Future* (Securing America's Future Energy, June 2018), 39, https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Americas-Workforce-and-the-Self-Driving-Future_Realizing-Productivity-Gains-and-Spurring-Economic-Growth.pdf.

variety of small, low-speed automated shuttles.⁹ Due to their low speed, small size, and limited operating environments, automated shuttles are being used in early demonstrations and pilots of Level 4 automation. Research and development of driving automation systems for full-size transit buses is in progress, although testing and piloting are still in the early stages.¹⁰

1.4. Methodology and Limitations

There is inherent uncertainty in predicting how an emerging technology may affect jobs and workers in the future. Currently, no consensus exists as to whether or when Level 4 or 5 vehicles will become commercially available or how they may impact freight, transit, or other sectors. This report presents findings based on existing data and a synthesis of the published literature on driving automation technology, labor markets, human factors, and other workforce considerations, rather than making definitive predictions. The literature review included many sources including academic journal articles, government and industry reports, media accounts, and other published materials, along with queries of statistical databases. Primary data collection and modeling were limited.

Several recent studies have estimated the potential driver workforce impacts from automation, including Viscelli (2018); Gittleman and Monaco (2018); Groshen, MacDuffie, Helper, and Carson (2018); Burks and Monaco (2019); and the Government Accountability Office (2019). This report synthesizes findings from these studies and integrates them with information from other sources.

1.4.1. Stakeholder Consultation

The literature review was supplemented by stakeholder consultation and targeted follow-up interviews to ensure that a wide variety of perspectives were represented. The two primary avenues for stakeholder consultation were a published request for comments (RFC) and an in-person stakeholder workshop. The RFC was designed to solicit feedback on the proposed scope of the study and potential information sources. It was posted to the *Federal Register* on October 9, 2018, and a total of 31 responses were received prior to the closure date of November 5, 2018.¹¹

RFC respondents included industry groups, labor unions, local governments, safety advocates, and other interested stakeholders. The comments provided additional detail on issues that are specific to certain segments of commercial driving, and suggested ways in which the study's scope could be expanded, for example, to cover impacts on non-driving jobs. Although there was no single theme running through the responses, many respondents cited the need to document both the positive and negative potential impacts of driving automation and noted the uncertainty about the future deployment path. Several

⁹ For an overview of activity in this field, see: Elizabeth Machek, et al., *Strategic Transit Automation Research Plan*, FTA Report No. 0116 (Washington, DC: Federal Transit Administration, January 2018), https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/114661/strategic-transit-automation-research-report-no-0116_0.pdf, and *Low-Speed Automated Shuttles: State of the Practice*, prepared by the Volpe Center for the Intelligent Transportation Systems Joint Program Office, September 2018 (FHWA-JPO-18-692), <https://rosap.ntl.bts.gov/view/dot/37060>.

¹⁰ Joshua Cregger, Elizabeth Machek, and Patricia Cahill, *Transit Bus Automation Market Assessment*, FTA Report No. 0144 (Washington, DC: Federal Transit Administration, October 2019), <https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/134451/transit-bus-automation-market-assessment-fta-report-no0144.pdf>.

¹¹ U.S. Department of Transportation, *Scope of the Study on the Impact of Automated Vehicle Technologies on Workforce*, Federal Register Number: 2018-21842 (Washington, DC, October 2018), <https://www.regulations.gov/document?D=DOT-OST-2018-0150-0001>.

responses also provided references to existing studies covering the areas of safety issues, training needs, and human factors.

The stakeholder workshop was held at U.S. DOT headquarters in Washington, DC, on March 20, 2019. Invited participants represented a wide range of stakeholder perspectives, including labor, industry, research, advocacy, and government. In order to provide structure to the workshop discussions, a set of example scenarios for long-haul trucking and transit buses were developed and shared. These scenarios examined a range of potential future states and were created using publicly available information on current industry investment in research, development, and commercialization.

The workshop's morning session was live-streamed via the Internet and featured an address from Elaine L. Chao, Secretary of Transportation, and Patrick Pizzella, Deputy Secretary of Labor, on their respective departmental initiatives related to driving automation. This was followed by a moderated panel discussion on workforce issues in trucking and transit.

In the afternoon session, participants divided into smaller breakout groups to provide input on the study's scope and methodology. While opinions reflected the diverse perspectives of participants, themes from the breakout discussions included expectations for a slow and phased introduction of automation into commercial driving and significant uncertainty regarding the feasibility of automating the varied non-driving tasks performed by drivers today. Full proceedings from the event are available from U.S. DOT.¹²

1.4.2. Technological and Operational Uncertainties

Driving automation technologies are in various stages of development, testing, and adoption. While some ADAS features are already in daily use, other capabilities with greater workforce implications have yet to demonstrate technical feasibility or achieve widespread acceptance. Moreover, the cost effectiveness of such systems and their compatibility with existing (or future) business models will only be determined over time through the actions of marketplace participants. At the same time, other technologies that are unforeseen today may emerge in the future. Meanwhile, other modes of transportation will continue to evolve and compete for market share of passengers and freight. Thus, an important limitation of this report is that it is not intended as an in-depth technical feasibility assessment, nor as a precise forecast of commercial adoption of driving automation. While such factors are addressed in the report, particularly when referenced by stakeholders or discussed in the published literature, the focus instead is on identifying the potential *workforce* impacts that would arise from adoption of these technologies, such as displacement or training needs.

As with any new technology, it is possible that entirely new paradigms and service models will emerge that make it even more challenging to identify future workforce impacts. Examples include the use of aerial delivery drones that might compete with local package delivery currently performed by trucks; the replacement of full-size, fixed-route buses with a number of smaller vehicles that can operate a more flexible point-to-point service enabled by driving automation; and new forms of multimodal robotic trucking that lead to profound shifts in supply chains and freight movements. Where relevant

¹² U.S. Department of Transportation, *U.S. Department of Transportation Automation and the Workforce Stakeholder Roundtable*, DOT-VNTSC-OSTR-19-03 (Washington, DC, June 2019), <http://www.dot.gov/av/workforce>.

throughout the report, the potential for these kinds of fundamental shifts in service patterns, business models, and vehicle platforms is described qualitatively.

1.4.3. Workforce Uncertainties

The automation of tasks affects the structure of work and the demand for human labor, but the actual trajectory of employment is complex and difficult to predict. Considerable uncertainty exists when attempting to predict the impacts of driving automation on employment, particularly given the multi-decade timescale involved and the current state of deployment.

The specific challenge for this report is that existing truck and bus jobs that are potentially impacted by driving automation are easily identified, but the potential future jobs that may be created by its introduction are hypothetical. To avoid presenting a distorted picture of employment impacts, this report attempts to identify related positive job opportunities—such as in programming and maintenance—in addition to the potential displacement risks to the extent possible based on the literature.

The trucking industry is structurally diverse, with workforce impacts that will likely differ across firms and submarkets. This report focuses on the long-haul market (as opposed to the short-haul and local delivery markets). The available literature does not support a more fine-grained analysis of the potential impacts in specialized areas such as hazardous materials, over-dimensional loads, automobile transport, refrigerated/perishables, and cross-border freight. In these areas, the adoption of driving automation and the associated workforce impacts could vary significantly due to differences in non-driving tasks, regulatory requirements, and other factors.

In addition, the report focuses on workers for whom driving of heavy trucks is their primary job responsibility, as distinct from a secondary job duty. Automation of driving is expected to have the most impact on people whose job involves driving as a primary duty. Although transit bus service does not necessarily have as much differentiation as trucking, there is still considerable variation across transit agencies in vehicle types, operational practices, and other important factors that will influence the workforce impacts of automation. Further research would be needed to identify impacts for individual market segments within heavy trucking or by type of transit agency, and to explore the potential impacts on other categories of workers, such as CDL holders who drive heavy trucks as a secondary job duty.

1.5. Federal Roles

Several Federal departments and agencies have responsibilities related to the safe integration of driving automation into the transportation system and for managing potential impacts of this new technology on the workforce. The following sections provide brief overviews of each agency that contributed to this report.

1.5.1. United States Department of Transportation

U.S. DOT's role in transportation automation is to ensure the safety and mobility of the traveling public while fostering economic growth. As a steward of the Nation's roadway transportation system, U.S. DOT plays a significant role in ensuring that vehicles equipped with driving automation can be safely and effectively integrated into the existing transportation system, alongside conventional vehicles, pedestrians, bicyclists, motorcyclists, and other road users. U.S. DOT also has an interest in supporting innovations that improve safety, reduce congestion, improve mobility and accessibility, and increase

access to economic opportunity for all Americans. Finally, by adopting market-driven, technology-neutral policies that encourage innovation in the transportation system, the Department seeks to fuel economic growth and support job creation.

1.5.2. United States Department of Labor

DOL collects, analyzes, and disseminates essential labor market and economic information; tracks changes in the Nation's workforce, including those driven by automation; and administers programs to help all workers adapt to those changes in the labor market, including sparking employer-led, work-based learning, such as apprenticeships. DOL shares information with job seekers and the public about jobs and skills in demand. Under the Workforce Innovation and Opportunity Act, DOL relies on the nationwide workforce system of American Job Centers to deliver career counseling, employment services, and training to job seekers—such as those impacted by automation.

1.5.3. United States Department of Health and Human Services

The mission of HHS is to enhance and protect the health and well-being of all Americans by providing for effective health and human services, and by fostering sound, sustained advances in the sciences underlying medicine, public health, and social services. Within HHS, the National Institute for Occupational Safety and Health (NIOSH) of the Centers for Disease Control and Prevention (CDC) is the lead research agency focused on worker safety and health to protect the Nation's millions of workers. NIOSH seeks to proactively address worker safety and health challenges that may be associated with automation, as well as leverage new technologies to improve safety and health.

1.5.4. United States Department of Commerce

The mission of DOC is to create the conditions for economic growth and opportunity. DOC promotes job creation and economic growth by ensuring fair and reciprocal trade, providing the data necessary to support commerce and constitutional democracy, and fostering innovation by setting standards and conducting foundational research and development. DOC provides U.S.-based companies and entrepreneurs useful tools through programs such as the Decennial Census, the National Weather Service, National Oceanic and Atmospheric Administration (NOAA) Fisheries, and the Foreign Commercial Service. Among many other functions, DOC oversees ocean and coastal navigation, helps negotiate bilateral trade agreements, and enforces laws that ensure a level playing field for American businesses and workers. The mission of the National Institute of Standards and Technology (NIST) is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology to enhance economic security and improve quality of life.

2. Workforce Impacts

Concerns about the displacement of workers by new technologies date back at least to the Industrial Revolution. Two centuries of continued technological innovation and the automation of manual tasks have generally shown, however, that automation is not a one-way ratchet in which human jobs are progressively eliminated. Instead, the impacts have been much more complex. The need for human labor has been ever present at the economy-wide level, even as the composition of the American labor force has changed radically. This section reviews the existing literature and current workforce characteristics and considers potential impacts for CDL-holding truck and transit bus drivers.

2.1. Historical Perspective: Labor Market Impacts of New Technologies

Although automated vehicles are a more recent development, researchers have evaluated the impacts of other new technologies on the workforce for many years. The literature notes that while labor-saving technologies can displace workers in particular jobs, they also foster the creation of other jobs, either in the management and operation of the machinery itself, or due to broader effects from higher productivity and greater demand for goods and services. This basic relationship has been known for some time, with Shiller (2019) quoting Marshall (1890):

*“Thus machinery constantly supplants and renders unnecessary that purely manual skill, the attainment of which was, even up to Adam Smith’s time, the chief advantage of division of labour. But this influence is more than countervailed by its tendency to increase the scale of manufactures and to make them more complex; and therefore to increase the opportunities for division of labour of all kinds, and especially in the matter of business management.”*¹³

Another way of phrasing Marshall’s observation is that technology and human labor can be both complements and substitutes, depending on the industry and the nature of production. While some technologies do replace human labor, others provide tools that enhance human productivity and thus increase demand for that labor (since each hour of work now produces more economic value). As a simplified example, the spread of personal computers has had very different impacts across industries (see **Box 2.1** for another example). Computer and internet access have improved the productivity of occupations such as lawyers and accountants, by automating certain routine functions and making information more readily accessible. By contrast, the ability to use personal computers to plan and book one’s own travel has led to a reduced demand for travel agents.¹⁴

¹³ Alfred Marshall, *The Principles of Economics* (London: Macmillan, 1890), Chapter IX, Section 3, quoted in Robert Shiller, “Narratives about Technology-Induced Job Degrations Then and Now,” (working paper, National Bureau of Economic Research, Cambridge, MA, February 2019), <http://www.nber.org/papers/w25536>.

¹⁴ “Travel Agents,” *Occupational Outlook Handbook*, U.S. Bureau of Labor Statistics, last modified April 12, 2019, <https://www.bls.gov/ooh/sales/travel-agents>.

Box 2.1. Workforce Impacts from Containerization

Containerization is an example of technological innovation that resulted in job losses in one occupation (longshoremen), but also resulted in off-setting employment gains in other industries and occupations. Pre-containerization, goods were stored in a variety of packages—barrels, crates, or even bags—and had to be loaded and unloaded manually by longshoremen. Vessels would often spend several days in port waiting to be loaded and unloaded. In the early 1950s, large ports, like New York and London, employed as many as 50,000 longshoremen.¹⁵ Introducing intermodal cargo containers of a uniform size brought assembly line-like efficiency to a previously individualized approach to cargo handling, increasing West Coast port efficiency from 0.8 tons per hour pre-containerization to 5.5 tons per hour in 1980.¹⁶ As a consequence, labor productivity at West Coast ports increased 34 percent between 1960 and 1964 for a labor cost savings of nearly 7.5 million work hours.¹⁷ This productivity improvement translated into reduced demand for longshoremen. Although not exclusively caused by containerization, the number of longshoreman jobs at the Port of New York and New Jersey declined from around 50,000 in the 1950s to 35,000 in the 1960s down to around 3,500 in the 1990s.¹⁸ Parallel changes to longshoreman hiring practices in New York, an emphasis on registered longshoremen as opposed to casual workers, and developments in international trade flows also contributed to the reduction in jobs.¹⁹ Despite the reduction in number of longshoreman positions, Gomtsyan (2016) finds that containerization and the subsequent boom in containerized seaborne trade *created* jobs in other industries, such that containerization *reduced* the unemployment rate in port cities with relatively large shares of longshoremen.²⁰

The adoption of automation technologies in a particular industry often leads to a shift in labor demand due to the altered balance between human and machine roles. The resulting jobs may require high technical skill and command higher wages. This has been the case in recent decades with the use of computer programs to replace manual activities, which has led to demand for higher-skilled jobs in software, management, and analysis.²¹ However, there are also historical examples in which the resulting jobs were lower-skilled, such as when mass production of textiles using power looms led to the replacement of higher-paid skilled artisans with relatively low-skilled mill workers.²²

¹⁵ Jean-Paul Rodrigue and Theo Notteboom, *The Geography of Transport Systems* (New York: Routledge, 2017), Port Terminals.

¹⁶ Kristen Monaco and Lindy Olsson, *Labor at the ports: A comparison of the ILA and ILWU* (California: METRANS Transportation Center, 2005): 24.

¹⁷ Bill Sharpsteen, *The Docks* (University of California Press, 2011), 283.

¹⁸ Rodrigue and Notteboom, *Geography of Transport Systems*, Port Terminals.

¹⁹ Marc Levinson, *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger* (New Jersey: Princeton University Press, 2008), 23.

²⁰ David Gomtsyan, *Rise of the Machines: Evidence from the Container Revolution* (University of Turin, 2016), 19.

²¹ David H. Autor, Frank Levy, and Richard J. Murnane, "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics* (November 2003): 1279-1333, as cited and summarized in Kristin Lee, "Artificial Intelligence, Automation, and the Economy," *The White House Blog* (blog), *Executive Office of the President*, December 20, 2016, <https://obamawhitehouse.archives.gov/blog/2016/12/20/artificial-intelligence-automation-and-economy>.

²² Daron Acemoglu, "Technology and Inequality," *NBER Reporter* (Winter 2002-03), <https://www.nber.org/reporter/winter03/technologyandinequality.html>; David Hounshell, *From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States* (Baltimore: JHU Press, 1985); John A. James and Jonathan S. Skinner, "The Resolution of the Labor-Scarcity Paradox," *The Journal of Economic History*

When technologies are new, it can be difficult to forecast the trajectory that employment will take in response to adoption. Automated teller machines (ATMs) were widely anticipated to put bank teller jobs in jeopardy, and this was true at first. However, teller jobs rebounded in the mid-1990s as banks opened more local branches and tellers' job descriptions were revised to include cross-selling of other banking products.²³ (These jobs are projected to decline again in future years as online banking quells growth in physical bank branches, and mobile payments diminish the use of cash and checks.²⁴)

Similarly, the use of an autopilot in commercial jets was a factor in reducing the standard cockpit crew from three to two (with the loss of the flight engineer position), but labor displacement has not gone beyond that point. Human pilots are still needed to manage the autopilot; communicate with air traffic control, dispatch, and passengers; and provide oversight and handle unusual situations.²⁵ The tremendous growth of the aviation sector in recent decades, in part due to deregulation, has created significant overall employment growth for pilots, even as pilots use increasingly sophisticated automated systems to improve safety and manage their workload.²⁶ Recently, the COVID-19 pandemic has brought uncertainty to the future career outlook for pilots due to reductions in demand for travel and tourism.

As these examples illustrate, automation technologies can interact in complex ways with other technologies and with institutional issues such as government regulation, labor-management relations, and broader societal trends. Initial predictions based on simplified models of technology's impacts can thus prove inaccurate—or as the authors of a recent report note, “Linear thinking about transformative technology often fails.”²⁷

One clear implication from the historical parallels is that new technologies can produce significant labor market shifts, and that these can affect the premiums placed on certain skill sets relative to others. This has often been associated with disruption to existing workers and their communities. Economic theory holds that competitive labor markets will adjust to these types of external shocks, re-establishing equilibrium through the wage mechanism to maintain near-full employment. However, there are scenarios where this new equilibrium can entail significantly lower earnings for workers in affected industries or cause significant periods of unemployment, which can have lasting effects on future

45, no. 3 (1985): 513-40, <https://doi.org/10.1017/S0022050700034483>; Joel Mokyr, “Technological Inertia in Economic History,” *The Journal of Economic History* 52, no. 2 (1992): 325-38, <https://doi.org/10.1017/S0022050700010767>, as summarized in Lee, “Artificial Intelligence, Automation, and the Economy.”

²³ Erica L. Groshen et al., *Preparing U.S. Workers and Employers for an Autonomous Vehicle Future*, Securing America's Future Energy (June 2018), 125-127, <https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Groshen-et-al-Report-June-2018-1.pdf>.

²⁴ “Tellers,” *Occupational Outlook Handbook*, U.S. Bureau of Labor Statistics, last modified September 4, 2019, <https://www.bls.gov/ooh/office-and-administrative-support/tellers.htm#tab-6>.

²⁵ Groshen et al., *Preparing U.S. Workers*, 119-120.

²⁶ U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0* (October 2018), 42-43, <https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/320711/preparing-future-transportation-automated-vehicle-30.pdf>.

²⁷ Montgomery et al., *America's Workforce*, 16.

earnings.²⁸ For the economy as a whole, however, the labor productivity gains that emerge from these adjustment processes support growth in incomes and higher living standards.

2.2. The Professional Driving Workforce

Many occupations include driving a motor vehicle as a primary job responsibility. These include truck, bus, and taxi drivers, as well as jobs that combine driving with delivery and sales functions. According to occupational data from the Bureau of Labor Statistics (BLS), roughly 4.6 million Americans (out of 144.7 million total employed individuals) earn their livelihood in occupations where driving a car, truck, or other vehicle is the primary job responsibility (see **Table 2.1** below, which summarizes available data on those driving occupations, including employment levels and earnings). Millions more work in other occupations that involve driving as a secondary job responsibility. For instance, some construction workers and utility workers must drive heavy trucks to and from job sites in addition to performing other types of skilled work while at the site. Other workers must do some on-the-clock driving of light-duty vehicles that is ancillary to core job responsibilities, such as real estate agents and appraisers, regional supervisors, and plumbers and other tradespersons who must travel between job sites. Supporting these positions are over 5 million jobs in occupations such as automotive repair and highway maintenance.

Table 2.1. Primary Driving Occupations²⁹

Occupation	Total Jobs	Median Annual Wage	Occupation Description
Heavy and Tractor-Trailer Truck Drivers	1,800,330	\$43,680	Drive a tractor-trailer combination or a truck with a capacity of at least 26,001 pounds gross vehicle weight rating (GVWR). May be required to unload truck. Requires commercial drivers' license. Includes tow truck drivers.
Light Truck or Delivery Services Drivers	915,310	\$32,810	Drive a light vehicle, such as a truck or van, with a capacity of less than 26,001 pounds GVWR, primarily to pick up merchandise or packages from a distribution center and deliver. May load and unload vehicle.

²⁸ Steven J. Davis and Till von Wachter, "Recessions and the Costs of Job Loss," *Brookings Papers on Economic Activity, Economic Studies Program, The Brookings Institution* 43, no. 2 (2011): 1-72, https://www.brookings.edu/wp-content/uploads/2011/09/2011b_bpea_davis.pdf; David H. Autor, David Dorn, and Gordon H. Hanson, "The China Syndrome: Local Labor Market Effects of Import Competition in the United States," *American Economic Review* 103, no. 6 (2013): 2121-2168, <http://dx.doi.org/10.1257/aer.103.6.2121>, summarized in Lee, "Artificial Intelligence, Automation, and the Economy."

²⁹ "Occupational Employment Statistics," U.S. Bureau of Labor Statistics, U.S. Department of Labor, accessed April 16, 2019, <https://www.bls.gov/oes>. Total jobs and mean hourly wages from Occupational Employment Statistics (OES) data for May 2018 except where noted; Occupation descriptions from "O*NET 23.2 Database," *O*NET Resource Center*, National Center for O*NET Development, accessed April 8, 2019, www.onetcenter.org/database.html, except where noted.

Occupation	Total Jobs	Median Annual Wage	Occupation Description
Bus Drivers, School or Special Client	504,150	\$32,420	Drive a school bus to transport students. Ensure adherence to safety rules. May assist students in boarding or exiting.
Driver/Sales Workers	414,860	\$24,700	Drive truck or other vehicle over established routes or within an established territory to sell or deliver goods, such as food products, including restaurant take-out items, or pick up or deliver items such as commercial laundry. May also take orders, collect payment, or stock merchandise at point of delivery.
Self-employed Automobile Drivers ³⁰	364,000	<i>Not available</i>	Self-employed drivers for ride-hailing platforms such as Uber and Lyft.
Taxi Drivers, Shuttle Drivers and Chauffeurs	207,920	\$25,980	Taxi: Drive a motor vehicle to transport passengers on an unplanned basis and charge a fare, usually based on a meter. Other: Drive a motor vehicle to transport passengers on a planned or scheduled basis. May collect a fare.
Bus Drivers, Transit and Intercity	174,110	\$42,080	Drive bus or motor coach, including regular route operations, charters, and private carriage. May assist passengers with baggage. May collect fares or tickets.
Self-employed Truck Drivers ³¹	150,000	<i>Not available</i>	Self-employed heavy truck and tractor-trailer drivers.
Motor Vehicle Operators, All Other	56,810	\$30,360	All motor vehicle operators not listed separately.
Ambulance Drivers and Attendants, Except Emergency Medical Technicians	15,380	\$25,750	Drive ambulance or assist ambulance driver in transporting sick, injured, or convalescent persons. Assist in lifting patients.

³⁰ Executive Office of the President, *Artificial Intelligence, Automation, and the Economy*.

³¹ United States Government Accountability Office, *Automated Trucking: Federal Agencies Should Take Additional Steps to Prepare for Potential Workforce Effects*, GAO-19-161 (Washington, DC, March 2019), 5.

Occupation	Total Jobs	Median Annual Wage	Occupation Description
Motor Vehicle Operators (Total)	4,587,490	\$37,130	N/A

Driving automation systems could affect all occupations that involve driving to some extent. For example, lowering the cost of travel or allowing in-vehicle time to be more productive could translate into impacts on wages. However, the most direct impacts will be on driving-related tasks rather than non-driving tasks. Consequently, the existing literature generally notes that the need for new worker training and the potential for job displacement related to driving automation will be most significant in occupations for which driving is the primary task.³² The remainder of the report considers two such occupations, long-haul heavy truck driving and transit bus driving, in detail.

2.3. Workforce Impacts for Long-Haul Heavy Trucking

The trucking industry comprises several individual market segments with different operational characteristics. As described in **Report Scope**, this report focuses on one such segment of the trucking industry workforce—CDL-holding, long-haul truck drivers—while noting that potential impacts across the entire workforce could be quite varied. This section discusses the size and characteristics of the current workforce and reviews the literature before considering potential impacts of automation technologies and related business models.

2.3.1. Size of Current Truck Driving Workforce

Regarding trucks, CDLs are required only for drivers of single trucks and combination vehicles that have a gross vehicle weight rating (GVWR) of at least 26,000 pounds, and any vehicle that carries hazardous materials. The typical tractor-trailer combination vehicle falls into that weight rating category.³³ (Note that CDL-holding transit bus operators are discussed in **Workforce Impacts for Transit Buses**.)

According to the “Pocket Guide to Large Truck and Bus Statistics, 2018” from the Federal Motor Carrier Safety Administration (FMCSA), 4.2 million CDL-holding drivers currently work for FMCSA-regulated motor carriers.³⁴ Some additional CDL-holding drivers work for State or local agencies that are not regulated by FMCSA (for example, bus drivers who work for public transit agencies or snowplow drivers employed by a city or town). CDL-holding drivers may work in a variety of industries. Many are

³² Executive Office of the President, *Artificial Intelligence, Automation, and the Economy* (Washington, DC, December 2016), 17.

³³ Note that this Phase 1 report does not address light-duty truck drivers who are not required to have a CDL; light-duty trucks are typically used in the short-haul local delivery segment.

³⁴ “2018 Pocket Guide to Large Truck and Bus Statistics,” Federal Motor Carrier Safety Administration, U.S. Department of Transportation, August 2018, <https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/safety/data-and-statistics/413361/fmcsa-pocket-guide-2018-final-508-compliant-1.pdf>.

employed by trucking firms and their primary job duty is driving. However, for some people such as utility workers or construction workers, driving is secondary to other job duties.

According to BLS, approximately 1.8 million people are employed as “Heavy and Tractor-Trailer Truck Drivers” when classified according to their primary job duty,³⁵ making it one of the largest occupational categories in the United States.³⁶ That estimate is based on surveys of employers and does not include self-employed drivers—so-called “owner-operators” (see **Box 2.2** below)—who are a key segment of the tractor-trailer market segment. Including self-employed truck drivers increases the estimate of the workforce by approximately 150,000 drivers.³⁷ Thus, the current size of the heavy truck and tractor-trailer driver workforce is approximately 2.0 million drivers.

Box 2.2. Owner-Operators

Owner-operators are small business owners who combine their time and labor, their business management skills, and their own capital investments in vehicles to provide transportation services. As an owner-operator, the driver generates their own work by identifying loads and negotiating rates with shippers (often they use freight brokers to assist in this latter task). The owner-operator must pay for all the out-of-pocket costs of the transportation including fuel, tolls, insurance, debt payment, meals, etc., and keeps the residual revenue as their income. Owner-operators shoulder more responsibility and greater risk than employee drivers but have more decision-making autonomy. Roughly half of all owner-operator vehicles are leased to other larger carriers while the rest have their own operating authority from FMCSA.

2.3.2. Trucking Industry Segments

The trucking industry makes a distinction between three types of market segments:

Long-haul trucking (sometimes called “over-the-road” trucking) involves long-distance cargo movements by truck, usually using tractor-trailer combinations. Long-haul drivers are often away from home for days or weeks at a time. The length of time spent moving goods across the country requires drivers to stop during the trip for rest breaks or to work as part of a team, whereby one team member is driving while the other rests in a sleeper berth in the back of the cab (a so-called “sleeper” cab). Single drivers may use a sleeper cab while parked at truck stops or other rest areas.

Short-haul driving includes shorter periods of uninterrupted highway driving and significantly more time spent navigating urban areas and surface streets. Short-haul drivers also spend significantly more of their time on non-driving tasks, such as providing customer service and cargo handling. Short-haul drivers return home every day and tractor-trailers used in short-haul service typically use a smaller day cab that does not have a sleeper berth.

Regional trucking is an intermediate operating model that has characteristics of both short- and long-haul trucking. Like short-haul drivers, regional drivers do generally return home daily. The regional routes are designed so that drivers transport goods from one freight terminal to another, drop those

³⁵ “Occupational Employment and Wages, May 2018 53-3032 Heavy and Tractor-Trailer Truck Drivers,” Occupational Employment Statistics, U.S. Bureau of Labor Statistics, updated March 29, 2019, <https://www.bls.gov/oes/current/oes533032.htm>.

³⁶ Jennifer Cheeseman Day and Andrew Hait, “Number of Truckers at All-Time High,” *U.S. Census Bureau*, June 2019, <https://www.census.gov/library/stories/2019/06/america-keeps-on-trucking.html>.

³⁷ U.S. GAO, *Automated Trucking*, 5.

goods, and take another load back to their starting point. These trips are generally planned so that they can be completed in one day of driving while staying in compliance with the FMCSA’s hours-of-service (HOS) regulations. As in long-haul driving, these drivers may spend a significant part of their day engaged in highway driving.

2.3.3. Scale of Potential Job Displacement from Driving Automation in Trucking

Given the differences in the operational characteristics of trucking market segments, it is likely that they may be impacted differently by the introduction of driving automation systems. Current efforts to automate the driving task for heavy trucks have generally focused testing activity on limited-access highways, in part because they are a less-complex operating environment than surface streets, although there have also been tests of “last mile” delivery with smaller vehicles. As the long-haul segment involves long periods of uninterrupted highway driving, some researchers argue that the long-haul segment is where the impacts from the introduction of driving automation may be initially felt, when compared to other segments of the heavy trucking industry.³⁸

No definitive data exists on the proportion of heavy truck and tractor-trailer drivers who operate on long-haul trucking routes. In the absence of specific data, researchers have attempted to estimate the number of long-haul truck drivers—or otherwise estimate the number of truck drivers—who could be impacted by widespread deployment of driving automation systems.

At the high end of the estimates, Groshen et al. (2018) analyzes the potential of driving automation to displace all categories of current driver jobs (not just trucking) and estimate that 60 to 65 percent of all heavy and tractor-trailer driver jobs will be eliminated after full implementation of Level 4 or 5 driving automation. However, the authors arrive at their estimate based on industry expertise rather than attempting to identify the size of the long-haul market, a limitation that they acknowledge.

Gittleman and Monaco (2018) use the Census Bureau’s Vehicle Inventory and Use Survey (VIUS) (last conducted in 2002) and note that a surprising number of heavy trucks, including both tractor-trailers and single unit trucks, have relatively short ranges of operation: roughly half operate in 50-mile ranges or less, while only one-quarter operate in ranges of 201 miles or more. They predict that this latter category would likely be impacted by Level 4 driving automation. The authors also suggest the impact would be concentrated on the “for-hire” segment, which would mean that just 19 percent of the heavy trucking workforce would be impacted.³⁹ Including the “in-house” segment raises that figure to be 25 percent. It is important to note that this estimate is based on data from 2002 and may not accurately depict the current market.⁴⁰

Viscelli (2018) also argues that driving in the long-distance heavy truck segment is most likely to be automated, and focuses on the revenue of the largest long-distance trucking firms—those that, the

³⁸ Maury Gittleman and Kristen Monaco, “Truck Driving Jobs: Are They Headed for Rapid Elimination?” *Industrial and Labor Relations Review*, Volume: 73 issue: 1, page(s): 3-24. <https://doi.org/10.1177/0019793919858079>

³⁹ For-hire carriers are carriers that sell their freight-hauling services to the public in contrast to private carriers that operate fleets and employ drivers to haul their own merchandise. Private carriage is also referred to as “in-house” trucking.

⁴⁰ The Bureau of Transportation Statistics (BTS) is in the process of restoring the VIUS, which will be released in 2023 to reflect fleet data as of 2021.

author believes, are most likely to invest in driving automation.⁴¹ The author uses 2017 data collected by *Transport Topics* and *Commercial Carrier Journal (CCJ)* to estimate the number of driving jobs at risk from driving automation for each long-distance trucking segment, including truckload, less-than-truckload (LTL), and parcel services. For segments with revenue estimates, the author estimates per-driver revenue and divides the total revenue of the largest fleets in each segment by the estimate of per-driver revenue to estimate the number of jobs. Aggregating across segments, Viscelli estimates that 294,000 long-distance truck driving jobs are at risk from driving automation.

Thus, while the available data to scope the size of the long-haul market is imprecise and somewhat outdated, it suggests that the *current* size of long-haul trucking workforce is approximately 300,000 to 500,000 jobs. The low end of the range is taken directly from Viscelli (2018) and the high end results from applying the 25 percent estimate from Gittleman and Monaco (2018) to the estimated two million current drivers in the heavy truck and tractor-trailer driver workforce.

This estimate does not necessarily mean that those jobs will be lost to driving automation. Rather, the estimate is simply provided to benchmark the potential magnitude of possible job impacts. Further, there are certain segments within long-haul trucking, such as hazardous materials transport, oversized loads, or transborder crossings, which may prove more resistant to adopting Level 4 or 5 automation due to the importance of the driver's non-driving tasks. Note that the range is lower than many other estimates found in the literature, which do not differentiate between short-haul and long-haul trucking or between heavy- and light-duty trucks. The estimate of 300,000 to 500,000 can also be considered in the context of the overall job market where 144.7 million people were employed as of May 2018, suggesting that no more than 0.2 percent to 0.3 percent of the overall job market might be impacted from automation in the long-haul trucking sector.

The estimated number of current long-haul heavy truck and tractor-trailer drivers should not be regarded as a precise forecast of the number of *future* workers who may be affected, since the trucking industry is likely to experience growth and change during the period before Level 4 driving automation becomes commercially available. Another factor to consider when assessing workforce impacts is the distinction between today's workers and future workers, especially given the older age profile of existing truck drivers. In other words, a sizable share of workers who are currently employed in driving occupations will have retired or moved to different jobs by the time Level 4 driving automation could become widespread.

2.3.4. Driver Demographics

Critical to assessing the potential workforce impacts of driving automation on long-haul trucking is understanding the current characteristics of the workforce. This sheds light on how workers may transition to other careers in the event of job displacement.

⁴¹ Viscelli, *Driverless?* 32-33, notes that port trucking could also potentially be a target for driving automation if it attracted the attention of larger firms, but that those shipments would likely be drawn for freight currently moved by rail, so there would not be an impact on the current truck driver workforce.

Driver Age and Gender

Truck driving in the United States is overwhelmingly male; just 6 percent of truck drivers are women.⁴² Truck drivers also tend to skew older in age relative to other blue-collar occupations;⁴³ the average truck driver age is 48 years (see **Figure 2.1**. Share of Workforce by Age (2015 to 2018): Driver/Sales Worker and Truck Drivers in the Truck Transportation Industry vs. Other Blue-Collar Occupations).⁴⁴ This older age profile is relatively new. Since 1994, the percentage of drivers between 25 and 34 has decreased significantly, from just over 30 percent to below 20 percent, while the percentage of drivers over 55 has increased from roughly 10 percent to almost 30 percent.

⁴² Bob Costello, *Truck Driver Shortage Analysis 2017* (American Trucking Associations, October 2017), 2, <http://progressive1.sef.playstream.com/truckline/progressive/ATAs%20Driver%20Shortage%20Report%202017.pdf>.

⁴³ Following Stephen V. Burks and Kristen Monaco, "Is the U.S. Labor Market for Truck Drivers Broken?" *Monthly Labor Review*, U.S. Bureau of Labor Statistics, March 2019, <https://www.bls.gov/opub/mlr/2019/article/is-the-us-labor-market-for-truck-drivers-broken.htm>, data and statistics for blue-collar occupations include all employed persons in the following broad occupational categories as defined by the Standard Occupational Classification system: construction and extraction; installation, maintenance, and repair; production; and transportation and material moving.

⁴⁴ Sarah Flood et al., *Integrated Public Use Microdata Series, Current Population Survey: Version 6.0* (Minneapolis, MN: IPUMS, 2018), <https://doi.org/10.18128/D030.V6.0>. The truck driver CPS category was identified using occupational and industry identifiers. "Drivers in Trucking Industry" refers to data in from CPS occupational code 9130, "Driver/sales workers and truck drivers", further narrowed to only include individuals employed in industry 6170, "Truck transportation."

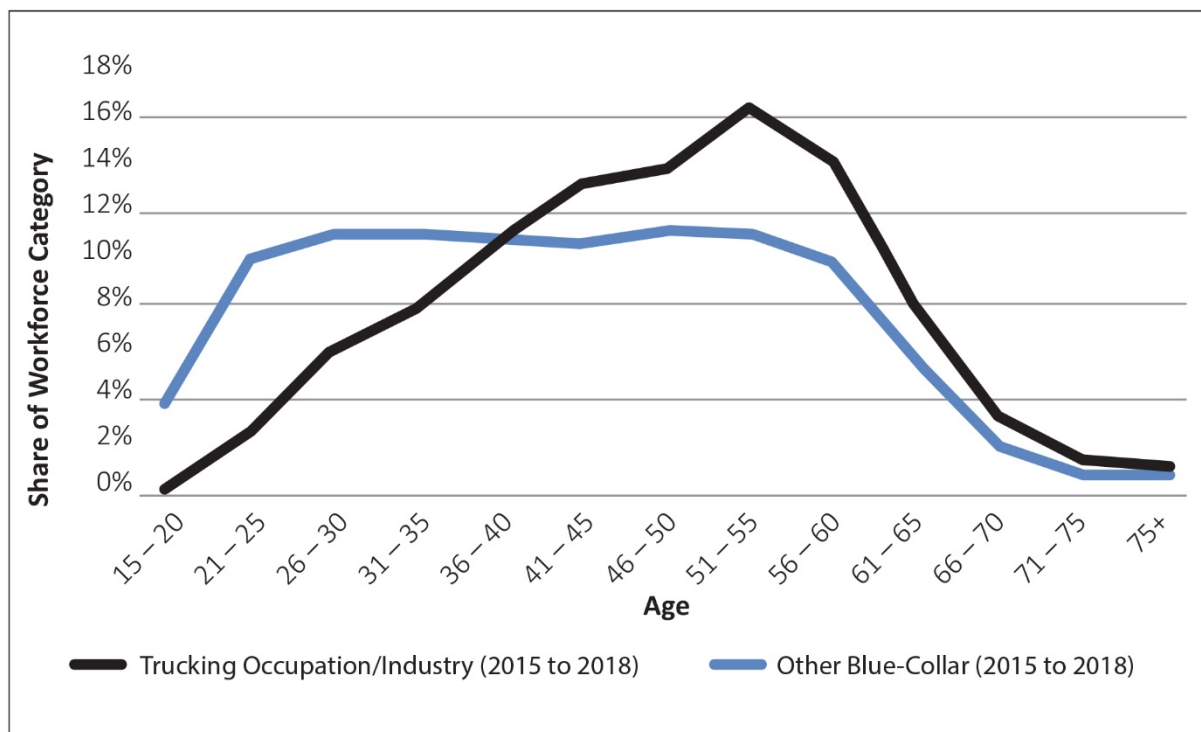


Figure 2.1. Share of Workforce by Age (2015 to 2018): Driver/Sales Worker and Truck Drivers in the Truck Transportation Industry vs. Other Blue-Collar Occupations⁴⁵

There are some structural reasons for the truck driving workforce to skew slightly older than the broader blue-collar workforce. First, to have a CDL and drive a truck conducting interstate commerce, truck drivers must be 21 years old, meaning that long-haul, heavy truck tractor-trailer driving is not open to recent high school graduates.⁴⁶ Moreover, insurance companies often require drivers of long-haul heavy trucks and tractor-trailers to be 25 years old, a more stringent requirement that further limits the pool of eligible drivers. The American Transportation Research Institute (ATRI) suggests that the post-high school gap is a deterrent to attracting young people to the industry, as they may have started on other career tracks upon graduation.⁴⁷

Truck driving is an attractive profession for older workers, such as those transitioning from the military or other careers. Sixty-one (61) percent of new truck drivers were age 40 or older when they last entered the profession and 33 percent were age 50 or older.⁴⁸ More than 10 percent of truck drivers are

⁴⁵ Flood et al., Integrated Public Use Microdata Series. “Drivers in Trucking Industry” refers to data in from CPS occupational code 9130, “Driver/sales workers and truck drivers” further narrowed to include only individuals employed in industry 6170, “Truck transportation.”

⁴⁶ Some States permit drivers to acquire a CDL at age 18. In these instances, an 18-year-old commercial driver could drive the 482 miles from Miami to Tallahassee, Florida, but the same driver would not be allowed to drive the 34 miles from Tallahassee, Florida to Thomasville, Georgia.

⁴⁷ Bob Costello, *Truck Driver Shortage Analysis 2015*, American Trucking Associations, October 2015, 8, <https://www.trucking.org/ATA%20Docs/News%20and%20Information/Reports%20Trends%20and%20Statistics/10%206%2015%20ATAs%20Driver%20Shortage%20Report%202015.pdf>.

⁴⁸ Flood et al., Integrated Public Use Microdata Series. Note the group of new entrants may include individuals who exited truck driving for another occupation before reentering again.

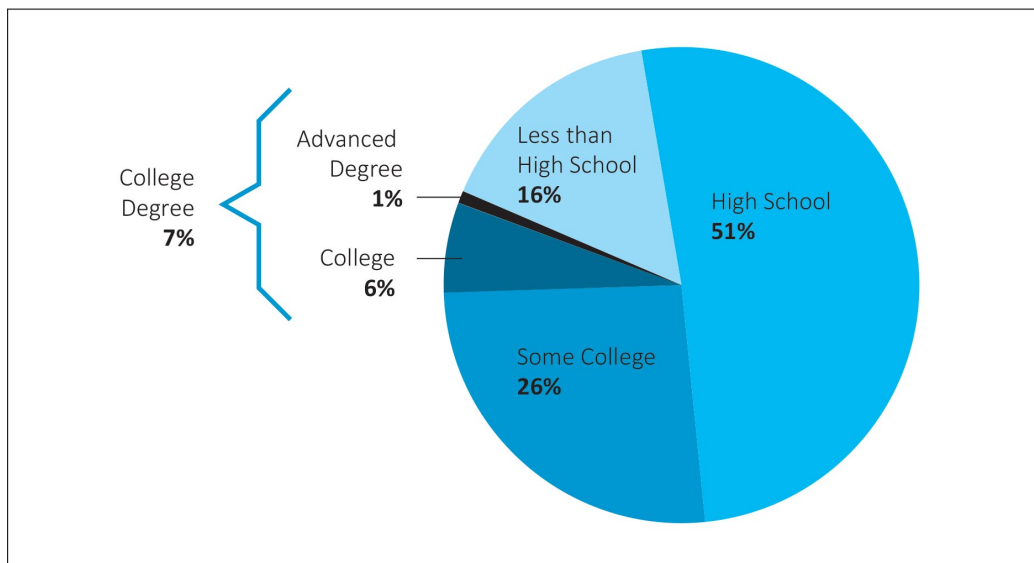
veterans, a significantly higher share than in the general workforce.⁴⁹ If driving automation results in fewer available truck driver positions, older workers seeking career changes may have fewer options.

Given the older age profile associated with truck drivers, it is likely reasonable to expect that many in the current workforce will retire by the time Level 4 or 5 driving automation achieves mainstream adoption. In 10 years, 28 percent of the current heavy truck driving workforce will be 65 years or older and in 15 years, the number will be 42 percent. Throughout that time, new drivers will continue to be needed.

To the extent that driving automation leads to job losses for people employed as drivers in the future, seeking new employment may be challenging for older workers. Although not specific to trucking or driving professions, one study found that workers who experience an involuntary job separation while in their early 50s rarely bounce back financially. Just 10 percent of such workers ever match their pre-job loss earnings.⁵⁰

Driver Education Level

For most delivery drivers (not just long-haul heavy truck drivers), their highest level of educational attainment is high school completion. Seven percent have earned a bachelor's degree or higher. Most heavy truck and tractor-trailer driver jobs (56 percent) have no degree requirements, and the remainder (44 percent) require only a high school diploma.⁵¹ **Figure 2.2** shows the full breakdown of educational attainment for all delivery driver jobs.



Source: Integrated Public Use Microdata Series, Current Population Survey⁵²

Figure 2.2. Delivery Driver Educational Attainment Level

⁴⁹ Cheeseman, Day, and Hait, “Number of Truckers at All-Time High.”

⁵⁰ Richard W. Johnson and Peter Gosselin, *How Secure is Employment at Older Ages?*, Urban Institute, December 2018, 13,

https://www.urban.org/sites/default/files/publication/99570/how_secure_is_employment_at_older_ages_2.pdf.

⁵¹ Gittleman and Monaco, “Truck Driving,” 32, citing BLS Occupation Requirements Survey of 2017.

⁵² Flood et al., Integrated Public Use Microdata Series.

Outside of formal education, drivers receive on-the-job training and must qualify for a CDL with both a written exam and practical test. After earning a CDL, a new driver also receives several weeks of training from the trucking firm that hires them for their first job. There are many heavy truck jobs available to new drivers: 20 percent of jobs require one month or less of vocational preparation (meaning vocational school or on-the-job training).⁵³ While drivers tend to have attained more modest levels of formal education, their work experience provides a high level of trucking-specific professional knowledge. A displaced truck driver may find some employment opportunities in logistics-related fields where their industry knowledge may be useful.

To the extent that driving automation results in driver displacement, the lower educational attainment in this occupation group suggests that transitioning to other careers may be difficult, particularly when combined with their higher ages. Many of the alternative blue-collar jobs that would be available have higher physical demands than truck driving. Pursuing vocational training for another occupation also requires an upfront investment of time and money, which could be difficult for older workers to recoup given their fewer remaining working years.

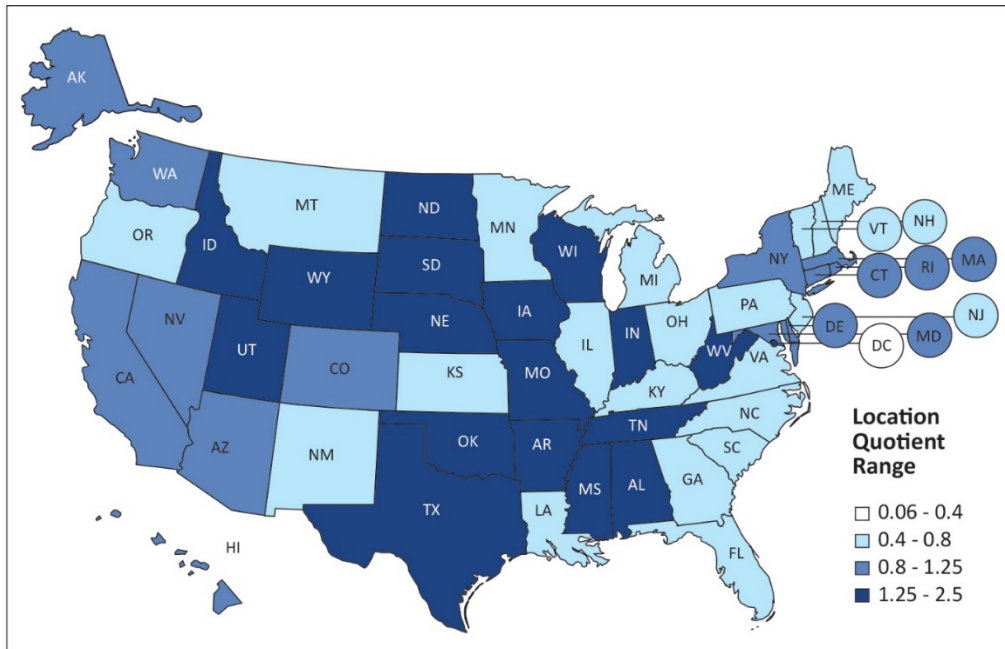
Regional Concentration

Long-haul trucking jobs are available to drivers almost anywhere in the country. While every State has residents employed as truck drivers, heavy and tractor-trailer truck drivers are relatively more concentrated in the heartland and southern regions of the country. Arkansas, Nebraska, North Dakota, Iowa, and Wyoming have the highest concentration of jobs (see **Figure 2.3**).⁵⁴ While historically there was a blue-collar wage premium in urban locations, recent research suggests that earning opportunities for non-college-educated workers may be better in rural locations.⁵⁵ Therefore, based on the residence of current truck drivers, there may be other opportunities for above-average earnings in alternative jobs, at least compared to occupations concentrated in urban areas.

⁵³ Gittleman and Monaco, "Truck Driving," 32.

⁵⁴ Location quotient represents the ratio of an occupation's share of area employment to its share of national employment and provides a measure of occupational concentration.

⁵⁵ David H. Autor, "Work of the Past, Work of the Future" (Richard T. Ely lecture, American Economic Association Annual Meeting, Atlanta, GA, January 4, 2019), <https://economics.mit.edu/files/16724>.



Source: Bureau of Labor Statistics⁵⁶

Figure 2.3. Location Quotient of Heavy and Tractor-Trailer Truck Drivers, 2018

2.3.5. Working Conditions

Working conditions are an important workforce consideration because of the influence that they have on job satisfaction and employee retention. Differences in working conditions can also produce pay differentials between otherwise similar jobs. In the case of truck drivers, the primary work location is the cab of their vehicle, with some loading, unloading, and other work being performed at pick-up and drop-off locations. As noted above, long-haul trucking is characterized by multi-day trips in which the driver spends nights away from home in the sleeper cab.

Long-haul drivers also face significantly higher rates of occupational death and injury than the workforce as a whole, with motor vehicle crashes being the most common source.⁵⁷ Compared to the average worker, motor vehicle operators are 10 times more likely to be killed on the job and nearly 9 times more likely to be injured on the job.⁵⁸ Motor vehicle crashes on public roadways caused the majority (68 percent) of work-related fatalities for heavy and tractor-trailer truck drivers.⁵⁹ It is important to note that these crash statistics are not normalized for exposure; in other words, long-haul drivers are at a higher risk for crashes primarily because they spend more time driving than most, not because other

⁵⁶ U.S. BLS, "Occupational Employment... Truck Drivers."

⁵⁷ Guang X. Chen et al., "NIOSH National Survey of Long-Haul Truck Drivers: Injury and Safety," *Accident Analysis & Prevention* 85 (December 2015): 66–72, <https://doi.org/10.1016/j.aap.2015.09.001>.

⁵⁸ David Beede, Regina Powers, and Cassandra Ingram, "The Employment Impact of Autonomous Vehicles," U.S. Department of Commerce (Washington, DC: 2017), https://www.commerce.gov/sites/default/files/migrated/reports/Employment%20Impact%20Autonomous%20Vehicles_0.pdf.

⁵⁹ "Table A6: Occupation by transportation incidents and homicides, 2017," Census of Fatal Occupational Injuries, U.S. Bureau of Labor Statistics (2019), <https://stats.bls.gov/iif/oshwc/foi/cftb0318.xlsx>.

factors make it more likely for them to crash. See **Quality of Life** for discussion of the potential impacts of driving automation on working conditions.

2.3.6. Driver Pay

Truck driving can provide access to a middle-class income for people without the need for a college degree. Heavy truck and tractor-trailer driving have been identified as an “opportunity occupation,” meaning that it is a job accessible to workers without a bachelor’s degree and typically pays higher than the national median annual wage of \$37,690, adjusting for regional differences in consumer prices. It is the second largest such occupation after nursing.⁶⁰ This data suggests that alternative occupations with similar earnings may be difficult to find. **Figure 2.4** presents average weekly earnings at various education levels compared to heavy truck driving.

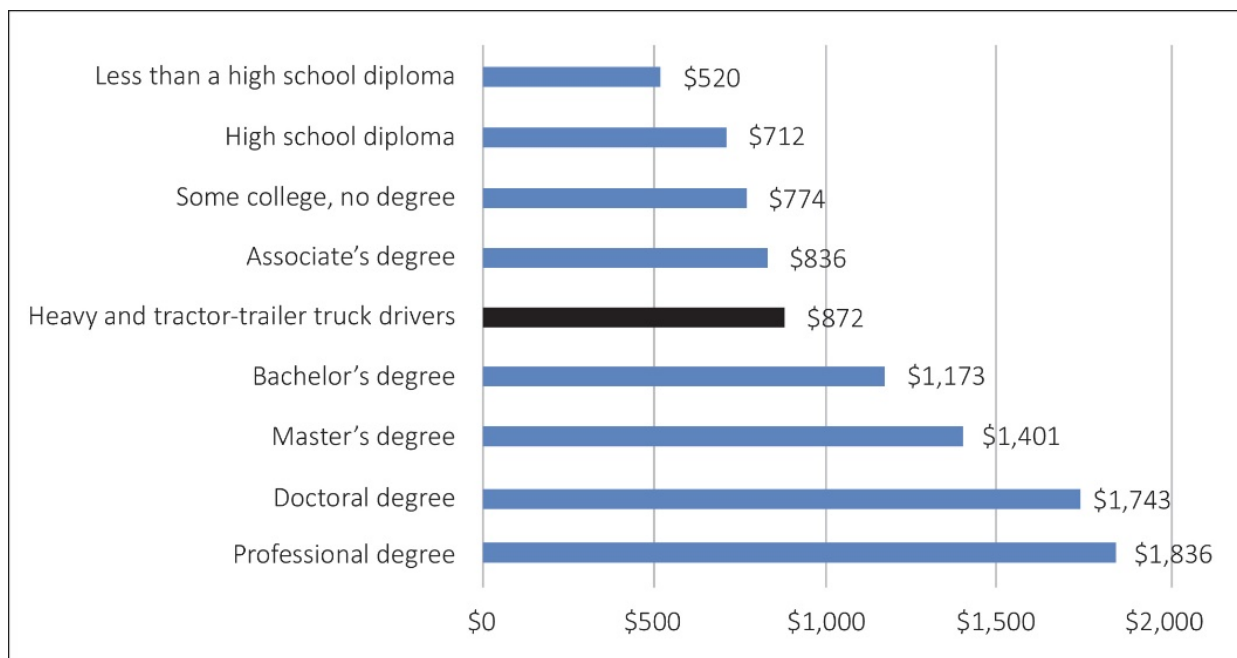


Figure 2.4. Median usual weekly earnings (\$) for heavy and tractor-trailer truck drivers, relative to overall earnings for all workers by education level⁶¹

However, those weekly earnings may obscure the fact that many of those tractor-trailer drivers are working long hours. Roughly 41 percent of tractor-trailer drivers work longer than 40 hours per week.⁶² **Figure 2.5** shows that relative to other blue-collar workers, truck drivers are more likely to have work weeks longer than 40 hours. This also suggests that opportunities to attain a higher annual income by working longer hours are rarer outside of trucking.

⁶⁰ Kyle Fee, Keith Wardrip, and Lisa Nelson, “Opportunity Occupations Revisited,” Federal Reserve Bank of Cleveland (2019), 6.

⁶¹ Elka Torpey, “Measuring the Value of Education,” U.S. Bureau of Labor Statistics, U.S. Department of Labor, April 2018, <https://www.bls.gov/careeroutlook/2018/data-on-display/education-pays.htm>; Truck driver weekly salary calculated based on BLS annual earnings for 2017.

⁶² Flood et al., Integrated Public Use Microdata Series. ASEC CPS data for years 2003 through 2017 were used to estimate weekly hours worked based on self-reported hours worked in previous week.

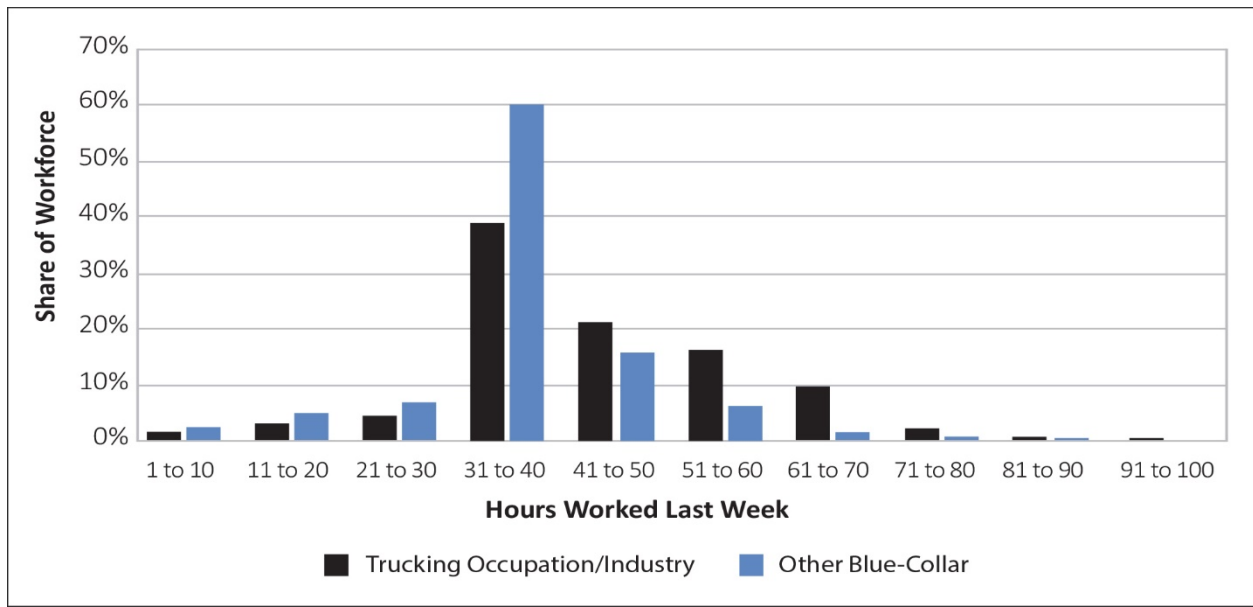


Figure 2.5. Distribution of Workforce Weekly Hours, Driver/Sales Workers and Truck Drivers in the Truck Transportation Industry⁶³

While long-haul driving jobs do provide earnings slightly higher than other blue-collar jobs, they are challenging jobs that require unusually long hours and time spent far from home. Truck drivers as a group also experience some poor health outcomes. The higher average wages may be to compensate for those job characteristics.

It is worth noting that long-haul truck drivers are typically paid on a per-mile basis, not per-hour worked, and are exempt from receiving overtime pay under the Fair Labor Standards Act (FLSA).⁶⁴ As a result, truck drivers are often only earning when actively driving, meaning that time spent waiting for loads to become available or loading and unloading cargo are unpaid. In 2016, average pay per mile was 52.3 cents. Specialty sectors requiring additional CDL endorsements, like tanker trucking, made more on average (67.4 cents per mile), while full truckload drivers made less (averaging 42.6 cents per mile).⁶⁵ A potential impact from adoption of Level 4 or 5 ADS in the long-haul sector is that long-haul drivers may switch to short-haul driving. However, wage data distinguishing between short-haul and long-haul heavy

⁶³ Flood et al., Integrated Public Use Microdata Series. “Drivers in Trucking Industry” refers to data in from CPS occupational code 9130, “Driver/sales workers and truck drivers” further narrowed to include only individuals employed in industry 6170, “Truck transportation.”

⁶⁴ “Fact Sheet #19: The Motor Carrier Exemption under the Fair Labor Standards Act (FLSA),” U.S. Department of Labor Wage and Hour Division, U.S. Department of Labor (November 2009), <https://www.dol.gov/whd/regs/compliance/whdfs19.htm>.

⁶⁵ Alan Hooper and Dan Murray, *An Analysis of the Operational Costs of Trucking: 2017 Update*, American Transportation Research Institute (October 2017), 33-34, <https://atri-online.org/wp-content/uploads/2017/10/ATRI-Operational-Costs-of-Trucking-2017-10-2017.pdf>.

trucking is not available, so the implications of shifts between short- and long-haul sectors are not clear.⁶⁶

2.3.7. Driver Responsibilities

Although driving is the primary job-related task of truck drivers, especially for long-haul drivers, a driver is responsible for many other non-driving tasks. While these tasks may not consume most of a driver's work time, they are critical to providing the transportation service. Non-driving-related tasks include, but are not limited to:⁶⁷

- Freight handling
- Cargo security
- Customer communications
- Paperwork
- Operating non-truck equipment
- Route planning
- Securing loads
- Fueling the vehicle
- Conducting safety inspections of the vehicle
- Identifying maintenance needs and either informing the trucking firm of those needs or arranging maintenance of those vehicles

The diversity of these tasks and the variety of environments in which they may occur present challenges to the deployment of Level 4 or 5 driving automation. These non-driving tasks are critical and must be accounted for under any driving automation use case that proposes elimination of the driver from a truck.⁶⁸ Therefore, trucking firms seeking to adopt ADS and remove the driver from the vehicle could elect to pursue some combination of the following options:⁶⁹

- *Transfer responsibilities to other firms.* For instance, service stations located on long-haul routes could provide staff to perform vehicle fueling, check load securement, and conduct safety inspections. Towing firms could journey to disabled vehicles to manage vehicle recovery and repair.

⁶⁶ Viscelli, *Driverless?*, ii. There are a number of factors that influence wages for short-haul driving. Local deliveries typically use light-duty trucks. The available BLS data show that, on average, heavy truck drivers earn more than light-duty truck drivers (see Table 2.1. Primary Driving Occupations). Conversely, firms with high rates of unionization, such as UPS, tend to see higher wages, with full-time drivers reportedly earning roughly \$75,000 a year (CNN Wire, "UPS, Teamsters May Be Headed Toward America's Biggest Labor Strike in Decades," *KTla*, June 5, 2018, <https://ktla.com/2018/06/05/ups-teamsters-may-be-headed-toward-americas-biggest-labor-strike-in-decades/>). At these same firms, part-time, non-unionized drivers or independent contractors may earn as little as \$10 per hour, putting their annual wages estimates much lower. At least one segment of short-haul heavy truck and tractor-trailer driving, port drayage involves difficult working conditions and low earnings.

⁶⁷ List adopted from Gittleman and Monaco, "Truck Driving," 11-14, and U.S. Bureau of Labor Statistics, "What Heavy and Tractor-trailer Truck Drivers Do," *Occupational Outlook Handbook*, last modified Friday April 12, 2019, <https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm#tab-2>.

⁶⁸ Gittleman and Monaco, "Truck Driving."

⁶⁹ These examples are listed to illustrate the potential range of options and do not represent policy or guidance on best practices.

- *Transfer responsibilities to customers.* Some of these tasks such as loading, coupling, opening doors, etc., which are generally performed at the customer site by the driver, could be performed by the customers, provided they have available staff at loading docks. Since not all customers have such staff, not all loading docks could be served by trucks without a worker onboard.⁷⁰
- *Perform responsibilities via other employees, remotely.* Tasks such as completing paperwork and communicating with customers could be conducted offsite, if employees have access to information on the status of the vehicle through remote supervision capabilities.
- *Deploy additional non-driving automation technologies.* In the future, it may be possible to automate activities such as door opening, loading, etc.

⁷⁰ Viscelli, *Driverless?*, 23.

Box 2.3. The Debate on the Long-Haul Truck Driver Shortage

Industry associations, including the American Trucking Associations (ATA), the American Transportation Research Institute (ATRI), the Truckload Carriers Association (TCA), and the National Tank Truck Carriers (NTTC), have identified a driver shortage and difficulty with driver retention as a top industry issue.^{71 72} Since 2005, ATA and ATRI have released several reports describing a driver shortage as one of the most important challenges facing the long-haul trucking industry. The latest ATA report estimates the shortage to be 60,800 drivers in 2018, and points to high firm-level turnover, especially in the for-hire truckload segment as evidence of high demand for drivers.⁷³ The trucking industry notes the difficulty in recruiting *qualified* drivers. Firms, due to their own safety focus and requirements from their insurance companies, only hire drivers that can pass criminal background checks, have clean driving records free of moving violations and DUIs, and can pass drug-screening tests. Driving automation is seen as a potential solution to the problem of a driver shortage by the trucking industry analysts.

Some researchers who focus on the trucking sector are skeptical that a true labor shortage could persist when the barriers to entering the occupation are low, allowing new workers to enter the market in response to higher wages.⁷⁴ Burks and Monaco (2018) find that the trucking labor market does appear to respond to increased wages in practice, so any shortage could be ameliorated with higher pay rates.⁷⁵

The Owner-Operator Independent Drivers Association (OOIDA) Foundation also disputes the existence of a driver shortage, noting instead that there is a problem of overcapacity of vehicles in the industry. OOIDA further notes that large numbers of new drivers enter the occupation each year: 2014 saw an estimated 455,000 new entry-level CDL holders and 98,000 CDL reinstatements.⁷⁶

Regardless, there is an acknowledged problem with recruiting and retaining drivers in the long-haul trucking sector.

2.3.8. Factors Influencing Adoption of Driving Automation

Testing and Fleet-Wide Deployment

The timetable to achieve widespread commercial availability of Level 4 or 5 driving automation for long-haul truck driving is still unknown. Further, it is likely that driving automation systems will be adopted

⁷¹ Lee Miller, "The Driver Shortage From a Tank Truck Perspective," *Transport Topics*, March 12, 2018, <https://www.ttnews.com/articles/driver-shortage-tank-truck-perspective>.

⁷² "Issues & Policies," Truckload Carriers Association, accessed June 28, 2019, <https://www.truckload.org/policy-positions>.

⁷³ Bob Costello, *Truck Driver Shortage Analysis 2019*, American Trucking Associations, July 2019, 4, <https://www.trucking.org/ATA%20Docs/News%20and%20Information/Reports%20Trends%20and%20Statistics/ATA%20Driver%20Shortage%20Report%202019%20with%20cover.pdf>. Large for-hire truckload carrier turnover rates have been 89 percent in recent years, while small, for-hire truckload carriers saw 73 percent turnover.

⁷⁴ Gittleman and Monaco, "Truck Driving," 9, points to the results of the Occupational Requirements Survey (2015–2017) which finds that most truck driving jobs do not require even a high school degree as evidence of low barriers to entry for the heavy and tractor-trailer truck driving profession.

⁷⁵ Burks and Monaco, "Is the Labor Market for Truck Drivers Broken?"

⁷⁶ "Truck Driver Shortage: A Myth or Reality?" *Owner-Operator Independent Drivers Association*, accessed October 17, 2019, <https://www.ooida.com/newsletter/TruckDriverShortageUpdated2019.pdf>; The estimates of number of new entry and reinstatement CDLs in 2014 are taken from Federal Motor Carrier Safety Administration, *Regulatory Evaluation of Minimum Training Requirements for Entry-Level Commercial Motor Vehicle Operators Final Rule*, Federal Motor Carrier Safety Administration, November 2016, <https://www.regulations.gov/document?D=FMCSA-2007-27748-1291>.

gradually into trucking. Two contributing factors are the time required to test designs and models of new technologies on the market, and the overall rate of fleet renewal.

Once new technologies reach the market, trucking firms will likely require time to test various models to identify the best fit for their business. The past technology deployment practices of individual firms can be instructive here. Schneider began testing automated transmission tractors as early as 2007 but did not make the decision to start widespread deployment until 2015. Now, every new tractor purchased by Schneider comes standard with an automated transmission, and Schneider expects fleet-wide implementation to be complete by 2019.⁷⁷ It took Schneider 12 years to implement this single, low-level improvement, moving from early testing to adoption and widespread fleet deployment.

Once a decision is made to invest in a new technology, additional time will likely be required to integrate the technology into the fleet through new vehicle purchases. Existing, non-automated new trucks are an expensive investment (at least \$100,000 for a new day-cab tractor and at least \$125,000 for a sleeper cab) and trucking firms want to extract as much value as they can from each vehicle before buying a replacement.⁷⁸ Large trucking firms generally buy trucks new from the manufacturers and then sell them after 500,000 miles when the warranties expire, which typically occurs within 3–5 years.⁷⁹ In contrast, smaller firms tend to buy used trucks (75 percent of owner-operators bought their trucks used), perhaps due to the challenge of obtaining financing for such a large purchase.⁸⁰ The smaller firms can keep the older trucks on the road by rebuilding the engines and performing other needed maintenance. Ultimately, a vehicle will be sold for scrap once the maintenance costs exceed the cost of buying a new or used replacement.

Based on an analysis of truck registration data, the typical useful life of a Class 8 tractor (Class 8 trucks are those that have a GVWR of 33,000 pounds or more and include tractor-trailers) is roughly one million miles or approximately 11 years. After 11 years or one million miles, the mileage put on older tractors drops off dramatically. Because tractors in the long-haul segment are used more intensely, the typical useful life is likely a bit shorter than the average—approximately nine years. Tractors used in short-haul service may last longer, perhaps 15 years, before they reach one million miles.⁸¹ Thus, nine years for the total long-haul fleet to be replaced with newly purchased vehicles is a reasonable expectation.

Manufacturing capacity may also impact the pace of adoption of new driving automation systems. Each year in the U.S., roughly 200,000 new Class 8 trucks are sold.⁸² When compared to the 1.5 million Class 8

⁷⁷ “Schneider Passes Halfway Mark in Fleet-Wide Implementation of Automated Transmission Tractors,” *Schneider*, August 2017, <https://schneiderjobs.com/about-us/newsroom/schneider-implementation-of-automated-transmission-tractors-news-release>.

⁷⁸ John O’Dell, “Tesla Reveals Semi Pricing – Trucks to Start at \$150,000,” *Trucks.com*, November 25, 2017, <https://www.trucks.com/2017/11/25/tesla-reveals-semi-pricing/>.

⁷⁹ Jennifer Smith, “Trucking Industry’s Tale of Woe: Too Many Big Rigs,” *The Wall Street Journal*, May 1, 2017, <https://www.wsj.com/articles/trucking-industrys-tale-of-woe-too-many-big-rigs-1494581408>.

⁸⁰ 2018 Owner-Operator Member Profile Survey, May 14, 2018, page 26.

⁸¹ Kenny Veith (president, ACT Research) in conversation by phone with the U.S. DOT, June 3, 2019.

⁸² Fleet Owner Staff, “Trucking by the Numbers 2018: The equipment fleets use, Slide 6—U.S. Retail Sales—Class 3-8,” *FleetOwner*, last modified August 2018, <https://www.fleetowner.com/trucking-numbers/trucking-numbers-2018-equipment-fleets-use/gallery?slide=6>.

trucks currently in the fleet that are aged 11 years or under, that sales figure suggests that there is manufacturing capacity sufficient to replace 13 percent of the active Class 8 fleet each year.⁸³

Assuming the current structure of truck sales continues, new forms of driving automation would likely first be adopted by the large trucking firms. Smaller trucking firms are likely to begin adopting driving automation when equipped trucks are sold into the secondhand market, but the adoption rate would lag the adoption rate of large firms. It is not clear whether Level 4 or 5 driving automation would ever be adopted by smaller firms since it may not be compatible with the owner-operator business model (see **Scale of Trucking Operations** below).

Overall, experience suggests that once a technology becomes commercially available, trucking firms may explore and test potential options for several years before selecting a specific product to incorporate into their new vehicle purchases. After a technology is tested and selected, the long-haul segment may require another decade or more before the whole fleet is replaced, as existing non-equipped vehicles are replaced at the end of their lifespan.

Motivation for Driving Automation

While investment in Level 1 or 2 driving automation systems is expected to provide safety or operational benefits or fuel savings, the primary economic motivation for investing in additional (e.g., Level 5) capabilities is to remove the need for a driver on a truck and thereby reduce costs. Those potential cost savings need to be weighed against the costs of developing, deploying, operating, and maintaining the technology to determine if investing in automation is commercially worthwhile. Those costs are largely unknown currently, making predictions on the commercial viability of driving automation systems difficult. However, information on the scope for potential cost *savings* is available. **Figure 2.6** describes the current share of total average marginal cost for each category of motor carrier costs to provide that context.

⁸³ Kenny Veith (president, ACT Research) in email correspondence with the U.S. DOT, June 3, 2019.

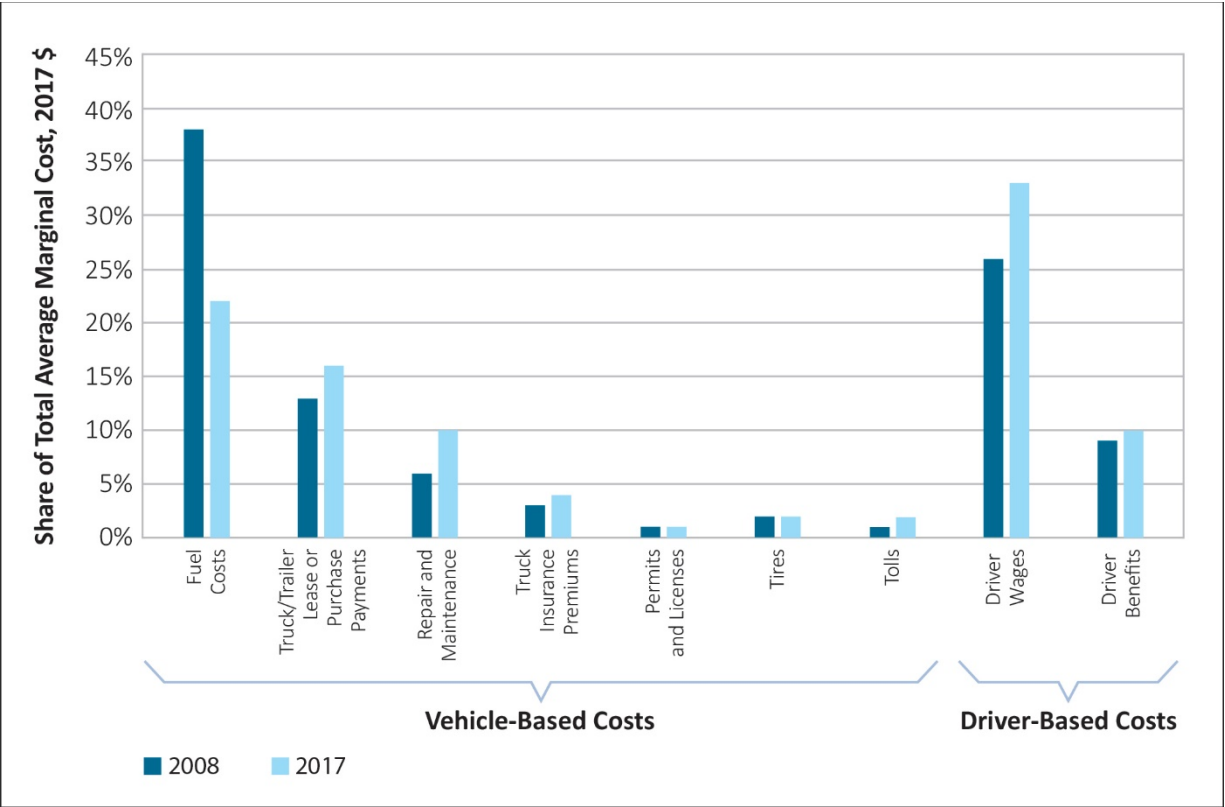


Figure 2.6. Trucking Firm Marginal Cost by Category (2008-2017)⁸⁴

Labor Cost Savings

One commercial benefit from automation in long-haul trucking would be to reduce labor costs by removing the need for a driver. In addition, driving automation is seen as a potential solution to the problem of costly occupational and firm-level driver turnover in the long-haul trucking segment (see **Box 2.3**). For trucking firms, driver compensation (wages, benefits, and bonuses) is the primary cost driver, accounting for 43 percent of marginal costs.⁸⁵ Since 2012, driver compensation has been the largest source of cost increases for motor carriers. However, labor costs would not be completely eliminated even without a driver onboard, as non-driving tasks (discussed in **Driver Responsibilities**) will still need to be performed and there may be additional labor costs associated with maintaining the more advanced technologies in these vehicles.

Fuel Cost Savings

Fuel costs are the second highest cost category for the trucking industry at 22 percent of total average marginal cost in 2017. While fuel costs as a share of average marginal costs have fallen significantly since 2008, driving automation could further decrease fuel costs by optimizing throttle and brake controls to minimize fuel burn.

⁸⁴ Hooper and Murray, *An Analysis... 2017*; Alan Hooper and Dan Murray, *An Analysis of the Operational Costs of Trucking: 2018 Update* (October 2018), <https://atri-online.org/wp-content/uploads/2018/10/ATRI-Operational-Costs-of-Trucking-2018.pdf>.

⁸⁵ Hooper and Murray, *An Analysis... 2018*, 21.

Additional fuel savings could be realized through close following (e.g., truck platooning).⁸⁶ When Level 1 platooning was tested, a study found that a three-truck platoon traveling at 65 mph can save between 5 and 6 percent of its fuel.⁸⁷ While the first truck does not experience significant fuel savings, the second truck is estimated to save between 6 and 7 percent, while the third truck saves between 9 and 11 percent.⁸⁸ However, there could be some additional energy use required to power the automated systems.⁸⁹

Other Cost Savings

In 2017, approximately 250,000 crashes in the U.S. involved combination trucks—2,910 of them were fatal crashes that resulted in 3,289 fatalities, as well as additional injuries and property damage (combination trucks refer to tractor-trailer combinations).⁹⁰ If driving automation provides safety improvements beyond the level of safety provided by human drivers, society would realize significant benefits in avoiding the injuries and other human costs associated with these crashes.⁹¹ While many crash impacts are intangible, trucking firms could also realize direct cost savings from reduced repair and maintenance costs, insurance premiums, and vehicle downtime.

The safety benefits from fully automated trucking are so far unproven, although there are studies suggesting safety benefits from driver assistance technologies and ADAS.⁹² The addition of camera- or sensor-based safety systems can provide drivers with 360-degree awareness and mitigate a large vehicle's natural blind spots, and some systems can apply braking force where needed to avoid a crash. This is particularly relevant for the types of crashes experienced by large trucks, including those related to the two most common pre-crash events: another vehicle's encroachment into the truck's travel lane and another vehicle's presence in the truck's lane.⁹³

In addition to those safety-related benefits, automated driving systems could provide capital cost savings through improvements in vehicle utilization. Vehicles with Level 4 or 5 ADS that do not have a

⁸⁶ Truck platooning consists of a group of automated trucks that use communications to enable negotiations between vehicles to support organized behavior and safe close following. Definition adopted from AV 3.0 report.

⁸⁷ The platooning was partially automated using cooperative adaptive cruise control (CACC), which automates truck speed control. The driver is still responsible for steering the vehicle, lane keeping, and monitoring roadway/traffic conditions; Steven Shladover et al., *Cooperative Adaptive Cruise Control (CACC) for Partially Automated Truck Platooning: Final Report*, Federal Highways Association, Cooperative Agreement No. DTFH61-13-H-00012, March 2018, 31.

⁸⁸ Shladover et al., *Cooperative Adaptive Cruise Control*, 31.

⁸⁹ Gawron et al., "Life Cycle Assessment of Connected and Automated Vehicles: Sensing and Computing Subsystem and Vehicle Level Effects," *Environmental Science & Technology* 52, no. 3: 3249-3256, <https://pubs.acs.org/doi/10.1021/acs.est.7b04576>.

⁹⁰ Federal Motor Carrier Safety Administration Analysis Division, *Large Truck and Bus Crash Facts 2017*, U.S. Department of Transportation), May 2019, 25-31, https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/safety/data-and-statistics/461861/l_tcbf-2017-final-5-6-2019.pdf.

⁹¹ Note that even if the crash performance of automated trucks were the same as conventional trucks, there would be fewer overall injuries and fatalities simply from not having a human driver in the vehicles that crash.

⁹² Jeffrey Hickman et al., *Onboard Safety Systems Effectiveness Evaluation Final Report*, (FMCSA, 2013).

⁹³ Federal Motor Carrier Safety Administration Analysis Division, *Large Truck... 2017*, 82.

human operator onboard could provide greater operational flexibility and improved levels of vehicle utilization, as they (presumably) would not require rest periods or meal breaks.

Factors Limiting the Pace of Adoption of Driving Automation

While driving automation offers the prospect of cost savings and greater efficiency, several practical factors may limit the speed and extent to which it can be adopted in the trucking industry. Existing ADAS technologies increase vehicle costs, and smaller firms and owner-operators may be slower to adopt them.⁹⁴ Even larger firms that elect to transition to automated driving for certain circumstances may choose to adopt ADS-equipped trucks as a fleet replacement option as human-driven vehicles age out of large-company fleet service. The rate of turnover would be tied to the expected lifecycle cost advantage (including capital, maintenance, fueling, and labor costs) that ADS-equipped trucks would offer over conventional trucks; if large enough, competitive pressures could push firms to adopt such vehicles more rapidly.

Nonetheless, it appears unlikely that widespread adoption and deployment of ADS-equipped trucks would happen quickly. While this might not change the total number of jobs impacted by adoption of driving automation in trucking, with a longer time horizon, younger workers can anticipate the reduced demand for truck drivers and explore alternative employment opportunities. Diverting potential new job entrants would allow job losses to be absorbed by retirements and occupational turnover rather than layoffs.

Cost of Technology

Any potential cost savings to companies needs to be weighed against the cost of investing in new technology, including costs of developing, deploying, operating, and maintaining the technology. At Levels 1, 2, or 3, the human driver is still in the vehicle, so the pool of potential cost savings that can be used to cover the upfront cost of adoption is smaller. While the potential for cost savings is higher with driving automation at Level 4 and above, the magnitude of the cost of adoption is highly uncertain.

Additional Training Costs

In addition to these direct costs, the existing workforce would likely require training on the new technology as the automated driving capabilities of trucks expand, which will impose costs on employers. Additionally, there would likely be a need for some reskilling: as trucks equipped with driving automation systems become increasingly dependent on computer systems, truck mechanics will be responsible for maintaining, diagnosing, and repairing increasingly complex technologies. These complex systems may be more expensive to maintain than their conventional, human-driver systems, further increasing adoption costs.

Scale of Trucking Operations

Trucking firms will generally only invest in driving automation if the technology can be proven safe and can pay for itself through increased productivity or lower operating costs. However, that hurdle may

⁹⁴ Matthew C. Camden et al., *Leveraging Large-Truck Technology and Engineering to Realize Safety Gains: Automatic Emergency Braking Systems*, (Washington, DC: AAA Foundation for Traffic Safety, September 2017), 28-29, https://aaafoundation.org/wp-content/uploads/2017/11/Truck-Safety_-Braking-Report.pdf; Jonah Chiarenza et al., *Optimizing Large Vehicles for Urban Environments: ADAS*, Prepared for the National Association of City Transportation Officials, (Cambridge, MA:U.S. DOT Volpe Center, December 2018), 11, https://nacto.org/wp-content/uploads/2018/12/NACTO-Volpe-Optimizing-Large-Vehicles_ADAS.pdf.

differ by firm size. Large firms may be able to negotiate bulk discounts on the technology and may have lower borrowing costs than smaller trucking firms, including owner-operators. An owner-operator is more likely to pursue a typical form of small-business financing, such as a small-business loan, which can be difficult to qualify for, or a personal loan. The initial expense may present an obstacle to adopting by smaller firms or an owner-operator.

Non-Driving Responsibilities

As discussed above in **Driver Responsibilities**, for any form of driving automation that proposes to remove the driver from the vehicle, other non-driving tasks currently performed by the driver will need to be handled by other means. This may be a limiting factor for the adoption of driving automation in long-haul trucking. For example, in-transit refueling of vehicles could require establishing a network of fueling stations with the necessary trained staff and equipment, along with contractual relationships to perform the refueling. Similarly, business models that rely on human drivers for some portion of the trip also necessarily rely on the existence of suitable transfer facilities. Such networks will take time to build and initially will likely only be present in certain corridors.

2.3.9. Workforce Impacts by Category

The workforce impacts discussed below include the potential for driver job displacement, changes in driver responsibilities, quality of life, new jobs created, wage impacts, and impacts on driver retention.

Driver Job Displacement

Driver job displacement would be limited for business models in which a driver remains in the vehicle, regardless of onboard duties (i.e., the driver may be driving, supervising, engaging in non-driving work, or resting). Some business models could potentially *increase* demand for long-distance truck drivers. For example, if a human driver remained onboard a Level 4 vehicle, the ADS could allow for the faster delivery times currently associated with team driving while incurring the labor costs associated with just a single driver. In this case, the ADS could take over for highway driving while the human driver rests in the back of a sleeper cab. This advancement could increase the attractiveness of truck-based shipping compared to air-based shipping where delivery time is an important consideration, and increase traffic volumes for trucking, which would in turn create additional demand for drivers. However, there might be a countervailing impact in cases where team driving is replaced by a single driver.

Some job displacement can be anticipated from the adoption of business models in which there is no human driver onboard the vehicle. Although there are approximately two million heavy truck and tractor-trailer drivers in the U.S., the size of the current long-haul workforce most likely to be impacted by the potential adoption of Level 4 or 5 automation in the coming decades is approximately 300,000 to 500,000 jobs (see **Scale of Potential Job Displacement from Driving Automation in Trucking**). Following Gittleman and Monaco (2018), this report assumes that the long-haul segment will be among the first to be impacted (compared to other segments of heavy truck and tractor-trailer driving) in part because:

1. Current driving automation system development focuses on limited access highways because they are a less-complex operating environment than surface streets;
2. Unlike the short-haul segment, the long-haul segment involves long periods of uninterrupted highway driving; and
3. Long-haul drivers have fewer non-driving responsibilities than short-haul drivers.

The introduction of driving automation into trucking presents some interesting dynamics. First, the demand for trucking services is expected to grow due to population growth and the associated increase in demand for goods, independent of changes in vehicle technology.⁹⁵ In addition, an increase in the potential supply of truck drivers would also be expected due to population growth. However, if younger cohorts of workers have sufficient warning of an expected decline in demand for long-haul truck drivers, they will likely not choose the occupation. As a consequence, the supply of new truck drivers will decline and act to mitigate potential job displacement.⁹⁶ The trucking industry currently has an occupational turnover rate of 10.5 percent, meaning that every year 10.5 percent of drivers leave the occupation due to reasons such as retirement or transferring to other occupations. That natural turnover can also absorb some portion of potential job losses instead of layoffs.⁹⁷ In addition, there is the potential for additional jobs, as is discussed below in **New Job Creation**.

Changes in Driving Job Responsibilities

Changes in job responsibilities could vary significantly under different business models. For Level 1 or 2 applications, the fundamental job responsibilities are likely to remain unchanged: a driver will still be required to be in the driver's seat and actively engaged, and driving or supervising the driving automation systems for the duration of the trip, as well as performing any non-driving tasks (e.g., load securement, equipment inspection, and administrative tasks), just as drivers of current commercial vehicles do.

In a Level 4 application where a human driver remains onboard, the human driver could theoretically ride in the sleeper cab when the ADS is engaged and the vehicle is within its operational design domain (ODD). The driver could potentially rest or engage in other non-driving tasks while riding in the cab during the automated portion of the trip, increasing overall worker productivity. The driver may require more skills and training to use and interact with the technology, and potentially perform some technical troubleshooting in the event of system malfunctions.

For business models where there is no human driver in the vehicle, non-driving tasks currently performed by the driver would need to be handled by other workers or through the implementation of new technologies. **Driver Responsibilities** discusses those responsibilities and potential methods for accomplishing the tasks no longer performed by a driver.

New Job Creation

The introduction of advanced driving automation technology may spur increased demand for complementary occupations. The expected new jobs include both driving and non-driving jobs, assumptions regarding which are explained below.

⁹⁵ See "FHWA Forecasts of Vehicle Miles Traveled (VMT): Spring 2019," Office of Highway Policy Information, Federal Highway Administration, May 2019, https://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.pdf, which presents an estimate of 1.5 percent annual growth in VMT for combination trucks over the next 20 years, based in part on forecast growth in population and income.

⁹⁶ International Transport Forum, *Managing the Transition to Driverless Road Freight Transport*, May 31, 2017, 32-34.

⁹⁷ Groshen et al., *Preparing U.S. Workers*, 40.

Driving Jobs

Demand for heavy-truck drivers in local delivery roles would be expected to increase from current levels under adoption models where only the highway portion of the trip is automated. This type of driver would be needed to complete the delivery trips for which the line-haul was performed using automation. At current truck traffic volumes, the number of new local delivery jobs would likely be lower than the number of long-haul driver jobs displaced.

However, this scenario potentially represents a dramatic productivity improvement for the trucking sector that could result in lower trucking freight rates that would attract increased demand for trucking services overall. The resulting faster delivery times might also attract some new freight movements to trucking. The lower truck freight costs would be due in part to lower labor costs, but also to improved fleet utilization from the ability of trucks to potentially run nearly nonstop, without the need for human drivers to rest. The magnitude of the increase in demand overall is unknown, but it would create an additional source of demand for local delivery truck driving. However, there is no guarantee that these local delivery jobs would be located near where the current long-haul trucking workforce lives.⁹⁸ These new local delivery jobs would likely be found near manufacturing centers, population centers, and seaports. As discussed in **Driver Demographics**, truck drivers are more likely to live in rural areas of the central and southern regions of the country. In addition, there is evidence that inter-state residential mobility has fallen in recent decades, meaning that Americans may be less likely to relocate from their current homes to seek other employment opportunities.⁹⁹

Under a business model where the last mile might be handled by a remote driver, there would be further impacts to drivers because the last-mile delivery job would be removed. However, this would potentially create new jobs for experienced drivers remotely piloting trucks from control centers. Remote drivers could make multiple moves in quick succession compared to *in situ* drivers who need to wait for loads to be made available or for trucks to be loaded or unloaded. However, the number of remote jobs would be lower under the situation where an *in situ* human driver performs the last-mile driving. The remote drivers could be located potentially anywhere that provided sufficiently robust telecommunications connections.

However, if the driving automation system can handle driving off the limited access highway to and from warehouses, the job gains in local delivery discussed above would not be present. In many cases, those warehouses may be located just off interstate highways, which could make those last-mile moves simpler and more feasible for automated trucks.¹⁰⁰ However, no data exists to quantify the portion of current long-haul trips that involve warehouse facilities located near highways.

⁹⁸ Groshen et al., *Preparing U.S. Workers*, 28.

⁹⁹ See, e.g., Greg Kaplan and Sam Schulhofer-Wohl, "Understanding the long-run decline in interstate migration," *International Economic Review* 58, no. 1 (2017): 57-94; "Table A-1. Annual Geographic Mobility Rates, By Type of Movement: 1948-2019," CPS Historical Migration/Geographic Mobility Tables, United States Census Bureau (2019), <https://www2.census.gov/programs-surveys/demo/tables/geographic-mobility/time-series/historic/tab-a-1.xls>.

¹⁰⁰ Viscelli, *Driverless?*, 28.

Non-Driving Jobs

More advanced driving automation systems may spur increased demand for complementary occupations, such as highly skilled mechanics, to help maintain and repair the increasingly complex technologies.

During automated driving, trucks may be remotely supervised, creating a new job category of “remote manager.” This job category would consist of personnel in an operations center who would monitor progress and troubleshoot potential issues that may arise (e.g., equipment faults, challenging road conditions). Prior truck driving experience may be a qualification for this job. The number of positions created will depend in part on how many trucks the supervisor is able/allowed to supervise at one time.

As noted in **Driver Responsibilities**, human drivers are currently responsible for many non-driving tasks, such as vehicle fueling, route planning, safety inspections, load securement, etc. These tasks could conceivably be delegated to workers in other occupations, such as fuel station attendants. If so, it is likely that automation would increase demand for those support job categories.

Finally, because trucking impacts many other industries, such as retail, agriculture, manufacturing, and construction, an increase in the productivity of the trucking sector could drive increased demand for workers in a variety of industries as a result of overall economic growth (see **Box 2.1**).

Quality of Life

Driving automation has the potential to improve the quality of life of long-haul truck drivers, in part because well-designed advanced driver assistance technologies may improve safety. Over time, long-haul truck drivers may shift to types of driving that allow them to stay closer to home. These jobs may involve picking up a truck at a location near a highway exit and driving it to its destination, doing local deliveries, or remotely supervising an ADS from a control center closer to home. For drivers who might want to balance work and family life, driving automation may open up new, more desirable employment opportunities associated with long-haul trucking.¹⁰¹

Wages

It is unclear whether Level 1, 2, and 3 applications would have any impacts on the wages of drivers, as the fundamental skills required for the job would remain largely the same, although interacting with the more sophisticated technology may require different skills.

However, there is a separate set of considerations for business models in which the use of Level 4 or 5 driving automation leads companies to remove the driver from the vehicle. As noted above, this transition would be gradual due to technological and other issues, the need to work out logistical challenges, testing requirements, and normal fleet turnover. During this transition period, there may be downward pressure on long-haul driver wages, as demand for drivers declines compared to driver supply.¹⁰² As discussed above, however, the strength of that downward pressure would depend on the lifecycle cost advantages that ADS-equipped trucks are ultimately able to provide. Furthermore, as wages decline in response to any reduced driver demand, the forecasted operational cost advantages of

¹⁰¹ Frank Morris, “Facing a Critical Shortage of Drivers, the Trucking Industry is Changing,” *NPR*, February 11, 2019, <https://www.npr.org/2019/02/11/691673201/facing-a-critical-shortage-of-drivers-the-trucking-industry-is-changing>.

¹⁰² U.S. GAO, *Automated Trucking*, 27.

automation would likewise diminish, which could in turn slow or limit the rate of adoption of such systems.

It is reasonable to expect that in this scenario, some former long-haul drivers will transition to jobs as local delivery drivers for the last mile of automated long-haul movements, similar to port truck driving.¹⁰³ Currently, port truck drivers are among the very lowest-paid heavy-truck drivers.¹⁰⁴ However, increased demand for workers in this sector may act to raise wages in that occupation.¹⁰⁵

Working as local delivery drivers would also be a possible alternative occupation. There are many factors that determine wages for short-haul driving. Local deliveries typically use light-duty trucks and the available BLS data show that, on average, heavy-truck drivers earn more than light-duty truck drivers (see **Table 2.1. Primary Driving Occupations**). Local delivery is a market sector undergoing changes today that may impact wages in the long term; the current trend among Internet retailers offering express delivery is the use of independent contractors to deliver packages.¹⁰⁶

In general, when people lose jobs, they usually end up with reduced lifetime earnings given the time it takes to find a new position, lower wages in a new position, or an earlier than expected exit from the workforce. It is likely that other jobs for which the cohort of long-haul truck drivers may qualify pay less than trucking (in part because this cohort has less formal education). Truck drivers tend to be older and may elect to retire rather than seek a new job. Although not specific to heavy truck and tractor-trailer driving, Groshen et al. estimate that the loss of a general driving job would result in an \$80,000 reduction in lifetime income per displaced worker.¹⁰⁷

Driver Retention

Impacts on retention are also uncertain. Truck driving as an occupation could become more desirable if the adoption of Level 1 or 2 driving automation were to make driving safer. In its RFC comments, the ATA stated, “ATA welcomes the continued development and deployment of automated technologies as driver-assist tools, which [...] can enhance our industry’s ability to recruit more drivers that are badly needed to fill our increasing driver shortage, and particularly the younger drivers that we need to replenish our aging workforce.” That said, Level 1, 2, or 3 technologies would not decrease time spent on the road and away from home, which is commonly listed as a reason for exiting the profession.

Regarding business models that automate the driving task but retain a human driver in the vehicle, anecdotes suggest that often truck drivers enjoy driving, so automating this aspect of the job may not actually improve its desirability and could even make existing drivers reconsider staying on the job, leading to voluntary attrition. Moreover, some drivers may not want to re-skill and learn how to use the

¹⁰³ The number of long-haul truck drivers who can transition to short-haul will be limited by the number who currently live in (or who would be willing to relocate to) metropolitan areas where these short-haul jobs are likely to be created.

¹⁰⁴ Note that port truck drivers are largely owner-operators and currently are a fairly small portion of the total local delivery market.

¹⁰⁵ U.S. GAO, *Automated Trucking*, 27.

¹⁰⁶ Bloomberg News, “Amazon copies FedEx’s delivery model to keep up with holiday demand and beyond,” *DigitalCommerce360.com*, December 17, 2018, <https://www.digitalcommerce360.com/2018/12/17/amazon-copies-fedexs-delivery-model-to-keep-up-with-holiday-demand-and-beyond/>.

¹⁰⁷ Groshen et al., *Preparing U.S. Workers*, 60.

new technology; such drivers may choose to leave the occupation.¹⁰⁸ **Labor Force Training and Retraining Needs** describes the programs available to workers making a transition to a new occupation.

It may be easier to recruit and retain truck drivers in general if the long-haul portion of the route could be performed using driving automation systems. Working as a local delivery driver for the last mile would allow drivers to return home each day.

2.3.10. Heavy Truck General Impacts

The impacts on the long-haul trucking driver workforce will be different for driving automation systems that *assist* the human driver versus those that *replace* the driver. ADAS could potentially be adopted by all segments of heavy trucking, potentially improving safety through crash avoidance, but would likely result in no job displacement.

Business models that remove the human driver from the vehicle may result in some reduction in the number of available long-haul driver jobs. As a result, some drivers may take on new positions in the logistical supply chain while other potential future workers will elect different career paths. Finally, some workers may be displaced and require new jobs, thus experiencing a period of transitional unemployment. Truck driving is currently a job that pays above average wages and does not require advanced education; it is unclear whether alternative employment opportunities available for truck drivers who may be displaced in the future would offer similar levels of pay.

Level 4 commercial motor vehicles are still in development and do not yet exist in the commercial marketplace. Once commercialized, it may take several more years for carriers to test and broadly adopt them. During that time, networks of supporting services (for example, fueling stations and transfer facilities) would need to be established. At that point, the long-haul sector may be expected to adopt ADS largely at the speed of fleet renewal, which could take close to a decade, unless overwhelming cost advantages over conventional systems accelerate adoption. Thus, job displacement for the long-haul sector may be a gradual process, likely several years in the future, and thus offset to some extent by retirements and other natural attrition. There may be an ongoing need for at least some long-haul drivers for certain types of cargo, such as oversized loads or hazardous materials.

2.4. Workforce Impacts for Transit Buses

This section analyzes the potential workforce impacts of driving automation for transit buses.

According to the National Transit Database (NTD), there are approximately 105,000 transit bus operators as of 2017. This includes employees in “vehicle operations” for the NTD-defined modes of bus, bus rapid transit, commuter bus, and trolleybus. As a point of comparison, BLS data for SOC 53-3021 (“bus drivers, transit and intercity”) show a total of 174,110 employees. This figure is higher because the BLS category includes drivers for other types of bus services, such as intercity services and chartered motor coaches. When filtering the BLS data to include only drivers who are employed by local

¹⁰⁸ U.S. GAO, *Automated Trucking*, 30.

government agencies and urban transit systems, the total is 109,530.¹⁰⁹ The two data sources fairly closely agree on the total number of transit operators.¹¹⁰

There are an additional 9,700 operators of demand-response transit vehicles. In addition to bus operators, transit agencies generally also have a range of non-driving occupations (dispatchers, supervisors, and maintenance yard workers, among others).

2.4.1. Driver Demographics

Demographic data on bus drivers comes from the Annual Social and Economic Supplement of the Current Population Survey (ASEC CPS), administered by the Census Bureau, and from the Bureau of Labor Statistics' Occupational Employment Statistics (BLS OES).¹¹¹ Both data sources define the bus driver category as including motor coach and charter bus drivers, rather than just transit bus operators. Thus, they may not be fully reflective of transit bus operator positions specifically.

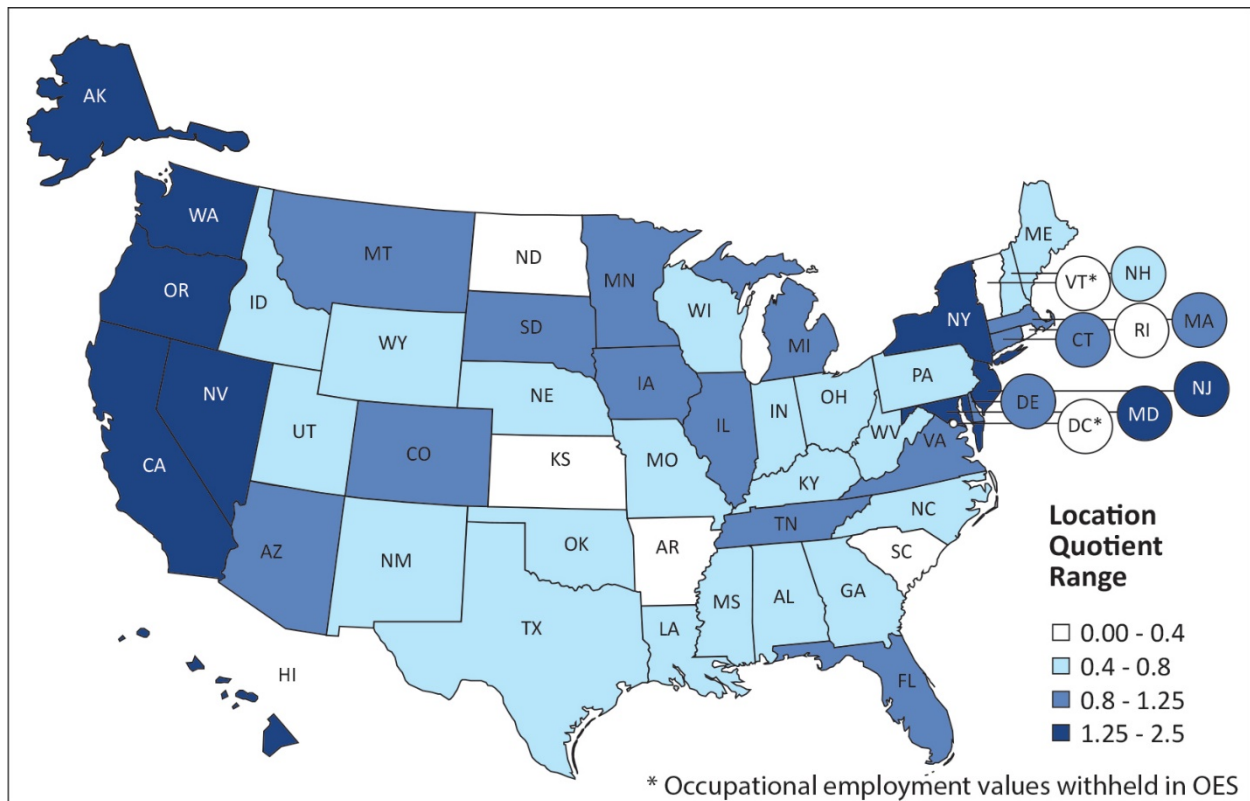
With this limitation in mind, some patterns do emerge. Bus driver jobs are disproportionately—but not exclusively—located in urban areas, as would be expected given that transit systems tend to be in larger cities (See **Figure 2.7**). Of bus drivers, 90 percent are in urban areas compared to 81 percent of other blue-collar jobs.¹¹² Further, just five major metropolitan areas (New York City, Los Angeles, San Francisco, Chicago, and Washington, DC) account for over 30 percent of bus driver employment. On a proportional basis, the “location quotient” of bus drivers is also highest in urbanized States such as Hawaii and New York.

¹⁰⁹ “2017 Employees,” Federal Transit Administration National Transit Database, accessed May 14, 2019, <https://www.transit.dot.gov/ntd/data-product/2017-employees>; “Occupational Employment and Wages, May 2018 53-3021 Bus Drivers, Transit and Intercity,” Occupational Employment Statistics, U.S. Bureau of Labor Statistics, updated March 29, 2019, <https://www.bls.gov/oes/current/oes533021.htm>.

¹¹⁰ Some data sources refer to this position as a “driver,” while the transit industry itself typically uses the term “operator.” In this section, “operator” is used except when citing external sources or datasets that use “driver.”

¹¹¹ Flood et al., Integrated Public Use Microdata Series. ASEC CPS data for years 2003 through 2017 were used to develop the demographic profile of bus drivers; U.S. BLS, “Occupational Employment... Bus Drivers.”

¹¹² “O*NET 23.2 Database.” Other blue-collar jobs include all employed persons in the following broad occupational categories as defined by the Standard Occupational Classification system: construction and extraction; installation, maintenance, and repair; production; and transportation and material moving (with the exception of bus drivers). These traditional working class occupations, particularly other transportation occupations, may be treated as reasonable alternatives to bus drivers. Notably, seven of the top ten “career changers matrix” occupations listed for bus drivers are transportation-related. These matrix occupations are lists of alternative occupations with the skill sets and experience most similar to those for a transit and intercity bus driver.



Source: BLS OES

Figure 2.7. Location Quotient of Transit and Intercity Bus Drivers, 2018

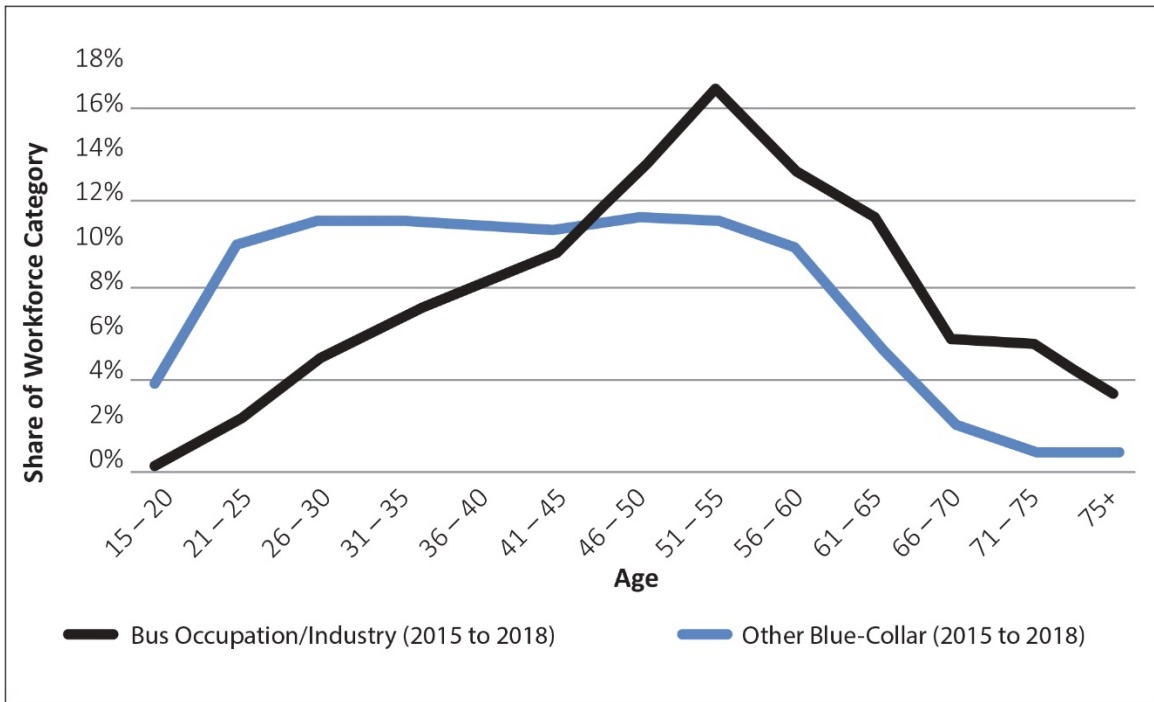
Relative to the blue-collar workforce as a whole, bus drivers also include larger shares of women and African Americans, which could have implications for future job displacement from driving automation (see **Table 2.2**). Whereas bus drivers are 40 percent female, women comprise just 14 percent of other blue-collar employment. African Americans comprise 32 percent of the bus driver workforce, compared to 12 percent of other blue-collar employment. The associated income losses and job insecurity would fall disproportionately on groups that have historically faced considerable employment discrimination.

Table 2.2. Demographics of bus drivers compared to other blue-collar workers¹¹³

	Location		Gender		Race		
	Rural	Urban	Female	Male	White	Black	Other
Bus Drivers in the Bus Service and Urban Transit Industry	10.5%	89.5%	40.2%	59.8%	62.7%	31.9%	5.4%
Other Blue-Collar Workers	19.5%	80.5%	14.2%	85.8%	81.8%	11.9%	6.3%

¹¹³ Flood et al., Integrated Public Use Microdata Series. ASEC CPS data for years 2003 through 2017.

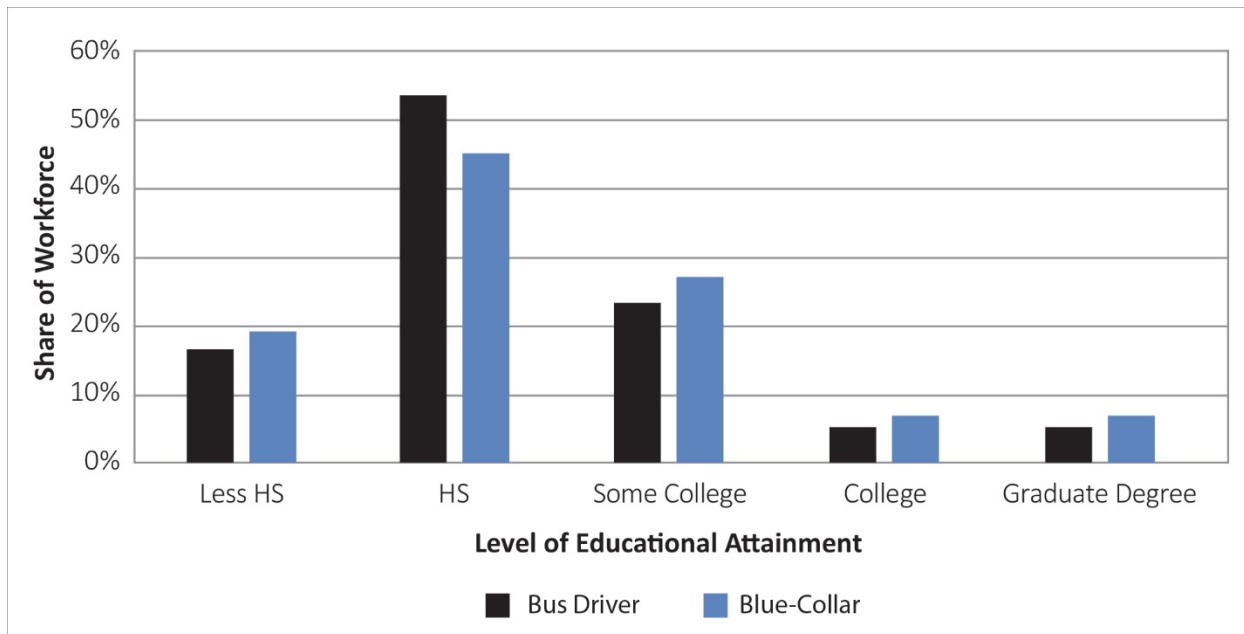
The distribution of bus drivers' ages also includes many more workers in the older age categories. This could mean that future driving automation-related job losses take place through retirements to some extent, rather than unemployment. If the age profile of drivers is maintained, in 10 years, 38 percent of the current bus driving workforce will be 65 years or older and in 15 years, the number will be 55 percent. Older workers who are displaced could find it more challenging to retrain for new positions or pursue new qualifications and credentials. Bus drivers' duties do, however, include customer service functions that may be transferable to other jobs.



Source: ASEC CPS

Figure 2.8. Share of Workforce by Age (2015 to 2018): Bus Drivers in the Bus Service and Urban Transit Industry vs. Other Blue-Collar Workers¹¹⁴

¹¹⁴ Flood et al., Integrated Public Use Microdata Series. “Bus Drivers in Transit Industry” refers to data in from CPS occupational code 9120, “Bus drivers” further narrowed to include only individuals employed in industry 6180, “Bus service and urban transit.”



Source: ASEC CPS

Figure 2.9. Level of Educational Attainment: Bus Drivers in the Bus Service and Urban Transit Industry vs. All Other Blue-Collar Workers¹¹⁵

2.4.2. Working Conditions

Transit bus operators’ working conditions including job responsibilities, working environments, and schedules influence workforce characteristics such as retention and pay. Bus operators face a stressful work environment with many competing pressures, long hours, and shift work, including split shifts that involve working both the morning and evening rush hours.¹¹⁶ Beyond driving the bus, operators face numerous additional demands on their time and attention. They must navigate through traffic, adhere to a fixed schedule, collect fares, and interact with riders.¹¹⁷ Transit bus operators have raised crime and related security issues as major concerns and noted that they frequently fear for their safety due to interactions with passengers.^{118 119}

¹¹⁵ Flood et al., Integrated Public Use Microdata Series. “Bus Drivers in Transit Industry” refers to data in from CPS occupational code 9120, “Bus drivers” further narrowed to include only individuals employed in industry 6180, “Bus service and urban transit.”

¹¹⁶ Katherine Turnbull, “Research on Fatigue in Transit Operations,” Technical Activities Division, Transportation Research Board, and National Academies of Sciences, Engineering, and Medicine (Washington, DC: Transportation Research Board, 2012), <https://doi.org/10.17226/22705>.

¹¹⁷ Laura Bliss, “There’s a Bus Driver Shortage. And No Wonder,” *CityLab*, June 28, 2018, <https://www.citylab.com/transportation/2018/06/why-wont-anyone-drive-the-bus/563555/>.

¹¹⁸ Gary W. Evans and Gunn Johansson, “Urban Bus Driving: An International Arena for the Study of Occupational Health Psychology,” *Journal of Occupational Health Psychology* 3, no. 2 (1998): 99-108.

¹¹⁹ “Preventing and Mitigating Transit Worker Assaults in the Bus and Rail Transit Industry,” Transit Advisory Committee for Safety (TRACS) 14-01, 2015, https://www.transit.dot.gov/sites/fta.dot.gov/files/Final_TRACS_Assaults_Report_14-01_07_06_15_pdf_rv6.pdf.

2.4.3. Driver Pay

NTD 2017 lists the average wage for a bus operator (vehicle operator in the motor bus mode) as \$28.22 per hour. This is defined as salary costs divided by hours worked and does not include fringe benefits. Average wages are slightly higher for the other NTD-defined bus modes, including bus rapid transit, commuter bus, and trolleybus; these more-specialized bus services collectively account for about 6 percent of bus operator positions.

Overall, with annual earnings in the range of \$40,000 to \$50,000 and sometimes higher, wages for the transit bus operator position generally compare favorably to other jobs that require only a high school diploma. Many transit agencies also provide a benefit package with health insurance, paid time off, and retirement plans.¹²⁰ However, the higher compensation levels likely reflect the concentration of transit jobs in major metropolitan areas, and thus pay levels may be somewhat offset by the higher cost of living in those locations. Wages levels also need to be considered given the working conditions noted above.

2.4.4. Driver Responsibilities

Transit bus operators drive the vehicle during revenue and non-revenue service, but they also have a wide range of non-driving duties. These include:

- Performing pre-departure safety and equipment checks
- Overseeing onboard fare collection
- Communicating with dispatch
- Providing customer assistance (e.g., stop and route information, answering questions)
- Identifying riders at curbsides and operating doors at stops
- Assisting with wheelchair securements, loading ramps, and other accessibility aids
- Securing the vehicle during breaks and layovers
- Conducting post-trip activities such as cleaning and recordkeeping

In addition to these routine duties, operators also handle special situations such as collisions, mechanical breakdowns, medical emergencies, security incidents, and equipment failures—such as stuck doors. Some non-driving functions have already been widely automated, such as audible stop announcements. However, many of the remaining non-driving tasks are difficult or costly to automate. Agencies seeking a fully unattended vehicle could elect to pursue some combination of the following options:¹²¹

- *Transfer responsibilities to other employees.* Have maintenance staff or supervisors carry out pre-departure checks.

¹²⁰ “1997 Table 13: Employer Paid Fringe Benefits: Details by Transit Agency,” Federal Transit Administration National Transit Database, accessed May 14, 2019, <https://www.transit.dot.gov/ntd/data-product/1997-table-13-employer-paid-fringe-benefits-details-transit-agency>. Although NTD no longer collects data on fringe benefits, the last available dataset generally accords with current descriptions from major transit agencies; see, for example: Massachusetts Bay Transportation Authority, *Employee Insurance*, accessed May 14, 2019, <https://www.mbtta.com/careers/employee-insurance>.

¹²¹ The examples listed illustrate the potential range of options and do not represent policy or guidance on best practices.

- *Use remote operation and supervision.* A remote employee could take over in case of road closures or other unusual situations, and passengers with questions could use an onboard audiovisual link to a customer care center.
- *Deploy additional non-driving automation technologies.* Tasks such as operation of wheelchair ramps and securements could be handled by automation.
- *Implement transit fare policy changes.* Use off-board fare collection or a “proof of payment” system instead of a fare box.

Some of these approaches might present challenges in the current legal and regulatory framework to the extent that laws assume the presence of an operator (or other transit agency staff person) who can assist passengers.¹²² Overall, the cost and complexity of automating or reassigning non-driving duties is likely to be considerable, meaning that displacement of bus operators may not happen quickly even when Level 4 or 5 automated driving systems become available in the transit market.

2.4.5. Factors Influencing Adoption of Driving Automation

Motivation for Driving Automation

Although very few transit buses currently in operation in the U.S. are equipped with driving automation systems, driving automation has been the subject of considerable interest and research activity in several segments of the transit community. Field tests of ADAS features date back at least as far as the Federal Transit Administration (FTA)-sponsored Vehicle Assist and Automation project in 2013. Many additional research projects and demonstrations have been launched since then, featuring vehicles with both lower (Level 1 and 2) and higher (Level 4) levels of driving automation; activity involving Level 4 automation has consisted primarily of demonstration projects with low-speed shuttles. FTA has also included an ADAS scenario as one of the technology packages in the Strategic Transit Automation Research (STAR) Plan, with plans for integrated demonstration projects to assess technical and institutional issues with deployment.¹²³

Transit agencies’ motivation for pursuing driving automation can vary. In some cases, driver-assistance systems can address a very specific operational need, such as helping operators maintain the bus’s position in a narrow lane or transitway on a particular route, or improving the precision of docking at the curbside to facilitate boarding. In other cases, there is a more general interest in reducing collision risk and improving operational efficiency. Labor costs are also a major component of transit operating costs, which limits the ability of transit agencies to launch or maintain services that have low ridership demand. That is, while smaller vehicles can sometimes be used to serve low-volume routes and save fuel, this does little to conserve labor costs since an operator is still required. Some agencies have looked at Level 4 automated shuttles as a means of providing new or more frequent service on routes for which demand does not warrant a full-size bus.

Technological Performance

One of the key benefits of ADAS is the potential for improved safety through collision-avoidance and pedestrian-detection capabilities. Transit bus operators must maneuver 40-foot long vehicles through busy urban environments, while watching for parked cars, pedestrians, bicyclists, and other road users.

¹²² For more details on non-driving duties, see Elizabeth Machek et al., *Strategic Transit*, Appendix C.

¹²³ Machek, *Strategic Transit*, 11-13.

Although transit is one of the safest modes of surface transportation, collisions do occur and can be a significant source of cost and liability exposure for transit agencies.¹²⁴ Moreover, collisions can create significant operational disruption, particularly if the bus must be taken out of service. With ADAS, sensing systems effectively serve as an additional set of eyes and ears for the operator, and can apply braking force when needed to avoid collisions. Level 4 or 5 driving automation, although not yet available for transit buses, would potentially have even greater collision-avoidance capabilities.

Operational Benefits

In addition to potential safety benefits, there is also evidence of operational benefits to driving automation for buses. Most of this comes from past trials of ADAS, but could apply to ADS as well. For example, lane-keeping systems can help improve run times by allowing bus operators to safely operate at slightly higher speeds in narrow lanes.¹²⁵ Likewise, longitudinal control systems can increase throughput in congested conditions.¹²⁶ Precision docking can improve the customer experience, particularly for passengers with disabilities, while also reducing waiting times. ADS could also improve vehicle utilization, as a potential bidirectional design can eliminate end-of-run turnaround loops, and there would be no need for operator breaks. Adoption of driving automation will depend critically on real-world performance of the technology and details of its implementation. Previous versions of lane-keeping systems—albeit with technology different from that available today—produced jerky vehicle movement that was uncomfortable for some passengers, and the precision docking system was associated with increases, rather than reductions, in average waiting time.¹²⁷

Union Support for ADAS

In the transit sector, there has been some concern that ADAS could lead to “deskilling” of the bus operator position, which might in turn lead to lower wages. The operational efficiencies associated with ADAS (e.g., reduced travel times) could also lead to a loss of overtime hours for operators, which are sometimes viewed as an important part of the overall compensation package.¹²⁸

Transit unions have been generally receptive to ADAS because these capabilities can help improve safety. Unions have emphasized that additional work is needed to ensure these technologies are used appropriately, with carefully designed human-machine interfaces and training on their use. In response to a request for comments from FTA about policy barriers to bus transit automation, the Transport

¹²⁴ Jerome M. Lutin et al., “A Research Roadmap for Substantially Improving Safety for Transit Buses through Autonomous Braking Assistance for Operators,” Transportation Research Board Annual Meeting 2016, 16-1246 (Washington, DC: Transportation Research Board, 2016).

¹²⁵ Brian Pessaro, “Impacts of the Cedar Avenue Driver Assist System on Bus Shoulder Operations,” *Journal of Public Transportation* 16, no. 1 (2013), <http://doi.org/10.5038/2375-0901.16.1.5>.

¹²⁶ Jerome M. Lutin and Alain Kornhauser, “Application of Autonomous Driving Technology to Transit: Functional Capabilities for Safety and Capacity,” presentation to 93rd Annual TRB Meeting (Washington, DC: 2014).

¹²⁷ Rob Gregg and Brian Pessaro, *Vehicle Assist and Automation (VAA) Demonstration Evaluation Report*, U.S. Department of Transportation Federal Transit Administration (Washington, DC: January 2016), https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Report_No._0093.pdf.

¹²⁸ Michael Greco, “Labor Concerns Should Not Deter Deployment of AV Bus Tech,” *Metro Magazine*, March 6, 2019, <https://www.metro-magazine.com/blogpost/733277/labor-concerns-should-not-deter-deployment-of-av-bus-tech>.

Workers Union of America, American Federation of Labor and Congress of Industrial Organizations (AFL-CIO), wrote:

FTA must collaborate with other modal agencies to ensure that commercial vehicle operators have the tools they need to safely interact with this technology, including updated training standards. The agencies must address human machine interface (HMI) designs to ensure the human operator knows the functionality and limitations of the ADS and therefore is prepared to react appropriately to technology failures. The HMI designs also must maintain human operator awareness and engagement to help ensure the safe transition between machine and human in cases of technology failure. Additionally, workers who evaluate, conduct diagnostic tests, and repair and maintain buses must receive the training needed to adjust to vehicles with ADS.¹²⁹

Factors Limiting the Pace of Adoption

Market Size

Market size is one key factor that may influence transit agencies' propensity to invest in driving automation. According to NTD data, the total transit bus fleet is about 71,000 vehicles, while new vehicle sales are roughly in the range of 5,000 per year. This makes the market for transit buses orders of magnitude smaller than that for light-duty vehicles and heavy trucks. The small market size makes it more difficult to use other vehicle markets to develop a viable business case for transitioning driving automation technologies to full-size transit buses.

The bus transit market is somewhat behind the light-duty market in the development of ADAS, and there are challenges in transferring existing technology to transit buses. Driving automation systems need testing and validation on each new vehicle model; they cannot simply be transferred over from other vehicle types. Adjustments may also need to be made to physically accommodate sensors on the bus and to adjust for different vehicle actuation systems and dynamics. Transit buses also have some unique characteristics, such as the presence of unrestrained—often standing—passengers, which may require further adjustment of vehicle control systems. More generally, the congested, multimodal urban environments in which transit vehicles typically operate have also proven challenging for systems that were developed for other roadway types.¹³⁰

While driving automation technologies can be adapted to transit buses, the ability to recoup these investments is limited when amortizing these transfer costs across only a small number of vehicles. These factors are discussed in more detail in a recent FTA report.¹³¹ The longevity of existing vehicles (12–14 years for a typical bus) also means that even if the technology is ready soon, it will take many years to filter into the fleet, unless retrofitting older vehicles is economically, technologically and commercially viable. Additionally, since transit bus systems do not face the same market competition pressures as commercial truck operators, they would be less likely to retire their existing fleet early even

¹²⁹ Federal Transit Administration, *FTA Request for Comment: Removing Barriers to Transit Bus Automation*, accessed May 14, 2019, <https://www.regulations.gov/document?D=FTA-2017-0025-0034>.

¹³⁰ California Transit Association, Response to RFC, Docket ID DOT-OST-2018-0150-0028, November 6, 2018.

¹³¹ Federal Transit Administration, *Transit Bus Automation Project: Transferability of Automation Technologies Final Report*, September 2018, <https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/research-innovation/118161/transit-bus-automation-project-transferability-automation-technologies-final-report-fta-report-no.pdf>.

if technological breakthroughs were to quickly lead to dramatically lower full lifecycle costs for automated transit buses.

Union Position Regarding Level 4 or 5 Automation

As noted above, transit unions have been receptive to ADAS because of the potential to reduce bus operator safety risks. In contrast, unions have raised worker displacement concerns with the adoption of Level 4 or 5 driving automation. In its RFC response, the Transport Workers Union wrote:

[The] government must understand that its actions to eliminate regulations and policies perceived to be barriers to automated commercial vehicle deployment, and its use of Federal funds to support research developing these technologies, are deliberate decisions that will create substantial financial gains for corporations and potential massive displacement of blue-collar workers. As a result, the DOT and Congress have the responsibility to consider and address these workforce implications in these beginning stages to prevent avoidable and needless harm to workers in the future.

More recently, the Transportation Trades Department (TTD) of the AFL-CIO issued a policy statement that addresses automation in more detail, noting that “strong unions and worker engagement are essential to mitigate harms inherent in rapid changes to industries.”¹³² These concerns are similar to those that have been raised by workers and organized labor groups throughout history as labor-saving technologies have been introduced into the economy.

Regulations and Status as Public Agencies

Transit providers are largely public agencies (at the local, regional, or State level) and thus may differ from the private sector in their adoption of driving automation. In general, these factors would tend to be associated with slower adoption of automated vehicles, but there could be circumstances where that is not the case. Compared to the private sector, public transit agencies typically:

- Have procurement processes that can be complex with long timeframes, making it more difficult to adapt to fast-changing product markets.
- Are more risk-averse due to their status as stewards of public funds, and the fact that failed ventures can receive widespread attention, particularly in services such as bus transit that the public interacts with daily.¹³³
- Are accountable to elected officials and the public rather than to shareholders, and thus have objectives that go beyond profit maximization.
- Do not face the same competitive pressures and market factors that might drive automation in the private sector.
- Have higher rates of unionization in their workforces.

Transit agencies are also sensitive to public perceptions and the customer experience. For example, if some transit riders are uncomfortable with traveling in a vehicle that has no staff presence, transit

¹³² Transportation Trades Department, *Principles for the Transit Workforce in Automated Vehicle Legislation and Regulations*, Policy Statement No. W19-05, March 11, 2019, <https://ttd.org/policy/principles-for-the-transit-workforce-in-automated-vehicle-legislation-and-regulations/>.

¹³³ Machek, *Strategic Transit*.

agencies consider passenger acceptance in their decisions regarding adoption of driving automation. As providers of a transit service that is open to the public, transit agencies are subject to the Americans with Disabilities Act (ADA) and its implementing regulations, which may present additional complexities for the concept of an unstaffed bus, since it is unclear how duties required by the ADA would be performed without onboard staff.¹³⁴

In addition, since almost all transit agencies rely on public-sector funding, they are subject to several procurement policies, which may cause other challenges. For example, 49 U.S.C. 5333(b)—often referred to by its earlier name as Section 13(c) of the Federal Transit Act—provides many labor protections for Federally-funded projects. These provisions are administered by DOL and can be complex, but generally require “fair and equitable” treatment of affected transit workers, which could include priority for reemployment and/or retraining programs.¹³⁵

Overall, transit agencies’ status as public agencies, along with several existing legal requirements, could reduce their interest or ability to invest in driving automation. Risk-averse agencies may prefer not to be lead adopters of new technology, and the business case for reductions in labor costs may be attenuated by retraining and other costs. On the other hand, past experience with rail and other modes has sometimes indicated that adoption of automation has been motivated by operational and safety benefits rather than significant labor savings.¹³⁶ Furthermore, the existence of Section 13(c) protections could help to ensure that adoption of driving automation is done in a way that fully considers the interests of the transit workforce.

2.4.6. Workforce Impacts by Category

The following sections discuss potential workforce impacts of adopting driving automation in the bus transit sector. The workforce impacts discussed below include the potential for transit bus operator job displacement, changes in operator responsibilities, new jobs created, wage impacts, quality of life, and impacts on operator retention. Across all these areas, the impacts will depend on the level of automation and the extent to which it is used in the transit agency. For Level 4 or 5 driving automation, the impacts would also hinge on the transit agency’s approach to handling non-driving duties.

¹³⁴ Federal Transit Administration Circular, *Americans with Disabilities Act (ADA): Guidance*, November 4, 2015, https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/Final_FTA_ADA_Circular_C_4710.1.pdf. See also 49 CFR 37.167(e).

¹³⁵ “Transit Labor Protection—A Guide to Section 13(c) Federal Transit Act,” *TRCP Legal Research Digest*, No. 4 (June 1995), http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_lrd_04.pdf.

¹³⁶ See F. Gerin, “L’heure des métros automatiques a-t-elle sonné?” *Paris Innovation Review*, January 5, 2012, <http://parisinnovationreview.com/article/lheure-des-metros-automatiques-a-t-elle-sonne>, and C. Braban, and P. Charon, “Re-signaling the Paris Line 1: from driver-based to driverless operation,” *WIT Transactions on the State of the Art in Science and Engineering* 46 (2010), <https://www.witpress.com/Secure/elibrary/papers/9781845644949/9781845644949006FU1.pdf>. One example is Line 1 of the Paris metro, which was converted to automated operation over the period from 2008-2012, but subject to an earlier agreement with the labor unions that there would be no layoffs in connection with the project. Drivers were reassigned to other lines or moved to the control center. The benefits of fully automated operation included higher throughput and improved speeds and energy efficiency, while the platform doors virtually eliminated the safety issues caused by trespassers and suicides on the line. The automated approach also allows the agency to add more frequent metro service to match surges in demand without the need to summon additional drivers.

Driver Job Displacement

The use of ADAS allows the bus operator to exercise more precise lateral and longitudinal control of the vehicle, but it does not diminish the need for an operator. Thus, little to no displacement of bus operators would be expected, even in the event of widespread ADAS adoption.

ADAS' safety and operational impacts can include avoided collisions, reduced fuel costs, and improved run times. As transit agencies begin to experience these impacts and re-optimize their service provision and scheduling accordingly, this could lead to small changes in bus operator employment in either direction. That is, faced with a fixed budget and lower (non-labor) operational costs per vehicle-mile, transit agencies may choose to respond by increasing service levels slightly, potentially increasing their labor demand. Conversely, improved transit reliability could potentially mean lower demand for the reserve operators ("extra board") who cover for absences and help transit operations recover from service disruptions.

At high levels of automation, there are many reasons why a human presence may continue to be needed on board, including operators' non-driving duties.¹³⁷ Transit agencies may elect to create a new job category of non-driving onboard attendant to handle customer assistance and other tasks. In that situation, outright displacement would be limited, particularly in cases where these positions are offered to existing operators. However, given the less-specialized skills required for such positions, the pool of potential candidates would be larger, and thus wages would likely be lower.¹³⁸

Conversely, if there is no onboard attendant position, existing bus operator positions would gradually be displaced. This amounts to approximately 105,000 positions nationally, according to NTD. The general view from the literature and stakeholder consultation is that this kind of change would be many years away.¹³⁹ The operation of a full-sized transit bus in revenue service, at normal speeds, and in mixed-traffic environments, is under development but it is not yet technically feasible. ADS, though successfully demonstrated in numerous tests, does not yet have widespread commercial availability in the light-duty vehicle or truck markets, and would take time to filter into the smaller market for transit buses. Many of these driving automation systems are also oriented toward highway driving, which is typically considered to be a less complex driving environment.

By contrast, most transit buses spend most of their service day in complex urban environments that would pose significant additional technology challenges. For the other reasons noted above related to unionization, agency risk-aversion, and other institutional factors, there may also be considerable time lags between when the technology is ready and when adoption begins. From that point, there would also be a transition period as existing buses were replaced, which would mean that any driver displacement would take place slowly and partly via routine attrition.

¹³⁷ Machek, *Strategic Transit*, Appendix C, 52-80.

¹³⁸ To the extent that union agreements and other policies limit the ability of transit agencies to offer such positions to other workers or at lower wages, this could limit any cost advantages of automated transit buses and thus slow the rate of adoption of such technologies.

¹³⁹ One exception is the automated shuttles that are currently being piloted, but these have small capacities and operate at low speeds. They are typically a supplement to rather than a replacement for existing transit service.

Changes in Job Responsibilities

For ADAS-equipped vehicles, the operator must remain at the controls and actively engaged in the driving task, even when ADAS is functioning. There is relatively little latitude to modify the operator's job description to include any significant new non-driving duties. However, the nature of the operator job will evolve with the need to monitor the automation. Operators will need training on the safe and effective use of ADAS.

For vehicles equipped with Level 4 or 5 driving automation, the position of bus operator, as it is defined now, would no longer exist. The bus operator position would have all driving tasks removed, assuming a vehicle that operates exclusively within its ODD. The job may be transformed into a customer service role comprised of existing non-driving duties. Although bus operators already perform many or all of these duties, this transformation would likely require some training on the new position. The attendant's role would also differ in that customer assistance would be the primary focus of the job, without the need to balance this against the demands of the driving task. This shift would likely be reflected in position descriptions and hiring practices, since the job would call for a different combination of skills.

Alternatively, some non-driving duties could be transferred to other transit employees, with associated training needs. Other duties could be automated through additional technologies—for example through off-board fare collection and passenger assistance via video link. However, the overall feasibility and cost-effectiveness of these approaches is unclear, and some changes (e.g., assistance to passengers with disabilities) might not be compatible with existing regulations.¹⁴⁰ Non-driving transit jobs could also see shifts in responsibilities, to the extent that transit agencies seek to re-allocate bus operators' non-driving tasks. For example, there may be new or additional staff at stops and stations to handle customer assistance and light vehicle maintenance tasks that were previously handled by the operator. New employees may also be needed for off-board fare collection and control center staff for remote monitoring of vehicles.

With the increased technical sophistication and sensing capabilities of buses equipped with driving automation systems, there would also be additional vehicle maintenance needs that could be handled through shifts in maintenance staff responsibilities or new hiring. At the same time, the trend toward automation could also include basic maintenance functions such as remote vehicle checks and engine diagnostics, which could be accelerated. This would free up time for maintenance staff to focus on more complex tasks.

New Job Creation

Driving automation would add new sensing equipment and technologies to transit buses, likely increasing their complexity and creating some additional demand for maintenance and repair employees. Level 4 or 5 buses would likely lead to increased demand for control center staff to provide remote supervision and dispatch. The vehicles' automated capabilities would also tend to create additional jobs in data management and cybersecurity.¹⁴¹

For ADAS specifically, there would also be demand for training courses on the safe and effective use of ADAS since a human driver must remain in control at all times. These impacts would likely be modest;

¹⁴⁰ Machek, *Strategic Transit*, 8-9.

¹⁴¹ New Flyer of America, RFC Response, Docket ID DOT-OST-2018-0150-0032, November 6, 2018.

they could involve a shift in responsibilities and scheduling for existing transit staff and/or hiring new personnel.

To the extent that Level 4 or 5 buses are operated without onboard staff, there could be greater demand for off-board customer service staff to support the kinds of passenger assistance tasks that operators currently perform, such as answering questions about routes and stops. Agencies moving to new fare collection systems to enable unstaffed vehicle operation would likely also have to hire additional personnel, such as fare inspectors for proof-of-payment systems. It is also possible that additional security personnel could be needed to provide passengers with a greater sense of safety on the unstaffed vehicles.

As buses with Level 4 or 5 driving automation are introduced, transit agencies would have temporary needs for community consultation and outreach staff to help explain the changes and how to use the new service.

Quality of Life

The introduction of ADAS for transit buses may improve the quality of life of drivers. Technologies such as collision avoidance, precision docking, and lane centering can help to reduce the burden on the bus operator and improve safety and rider experience.

Driving automation may also introduce new types of jobs in the transit bus sector, with uncertain health and quality of life impacts. If a bus is engaged in Level 4 or 5 ADS, a transit employee may remain in the bus, but the types of tasks that this person is likely to do may change. Rather than primarily working as a driver, the employee may engage in more customer-facing activities, such as assisting passengers with disabilities and providing directions to riders. Driving automation may also introduce a new role of remote monitoring and supervision. The impacts of these new roles will depend upon the final form which they take.

Wages

There are occasional references to possible deskilling associated with ADAS, with the effect of reducing wages, on the theory that the driving task would be simplified.¹⁴² However, this concern appears to be overstated, as even the most sophisticated ADAS technologies cannot function in all driving environments, and in any event would still require a highly trained professional operator. On the contrary, incorporating ADAS into driving would tend to require additional training and expertise.

Another concern that has been raised is that the efficiencies created by ADAS would lead to a loss of overtime hours for operators, which are sometimes an important component of their overall compensation.¹⁴³ While this could be true in some locations, the impacts are likely to be modest, and would tend to have less influence on overtime than other aspects of the agency's human resources policy and scheduling practices. As noted above, these impacts could also work in the other direction, to the extent that transit agencies leverage the ADAS efficiencies to offer more transit service.

With Level 4 or 5 driving automation and a conversion of the operator role to an onboard attendant, there would be a deskilling of the position in that the driving component and CDL credential

¹⁴² Greco, "Labor Concerns."

¹⁴³ Greco, "Labor Concerns."

requirement would be removed.¹⁴⁴ Although this may be partly offset by a greater emphasis on “people skills” and the customer service elements of the job, the net effect would tend to put downward pressure on wages.¹⁴⁵ Indeed, it is somewhat unlikely that transit agencies would pursue this strategy of investing in driving automation technology and replacing operators with non-driving attendants, unless there were some associated labor savings (or significant operational benefits). The magnitude of this impact is difficult to assess because there are very few examples of non-driving attendants in the U.S. transit bus context, and examples from other modes may not be relevant.¹⁴⁶ Negotiations with labor unions and the requirements of Section 13(c) would also influence any changes in wage levels.

Nevertheless, in cases where the bus operator position is eliminated, there would be a need for these employees to transition to other jobs. Such transitions are a common feature of the labor market, and there are programs available to assist those affected (see **Labor Force Training and Retraining Needs**). However, as noted above, average wages and benefits for transit bus operators tend to exceed those for similar jobs with the same educational requirements, suggesting that displaced workers moving to other jobs would experience overall income losses. Though their analysis was not specific to the transit bus operator position, Groshen et al. (2018) estimate the lifetime income loss to displaced professional drivers would be in the range of \$80,000.

Driver Retention

ADAS may improve safety and thus the driving experience of the operator, which could have positive impacts on driver retention. Attendees at the March 20, 2019, stakeholder event noted, however, that careful attention must be paid to system design and the human-machine interface, not only to avoid introducing new safety issues due to misuse or misunderstanding of the systems, but also to avoid the distraction and distress of false alarms. This is particularly true when considering the often poor ergonomics of transit bus operators’ current workstations, many of which have safety systems and displays that have been added piecemeal in ways that can be distracting for drivers.

Widespread adoption of Level 4 or 5 driving automation could present a retention challenge, as operators anticipate future job losses and seek other opportunities. This would be particularly true if

¹⁴⁴ Amalgamated Transit Union (ATU), RFC Response, Docket ID DOT-OST-2018-0150-0013, November 5, 2018. As ATU noted in its RFC response, “Transforming skilled bus drivers into ‘onboard customer representatives’ could potentially reduce the wages and benefits of the workers due to the expanded pool of people who could fill those roles.”

¹⁴⁵ Transport Workers Union of America, AFL-CIO, RFC Response, Docket ID DOT-OST-2018-0150-0015, November 5, 2018. TWU cited a recent example of a pilot program using automated shuttles, for which the wage rate for the non-driving onboard attendant is roughly 60 percent of that for senior bus operators at a nearby transit agency. While this is only a single example, and a more apt comparison would be with average or even entry-level wages rather than senior wages, it does suggest that wages may be lower for the onboard attendant position.

¹⁴⁶ The Unitrans bus system in Davis, California does employ onboard attendants in addition to operators. Based on job postings from the agency, starting wages for the attendant (conductor) position are higher than those for the driving position, at \$10.25 per hour, versus \$9.75 per hour. However, both of these rates are significantly lower than current bus operator wages and may reflect the unique nature of this town-gown partnership, rather than more typical market conditions. See listings <https://vacancy.ucdavis.edu/listings/715/> and <https://vacancy.ucdavis.edu/listings/803/>; “May 2018 National Industry-Specific Occupational Employment and Wage Estimates: NAICS 485100 - Urban Transit Systems,” Occupational Employment Statistics, U.S. Bureau of Labor Statistics, accessed April 2, 2019, https://www.bls.gov/oes/current/naics4_485100.htm#53-0000. According to BLS data, average earnings for “transportation attendants, except flight attendants” (53-6061) working in Urban Transit Systems are considerably lower than for driving occupations, with a median of \$11.33 per hour.

there were no onboard attendant as a fallback position or if the wages for that position were lower. However, the collective bargaining process and State and local policy decisions could result in some form of job guarantee for existing operators, as has been the case in some automation projects internationally.

2.4.7. Transit Bus General Impact Summary

Based on the available literature and stakeholder input, the use of ADAS on transit buses is generally viewed as plausible for the near- to medium-term. It is based on technology that has been tested in transit and is becoming mainstream in other vehicle markets, and offers at least the potential of noticeable safety and operational benefits. However, there are some factors that may limit or delay the adoption timeline, particularly related to the small size of the transit bus market and the challenges in modifying ADAS products that were developed for other vehicle types.

Adoption would tend to take place gradually as existing transit vehicles are retired and replaced, though retrofitting of existing vehicles could also be possible. No significant displacement of operators would occur, because the technology always requires that a human operator remain at the controls and in overall command of the vehicle. As such, it is also unlikely that the duties of the bus operator position would be altered or expanded. Some smaller changes in operator employment levels or wages could result from the secondary impacts of ADAS' improvements to transit performance, but these will vary and would be expected to be minor. Safety training would be required for bus operators on the use of ADAS, and some training would also be needed for transit vehicle maintenance staff.

Full-size transit buses equipped with ADS are unlikely to be seen in the short- to medium-term, as the technical and operational feasibility remains somewhat unclear, and any transition would take place gradually with the turnover of the transit bus fleet. As discussed above, there are factors unique to the transit vehicle marketplace that may limit adoption. Perhaps more importantly, there are many non-driving tasks that bus operators currently perform and that would be costly to automate or reassign. To the extent that these issues could be overcome, however, all or a portion of the Nation's 105,000 transit bus operators could potentially face displacement by Level 4 or 5 driving automation as it is gradually phased in. Any such transition would take place in parallel with retirements and other natural attrition in the operator ranks, reducing the likelihood of layoffs.

If transit agencies keep a human presence onboard, existing operators could see their position evolve into the role of a non-driving vehicle attendant. This would involve reskilling and a change in job responsibilities, with a greater emphasis on the customer service role but the removal of the driving task and CDL credential requirement. The limited available evidence suggests that the net impact on wages would be downward.

In practice, transit agencies may elect to pursue a mix of these two strategies. One agency that is planning a transit service using driving automation described the approach not as a workforce reduction, but rather a process of workforce transformation to leverage driving automation's capabilities and provide better service to the community.¹⁴⁷

These impacts on bus operator jobs may be slightly offset by the additional demand for vehicle maintenance and control center staff, along with emerging roles in cybersecurity and data analytics.

¹⁴⁷ Jacksonville Transit Authority, Response to RFC, Docket ID: DOT-OST-2018-0150-0011, November 5, 2018.

There would also be new training needs and wider changes in overall job responsibilities across transit agency staff, such as if fare collection and other procedures are revised to support the unstaffed vehicle concept.

More broadly, the potential removal of labor as a major component of vehicle operating costs could lead to fundamental changes in transit service, making the longer-term outlook particularly difficult to forecast. For example, transit agencies may re-optimize their service patterns to take advantage of driving automation capabilities, replacing low-volume bus routes with smaller vehicles, or even moving toward a “mobility on demand” concept. It is also possible that the most significant workforce impacts may come not from adoption of driving automation in the transit bus sector itself, but from changes to competing modes of travel or emerging travel options such as micromobility. The adoption of higher-level automation of private automobiles or ride-hailing services could erode some of transit’s time, cost, or convenience advantages relative to these modes, thereby reducing overall demand for transit services.¹⁴⁸

2.5. Summary

As driving automation technologies mature, the transportation modes against which trucking and transit compete for customers will also be evolving, both through technological and other improvements. New modes or business models may also emerge. The uncertain outcomes of this competition make it difficult to forecast workforce impacts with any precision. However, certain tentative conclusions can be made.

In the near term, the adoption of ADAS will likely lead to changes in the nature of the driving position, with associated training needs and improvements in safety and operations. There would be no expected driver job displacement because these systems require a human driver.

The potential for higher level automation to completely displace drivers exists, but a number of factors suggest that it may take many years to unfold: these systems are not yet market-ready and are expected to require time for development, testing, and then additional time for newly-purchased vehicles to be absorbed into the on-road fleet, as older vehicles are replaced. There are also market and institutional factors that may act as checks on adoption of Level 4 or 5 vehicles, particularly for transit. As drivers also perform a range of essential non-driving tasks, trucking companies and transit agencies seeking to operate Level 4 or 5 vehicles may also need to modify their operational practices, for example, with additional staff or technology investments. Overall economic growth during this transition period would be expected to create additional employment options. Truck drivers and transit bus operators are disproportionately in the older age groups, so this potentially long transition period implies that the gradually decreasing demand for drivers may be realized through retirements and other natural attrition rather than through layoffs.

Within the trucking sector, job displacement may be experienced first in the long-haul sector due to the long periods of uninterrupted highway driving (a less complex driving task to automate). While the available data is imprecise and somewhat outdated, it suggests that the size of the current long-haul workforce is approximately 300,000 to 500,000 jobs out of the total two million current heavy truck and

¹⁴⁸ See, for example, Steven Polzin, “Implications to Public Transportation of Emerging Technologies,” *National Center for Transit Research*, November 2016, <http://www.nctr.usf.edu/wp-content/uploads/2016/11/Implications-for-Public-Transit-of-Emerging-Technologies-11-1-16.pdf>.

tractor-trailer driving jobs in the country. In transit, there are approximately 105,000 bus drivers who could potentially be impacted by Level 4 or 5 automation over time. These employment totals are quite small relative to the Nation's total employment of nearly 160 million, though driving jobs are disproportionately prevalent in some geographic areas and demographic groups.¹⁴⁹

While automation of the driving task would be expected to decrease the number of driving jobs, some new jobs will also likely be created. These new jobs would perform the non-driving tasks currently performed by the human driver, such as securing cargo and refueling the vehicle (in trucking) or collecting fares and securing wheelchairs (in transit). There could also be new truck-driving jobs that focus on the types of driving that cannot be easily or cost-effectively performed by automation, as well as jobs in maintenance for the increasingly sophisticated driving automation technology. Increased productivity in the trucking sector would also tend to lower overall freight costs, creating new jobs in the larger economy from general economic growth. Transit operator jobs could see a change in responsibilities because of the non-driving duties that would remain. These jobs could evolve into a customer assistance role, a transition that would tend to put downward pressure on wages due to the less-specialized skills that would be required.

However, it is not clear whether the new jobs will be a good match for the existing driving workforce in terms of skills and geographic location. In addition, the new jobs may not provide the same level of earnings, with some research finding that the loss of a professional driving job (not specific to transit buses) is associated with an \$80,000 loss in lifetime earnings.

3. Situation Awareness and Platooning

3.1. Situation Awareness and Driving Automation

Driving automation has the potential to improve both the safety and efficiency of operations; however, understanding how vehicles with ADS and ADAS may affect the situation awareness of the operator is critical to their safe and successful implementation. Situation awareness is often defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.”¹⁵⁰ Situation awareness can require the integration of many, often simultaneous events and involves many related cognitive processes—including attention and memory—all of which can be influenced by one's internal state (such as fatigue, distraction, expectations) and external factors (such as the complexity of the environment and feedback provided from the ADS or ADAS).¹⁵¹

¹⁴⁹ “Employment Situation News Release,” U.S. Bureau of Labor Statistics, November 1, 2019, https://www.bls.gov/news.release/archives/empsit_11012019.htm. “Employment Situation News Release,” U.S. Bureau of Labor Statistics, November 1, 2019, https://www.bls.gov/news.release/archives/empsit_11012019.htm. “Employment Situation News Release,” U.S. Bureau of Labor Statistics, November 1, 2019, https://www.bls.gov/news.release/archives/empsit_11012019.htm.

¹⁵⁰ Mica R. Endsley, Situation Awareness Global Assessment Technique (SAGAT), *Proceedings of the National Aerospace and Electronics Conference*, (New York: IEEE, 1988), 789-795.

¹⁵¹ Nadine B. Sarter and David D. Woods, “Situation awareness: A critical but ill-defined phenomenon.” *International Journal of Aviation Psychology* 1, no. 1 (1991): 45-57.

Research indicates that, across domains, increased levels of automation are associated with a decrease in an operator's situation awareness.¹⁵² With regard to driving automation specifically, these findings apply at least at the level of ADAS that do not employ any design strategies intended to manage the operator's attention.¹⁵³ Developers of ADS and ADAS may want to explore the human factors issues that may arise, as well as the potential impacts of design approaches that could aim to mitigate the problems with decreased situation awareness.

To maintain an operator's situational awareness with Level 0 to 2 systems, which assist the drivers, but do not alter their driving role, it is critical that the operator understands both the actions of the system (what it will do, when, why, and limitations), and also how, when, and why to intervene. In contrast, with Level 3 systems, the goal shifts from maintaining to regaining the operator's situation awareness when the operator is requested to intervene by the system. There are many factors that could affect the time it may take for an operator to safely take control of a vehicle. These include the complexity of the environment and the actors and potential threats within it, the experience (and expectations) of the operator, and the type and modality of alerts and information provided by the system.¹⁵⁴ The Department will continue to research these critical human factors issues, which could have impacts for all users of ADS and ADAS, including professional drivers.

3.2. Visibility, Mobility, and Safety Issues Related to Truck Platooning

A platoon is a group of vehicles, equipped with some level of driving automation system, that share information wirelessly to support close following distance.¹⁵⁵ Platoons are comprised of one lead vehicle and at least one following vehicle. They can vary in: (1) the number of following vehicles; (2) the speed at which the vehicles travel; (3) the distance (gap) between the vehicles; and (4) the level of driving automation implemented on the following vehicles. Many different implementations of truck platooning are under consideration by industry, ranging from the inclusion of drivers in each vehicle of a platoon to the potential use of remote operators or supervisors. This section will focus on visibility, mobility, and safety issues related to truck platooning in general. It also has implications for transit bus platooning, which has received less investment and attention, but is being researched as an application for bus rapid transit systems, for example.

Given that platooning assumes close following between vehicles, it raises unique questions around visibility and mobility, both of which can affect the situation awareness of the vehicle operators. The safety and efficiency of platooning depends on numerous factors, including the level of automation and the type of operation. Trucks tend to operate at relatively faster speeds on the highway, while transit

¹⁵² Linda Onnasch et al., "Human performance consequences of stages and levels of automation: An integrated meta-analysis," *Human Factors* 56, no. 3 (2014): 476-488.

¹⁵³ Joost C.F. de Winter et al., "Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of empirical evidence," *Transportation Research Part F* 27 (2014): 196-217.

¹⁵⁴ Ravi Agrawal et al., "Effects of a change in environment on the minimum time to situation awareness is transfer of control scenarios," *Transportation Research Record: Journal of the Transportation Research Board* 2663 (2017): 126-133; Mica R. Endsley, "Toward a theory of situation awareness in dynamic systems," *Human Factors* 37, no. 1 (1995): 32-64; Trent W. Victor et al., "Automation expectation mismatch: Incorrect prediction despite eyes on the threat and hands on the wheel," *Human Factors* 60, no. 8 (2018): 1095-1116; Myra Blanco et al., *Human factors evaluation of level 2 and level 3 automated driving concepts*, (Report No. DOT HS 812 182), Washington, DC: National Highway Traffic Safety Administration, August 2015.

¹⁵⁵ *Automated Vehicles 3.0: Preparing for the Future of Transportation*, U.S. DOT (2018).

buses operate at slower speeds on surface roads. In lower levels of platooning implementation, the distance between the vehicles and the speed at which they are traveling impacts the amount of time that can be afforded to an operator to gain situation awareness, take control of the vehicle, and appropriately intervene (e.g., brake) in case of an unexpected event or loss of platooning vehicle connectivity.

The close distance between commercial motor vehicles in a platoon may have implications for visibility of nearby traffic and road conditions. Given the way that platooning is designed to work, in lower levels of automation implementation operators of the following vehicles have reduced visibility unless augmented by design in other ways, such as broadcasting roadway views from lead trucks to following units. The operators of the following vehicles may not naturally see the road and traffic ahead of the lead vehicle due to obstructions caused by a close following distance to the leading unit. This can adversely impact the ability of the operator of the following vehicle to maintain situation awareness, anticipate hazards (such as a stationary vehicle in the road ahead), and take control of the vehicle in a timely manner. Platooning may also limit the visibility of the lead vehicle operator to see traffic from behind and anticipate vehicles in blind spots, and could impact the ability of drivers (including other road users) to see upcoming signs on the road or nearby traffic.

There are research questions around whether there may be a safety benefit for other road users to have insight into exactly which commercial motor vehicles are linked together in a platoon such that these other road users could potentially modify their own behavior accordingly. Some studies suggest that platooning vehicles should use a designated lane (i.e., on the highway for commercial trucks, or a designated bus lane for transit vehicles).¹⁵⁶ Others suggest that platooning vehicles could use lights or markings to indicate their status¹⁵⁷ and inform other road users of the presence of a platoon. Such an indication may help set expectations of how the platooning vehicles should maneuver (i.e., with a short following distance) and inform how other road users should behave (i.e., avoid driving in between vehicles operating in a platoon).

Platooning vehicles may have limited options for mobility and maneuvering on the roadway—for example, when changing lanes and entering/exiting the highway. A change in lane for one vehicle could interrupt or even disrupt the platoon. Given this, there may be value in increased information sharing and communication between the operators in the platoon. Information exchanges between the vehicles and the drivers/operators that could address these challenges are still being researched. It is also an open question as to how the operator of a following vehicle can have insight into the anticipated maneuvers of the lead vehicle (e.g., change lanes ahead) for transitions to be planned and appropriately coordinated.

Platooning vehicles may also adversely impact the mobility of other road users—particularly when merging onto the highway. Other users may need to modify their behavior when driving near a platoon, either accelerating to get ahead of the lead vehicles or decelerating to allow the platoon to pass. Either

¹⁵⁶ Peirce et al, “Assessing the Transit Agency Business Case for Partial and Full Automation of Bus Services” in *Transportation Research Record: Journal of the Transportation Research Board*. pp 109-118, Vol 2673, Issue 5. Washington, DC: National Academies Press, Washington, DC.

¹⁵⁷ See *White paper: Automated Driving and Platooning Issues and Opportunities*, ATA Technology and Maintenance Council, Automated Driving and Platooning Task Force, 2015.

of these maneuvers could be challenging, depending on the amount of surrounding traffic and speed of the vehicles.

As truck platooning continues to evolve, there is a need to understand and integrate lessons learned from recent operational tests, such as Safe Road Trains for the Environment (SARTRE), the European Union Trucking Challenge, Germany's KONVOI project, and those funded by Federal Highway Administration (FHWA) and Federal Motor Carrier Safety Administration (FMCSA).¹⁵⁸ Analysis of this operational experience can identify areas of emphasis that can be helpful to continued technological development.

4. Labor Force Training and Retraining Needs

Training is a necessary component of preparing individuals in any occupation to safely and effectively perform their jobs. This section discusses potential labor force training and retraining needs related to the adoption of driving automation systems in long-haul trucking and transit bus vehicles. *Training needs* refers to new knowledge and skills required for drivers to operate vehicles that utilize new technologies. *Retraining needs* refers to training services designed to equip workers with the knowledge and skills needed to seek employment in a new industry when a worker is dislocated due to job elimination. These retraining needs are closely related to and informed by workforce demographic trends, as discussed in **Workforce Impacts** of this report.

This section discusses the potential training needs to prepare truck and bus operators to safely drive vehicles equipped with Levels 1–3 driving automation systems, as well as the potential retraining needs to enable workers to find suitable reemployment in other industries if they are dislocated by the introduction of Level 4 or 5 driving automation.

4.1. Training Needs

The introduction of any new vehicle technology can create associated training needs for operators. As Level 1–3 driving automation systems are deployed in long-haul trucks and transit buses, operators will likely need reskilling on how to safely and effectively use driver-assistance technologies to perform their jobs. Reskilling is the process of equipping workers with new skills necessary to continue in their work even as job responsibilities change and evolve over time. Because driving automation systems for commercial vehicles are currently under development and not available for wide-scale use, existing training programs for truck drivers and bus operators do not incorporate considerations for automation technologies. As a result, training programs—including training to obtain a CDL—could incorporate new

¹⁵⁸ Carl Bergenhem et al., *Challenges of Platooning on Public Motorways* (2010); Tom Robinson and Erik Coelingh, *Operating Platoons on Public Motorways: An Introduction to the SARTRE Platooning Programme* (2017); Robbert Janssen et al., *Truck Platooning; Driving the Future of Transportation* (2015); Stefan Deutsche et al., "Use of electronically linked Konvoi truck platoons on motorways," *ATZ worldwide* 112, no. 7-8 (2010): 74-79, <http://doi.org/10.1007/bf03225258>; Shladover et al., *Cooperative Adaptive Cruise Control (CACC) for Partially Automated Truck Platooning: Final Report* (2018); Jeff Loftus and Robert Tershak, "Truck Platooning: The State of the Industry and Future Research Topics," (Presentation, 2018 Transportation Research Board 97th Annual Meeting, January 9, 2018), retrieved from <https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/safety/395146/loftus-tershak-truck-platooning-final-508c.pdf>.

curriculum elements to teach drivers the knowledge and skills required to operate vehicles equipped with these technologies.

4.1.1. Current Training Requirements

Commercial vehicle operators generally require a CDL with appropriate endorsements for specialized activities, such as driving a passenger vehicle or transporting hazardous materials. The U.S. DOT sets standards for knowledge and driving skills tests, as well as other requirements for CDLs, via FMCSA. However, because CDLs are State-issued licenses, specific requirements vary by State.¹⁵⁹ In February 2022, new minimum training standards for certain individuals applying for a CDL will take effect through FMCSA’s Entry-Level Driver Training Final Rule. This rule mandates that drivers complete a theory and behind-the-wheel training curriculum, though no minimum training hours are required.¹⁶⁰

CDL training requirements are typically met through completion of a program provided by a truck driver training school, which can be a private school or a public program offered through a community college or similar institution.¹⁶¹ For bus operators, transit agencies typically provide operator training. Training programs may also incorporate best practices identified in non-regulatory training standards published by industry groups for transit bus operators and truck drivers.¹⁶²

4.1.2. Future Training Needs

As driving automation systems are incorporated into long-haul trucks and transit bus vehicles, drivers will likely need training on how to safely and effectively operate them. With technologies still in development, it is not possible to comprehensively identify future training needs, as it is unclear which driving automation systems will ultimately be adopted or when they will be implemented. This section highlights identified topical areas relevant to driving automation where driver training will likely be needed.

The implementation of driver-assistance technologies, such as adaptive cruise control, lane keeping assistance, or automatic emergency braking, may raise human factors concerns for which training can be an effective countermeasure. With these technologies, operators must understand how to engage, disengage, and interpret system functions and information. The introduction of these technologies can also present new situations and potential difficulties for operators. Training can also help to build trust in technology and establish a thorough understanding of the operational environment, as well as to establish an understanding of a technology’s limitations.

4.1.3. New Operational Positions

In addition to introducing new training needs for existing operational jobs, driving automation may also introduce new operational positions, such as remote supervisors or remote operators who may exercise control over a vehicle from another location. Any new jobs created by driving automation will also

¹⁵⁹ “Entry-Level Driver Training (ELDT),” Federal Motor Carrier Safety Administration, last modified March 6, 2019, <https://www.fmcsa.dot.gov/registration/commercial-drivers-license/eldt>.

¹⁶⁰ “Commercial Driver’s License Program,” Federal Motor Carrier Safety Administration, last modified February 7, 2018, <https://www.fmcsa.dot.gov/registration/commercial-drivers-license>.

¹⁶¹ U.S. GAO, *Automated Trucking*.

¹⁶² *Recommended Practice for Transit Bus Operator Training*, BTS-BO-RP-001-07 (Washington, DC: American Public Transportation Association, 2007); “Entry Level Truck Driver Training Standards,” Professional Truck Driver Institute, accessed April 2, 2019, <http://www.ptdi.org/Standards>.

introduce new training needs to ensure workers are equipped with the necessary skills and knowledge to safely perform job tasks in these new positions.

Many of the same training considerations identified above for in-vehicle operators will also likely apply to any remote operational positions. For example, training could include targeted situation awareness training to ensure remote operators are engaged, attentive, and prepared to manually operate a vehicle when necessary. Until these remote operator positions are realized, it is difficult to fully identify necessary training needs due to the uncertainty surrounding what these positions and the technologies that enable them will look like in reality. However, as the technology is developed and brought to market, training needs will be identified and documented for these positions.

4.1.4. Addressing Skill Gaps

How best to reskill workers and address these future training needs remains an open question. As these technologies are adopted and incorporated into vehicles, specific training needs will likely be identified and developed as the industry seeks to bring these technologies to market.

In the private sector, industry groups have already identified and started to address future training needs resulting from automation. For example, the Partnership for Transportation Innovation and Opportunity includes understanding training needs and delivery as part of its research agenda on automated vehicles. Truck industry representatives have also stated they anticipate the barriers to incorporating training for trucks with driving automation to be relatively low and that existing training and certifications can be adapted to new technologies. Public-private partnerships are also being formed to address training needs; for example, a community college in Arizona has partnered with a private automated long-haul trucking company to offer the first autonomous driving certificate program for truck drivers.¹⁶³ (As a Federal Government entity, U.S. DOT does not endorse or recommend these training programs; they are noted here for informational purposes only.)

Additionally, how existing training resources can best be utilized in light of driving automation may also need to be considered. For example, recent efforts have sought to catalog available training resources for transit operators so that transit agencies can more easily meet the needs of their operators and staff.¹⁶⁴ U.S. DOT-sponsored resources such as the Transportation Safety Institute, National Transit Institute, and National Rural Transit Assistance Program currently provide a number of training courses and resources that could play a role in establishing appropriate training for driving automation systems. U.S. DOT could also leverage resources from its Intelligent Transportation Systems Professional Capacity Building Program to inform future technology-focused training.¹⁶⁵ In partnership with community colleges and technical schools, this program has already undertaken efforts to develop workforce

¹⁶³ “TuSimple and Pima Community College Announce Details of First of its Kind ‘Autonomous Vehicle Driver and Operations Specialist’ Certificate Program,” *Pima Community College*, last modified June 13, 2019, <https://www.pima.edu/press-room/news-releases/2019/201906-tu-simple.html>.

¹⁶⁴ Janet Weisenford, et al., *Transit Technical Training, Volume 1: Guide to Applying Best Practices and Sharing Resources*, TCRP Research Report 199 (Washington, DC: The National Academies Press, 2018); Janet Weisenford, et al., *Transit Technical Training, Volume 2: Guide to Overcoming Barriers to Implementing Best and Innovative Training*, TCRP Research Report 199 (Washington, DC: The National Academies Press, 2018).

¹⁶⁵ “About the ITS Professional Capacity Building Program,” U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office, accessed April 2, 2019, https://www.pcb.its.dot.gov/pcb_role.aspx.

educational materials and equipment—including training materials—to prepare the future transportation workforce.

4.2. Retraining Resources

For Levels 4 or 5—in which the system drives the vehicle without the need for human supervision or intervention—the role of vehicle operator changes more significantly due to the elimination of the driving task. As a result of this fundamental change, job dislocation for operators can occur as these technologies are adopted in trucking and transit operations. Because the specifics of driving automation for trucking and the development timelines are unknown, it is unclear if job dislocation will occur, and, if it does, how many workers will be impacted. For example, potentially-impacted workers may be retiring when new technologies are introduced—depending upon the timeline of technology development and deployment—thus reducing dislocation effects.

In the event job dislocation does occur, retraining—that is, training and job support services to find reemployment in another field—will be a critical need to find new economic opportunities for impacted workers. Many of these workers, as discussed in the **Workforce Impacts** section of this report, are older in age, have modest educational attainment, and live in rural areas. As a result, these workers are more likely to live further away from job centers and have limited access to other employment opportunities. For these dislocated workers, targeted training can be particularly important for identifying and acquiring new skills and employment opportunities.

DOL currently provides funding for several employment service and retraining resources for dislocated workers at nearly 2,400 American Job Centers across the country. These resources available to dislocated workers are described below.

4.2.1. Workforce Innovation and Opportunity Act

The Workforce Innovation and Opportunity Act (WIOA) was signed into law on July 22, 2014, as the first legislative reform of the public workforce system in 16 years.¹⁶⁶ It is one of the primary pieces of legislation governing and guiding training programs offered by DOL. WIOA is designed to help job seekers access employment, education, training, and support services to succeed in the labor market and to match employers with the skilled workers they need to compete in the global economy. It brings together core programs of Federal investment in skill development—including employment and training services for dislocated workers.

WIOA Dislocated Worker Program

One key program authorized by WIOA is the Dislocated Worker Program.¹⁶⁷ This program provides formula grants to States for services to dislocated workers. Approximately 80 percent of dislocated worker funds are allotted by formula grants to States (which in turn allocate funds to local entities) to provide training and related services to qualified unemployed individuals. Each State's funding allotment is used to fund three categories of activities: statewide, rapid response, and local activities.

¹⁶⁶ "Overview, WIOA, Employment, & Training Administration," U.S. Department of Labor, <https://www.dol.gov/agencies/eta/wioa/>, accessed June 1, 2020.

¹⁶⁷ David H. Bradley, *The Workforce Innovation and Opportunity Act and the One-Stop Delivery System*, CRS Report R44252 (Washington, DC: Congressional Research Service, 2015).

To qualify as a dislocated worker under the WIOA Dislocated Worker Program, an individual must meet three requirements. The individual must (1) have been laid off from employment; (2) be sufficiently attached to the workforce (e.g., eligible for unemployment benefits); and (3) be unlikely to return to the occupation or industry from which the worker was laid off. Individuals are also considered eligible in cases of anticipated facility closings and for self-employed workers; however, the core eligibility requirement is dislocation due to employment termination or facility closing.

Services available under the WIOA Dislocated Worker Program include career services such as job search assistance, skill assessment, career planning, case management, as well as training (including occupational skills training and on-the-job training). These services are delivered at the local level to eligible workers through community colleges, American Job Centers—which are designated to be one-stop locations for dislocated workers to access and receive services—or other training facilities.

Rapid Response Activities

States are required to reserve not more than 25 percent of their WIOA grant funding to provide rapid response activities.¹⁶⁸ Rapid response activities are designed to help dislocated workers transition to new jobs and find reemployment as quickly as possible. Rapid response is a proactive, business-focused, and flexible strategy designed to respond to layoffs and plant closings by quickly coordinating services and providing immediate aid to companies and their affected workers. Typically, a dislocation event is defined as a permanent closure or mass layoff at a facility resulting in mass job dislocation. Disasters, natural or otherwise, can also qualify as a dislocation event eligible for rapid response funding.

Rapid response teams work with employers and any employee representative(s) to quickly maximize public and private resources to minimize disruptions associated with job loss. Rapid response can provide customized services on-site at an affected company, accommodate any work schedules, and assist companies and workers through the painful transitions associated with job loss. Customized services provided by rapid response teams can include:

- Providing information about and access to employment and training programs available through the WIOA Dislocated Worker Program.
- Assisting with the establishment of a labor-management agreement to determine employment and training needs of affected workers.
- Providing emergency assistance.
- Providing assistance to affected local communities in developing a coordinated response in seeking State economic development assistance.

National Dislocated Worker Grants

National Dislocated Worker Grants (formerly called National Emergency Grants) are discretionary grants awarded by the Secretary of Labor to States or entities that are affected by major economic dislocations, such as plant closures or mass layoffs.¹⁶⁹ These grants are funded by approximately 20 percent of dislocated worker funds reserved by DOL and are not distributed by formula to the States.

¹⁶⁸ Bradley, *WIOA and the One-Stop Delivery System*.

¹⁶⁹ “National Dislocated Worker Grants, Employment & Training Administration,” U.S. Department of Labor, <https://www.dol.gov/agencies/eta/dislocated-workers>, accessed June 1, 2020.

National Dislocated Worker Grants provide resources to States and other eligible applicants to respond to large, unexpected layoffs causing significant job losses. This funding is intended to temporarily expand capacity to serve dislocated workers—including military service members—and to meet the increased demand for WIOA employment and training services, aiming to reemploy laid off workers and enhance their employability and earnings. National Dislocated Worker Grants targeted at disasters provide funding to create temporary employment opportunities to assist with clean-up and recovery efforts. To qualify, an area impacted by a disaster is declared eligible for public assistance by the Federal Emergency Management Agency, or otherwise recognized by a Federal agency with authority or jurisdiction over Federal response to the emergency or disaster.

4.2.2. Worker Adjustment and Retraining Notification Act

The Worker Adjustment and Retraining Notification (WARN) Act does not authorize or mandate additional training resources, but it can impact dislocated workers.¹⁷⁰ Under the WARN Act, qualified employers who intend to carry out plant closings or mass layoffs must provide a 60-day notice to affected employees, States, and localities. This notice allows workers to seek alternative employment, arrange for retraining, and otherwise adjust to employment loss.

The purpose of notifying States and localities is to allow them to promptly provide services to the dislocated workers and otherwise prepare for changes in the local labor market. The WARN Act applies to employers with at least 100 or more employees (excluding part-time employees). Federal, State, and local government employers are not subject to the act. Broadly speaking, plant closings or layoffs that result in the loss of at least 50 employees at a single employment site are subject to the WARN Act provisions. After a company makes a WARN notification, a rapid response team (discussed above) may come on-site or otherwise work with impacted employees. However, because there is uncertainty about timing and scale of potential dislocation effects for the driving workforce, the WARN Act may or may not be applicable for these workers.

4.2.3. Trade Adjustment Assistance Program

Currently, DOL administers the Trade Adjustment Assistance (TAA) Program, which is designed to provide benefits to workers who are adversely affected by the impacts of increased imports or reduced hours or wages caused by shifts in production outside the United States.¹⁷¹ The program's benefits take the form of training, employment and case management services, job search allowances, relocation allowances, and income support in the form of Trade Readjustment Allowances. Reemployment Trade Adjustment Assistance and Alternative Trade Adjustment Assistance may also be available. These provide wage supplements for reemployed older workers whose reemployment resulted in lower wages than those earned in their trade-affected employment. Workers dislocated by driving automation may also be eligible for this program, depending upon the circumstances related to their dislocation.

¹⁷⁰ "Plant Closings & Layoffs," U.S. Department of Labor, accessed March 27, 2018, <https://www.dol.gov/general/topic/termination/plantclosings>.

¹⁷¹ "Trade Act, Employment & Training Administration," U.S. Department of Labor, accessed June 1, 2020, <https://www.dol.gov/agencies/eta/tradeact>.

4.3. Apprenticeships

Apprenticeships could offer another retraining pathway for dislocated workers. Apprenticeships are an employer-driven, “learn-while-you-earn” model. They combine on-the-job training, provided by the employer that hires the apprentice, with job-related instruction in curricula tied to the attainment of national skills standards.¹⁷² There are four components to typical apprenticeship programs. These include:

- **Business involvement.** Employers play an active role in building the program and remain involved along every step of the apprenticeship. Employers frequently work together via apprenticeship councils, industry associations, or other partnerships in order to share the administrative tasks involved with maintaining apprenticeship programs.
- **Structured on-the-job training.** Apprentices receive hands-on training from an experienced mentor at the job site. On-the-job training focuses on the skills and knowledge an apprentice must learn during the program to be fully proficient on the job. This training is based on national industry standards, customized to the needs of the employer.
- **Related instruction.** Apprenticeships combine on-the-job learning with instruction on technical and academic competencies applicable to the job. Education partners collaborate with businesses to develop the curriculum, which often incorporates established national-level skill standards. The related instruction may be provided by community colleges, technical schools, apprenticeship training schools, or by the business itself. It can be delivered at a school, online, or at the job site.
- **Nationally recognized credential.** Every graduate of an apprenticeship program receives a nationally recognized credential. This is a portable credential that signifies to employers that apprentices are fully qualified for the job.

The Department of Labor recognizes two types of apprenticeship: Registered Apprenticeship Programs (RAPs) and Industry-Recognized Apprenticeship Programs (IRAPs).¹⁷³

- Registered Apprenticeship is a proven model that has been validated by the U.S. Department of Labor or a State Apprenticeship Agency.
- Industry-Recognized Apprenticeship Programs are new, high-quality programs that are validated by third-party Standards Recognition Entities, also referred to as SREs. An SRE is a third-party entity, recognized by the Department as qualified to recognize apprenticeship programs as IRAPs. The types of entities that can become SREs include, but are not limited to:
 - Trade, industry, and employer groups or associations;
 - Companies and other corporate entities;
 - Educational institutions, such as universities or community colleges;
 - State and local government agencies or entities;
 - Non-profit organizations;
 - Unions;
 - Joint labor-management organizations;
 - Certification and accreditation bodies or entities for a profession or industry; or

¹⁷² U.S. Department of Labor, accessed April 3, 2019, <https://www.apprenticeship.gov/>.

¹⁷³ “Registered Apprenticeship Program,” U.S. Department of Labor, accessed April 3, 2019, <https://www.apprenticeship.gov/employers/industry-recognized-apprenticeship-program>.

- A consortium or partnership of entities such as those above.

4.4. Effectiveness of Retraining Resources

Evaluations of job training and retraining strategies and programs have identified key elements that make these strategies and programs successful and effective. A 2014 synthesis of available evidence on job training identified six key findings on what works for job training for adults:¹⁷⁴

- **A degree or credential.** The most important determinant of a worker's lifetime earnings is the possession of a degree or industry-recognized credential related to in-demand jobs.
- **Flexibility and innovation.** Evidence suggests that approaches such as contextual learning and bridge programs have promise to deliver effective outcomes for adults.
- **Close connections to an occupation.** The more closely related a training program is to a specific job or occupation, the better the outcomes for training participants will be.
- **Alignment with employer needs.** When training programs are developed in coordination with employers to align with their needs, training outcomes are better for workers.
- **Readily available information.** When potential training participants have access to labor market data and receive guidance about career and training opportunities, individuals can make better decisions about training opportunities, which leads to better outcomes.
- **Coordinated strategies across systems.** For lower-skilled individuals and those experiencing multiple barriers to employment, coordination across systems they interface with can lead to better outcomes in training and employment.

A recent Council of Economic Advisers report concluded that most government training programs are not effective at securing higher-paying jobs for program participants.¹⁷⁵ However, the report found mixed results concerning the effectiveness of WIOA programs. Evidence reviewed in the report suggests there is not a significant effect on earnings for training through the WIOA Dislocated Worker Program; however, training through the WIOA Adult Program may produce a small positive effect on earnings. The report also noted that evidence showed that intensive services, like career services and skill assessments, offered under the WIOA Dislocated Worker Program, had a positive effect on reducing length of unemployment—a primary goal of the program. The report also found that evaluations of the TAA program suggest there may be positive, but small, returns to training in terms of employment and earnings. Additionally, evaluations reviewed in the report occurred prior to changes to training programs implemented with the passage of WIOA in 2014.¹⁷⁶

Another evaluation study found that, among older individuals, those who used the WIOA Dislocated Worker Program to obtain a credential such as an occupational license were more likely to be employed and experienced lower wage losses than individuals who did not obtain a credential.¹⁷⁷ Notably, however, consistent with other research, these workers still had lower earnings after retraining than

¹⁷⁴ "What Works in Job Training: A Synthesis of the Evidence," U.S. Department of Labor, July 22, 2014, <https://www.dol.gov/asp/evaluation/jdt/jdt.pdf>.

¹⁷⁵ *Government Employment and Training Programs: Assessing the Evidence and their Performance* (Washington, DC: Council of Economic Advisers, 2019).

¹⁷⁶ Kenneth Fortson et al., *Providing Public Workforce Services to Job Seekers: 30-month Impact Findings on the WIA Adult and Dislocated Worker Programs* (Washington, DC: Mathematica Policy Research, 2017).

¹⁷⁷ Phyllis A. Cummins, "Credential Attainment by Older Workers: The Role of Community Colleges and the Dislocated Worker Program in Successful Employment Outcomes," (PhD diss., Miami University, 2013).

they did prior to dislocation. Given that the driving workforce skews older and has less formal education than the workforce at large, this finding suggests training programs resulting in an industry-recognized credential may be of particular use and importance if drivers experience dislocation as a result of driving automation, though these workers may still experience a reduction in wages even with retraining and credentialing.

Research has found that individuals who completed apprenticeship programs had higher employment rates and higher average annual earnings than similar individuals who were eligible for apprenticeship programs but did not participate.¹⁷⁸ A review of apprenticeship programs internationally found they tend to have a positive effect on employment and can increase wages.¹⁷⁹ Though evidence on apprenticeship programs in the United States is limited, the close linkage between training and employer and the direct relationship of an apprenticeship to a specific job suggest that apprenticeship programs could be appropriate and effective if drivers experience dislocation.

4.5. Summary

The introduction of new technologies into long-haul trucks and transit buses may lead to truck drivers and bus operators needing to develop new skills to safely and effectively operate vehicles equipped with driving automation technologies at Levels 0-3. Technologies at Levels 4 or 5 could result in reduced demand for truck drivers and bus operators. If this occurs, retraining programs that enable dislocated workers to develop new knowledge and skills are expected to be an important resource for workers to find reemployment opportunities in other industries.

- Training and retraining impacts for drivers will vary based on the type of driving automation adopted.
- Existing driver training programs will likely need to begin incorporating driver education on how and when to use driving automation systems and other relevant human factors concerns.
- If drivers experience dislocation as a result of driving automation adoption, workers will be eligible for retraining and other career services through existing WIOA programs and TAA.
- The driving workforce is older, has less formal education, and is more likely to live in rural areas. Evidence suggests that if these workers experience dislocation from the industry, they will be likely to face challenges in matching their existing wages in other industries.

5. Conclusion

This report has provided a preliminary analysis of the potential impacts of driving automation on two segments of the professional driving workforce in the United States. The adoption of driving automation will change professional driving jobs in diverse ways, including job responsibilities, wages, and quality of life. As noted throughout, this analysis is based primarily on existing research, and there are considerable uncertainties at this point in the technology's development. Accurate, up-to-date data are also not fully available. The specific ways in which these jobs will change may vary significantly across

¹⁷⁸ Debbie Reed et al., *An Effectiveness Assessment and Cost-Benefit Analysis of Registered Apprenticeship in 10 States* (Oakland, CA: Mathematica Policy Research, 2012).

¹⁷⁹ *Evidence Review 8: Apprenticeships* (London, UK: What Works Centre for Local Economic Growth, 2015), https://whatworksgrowth.org/public/files/Policy_Reviews/15-09-04_Apprenticeships_Review.pdf.

market segments and operating environments and will be influenced by contemporaneous changes in related industries.

In the near-term, increased adoption of Level 1, 2, and 3 driving automation systems is unlikely to bring about driver job displacement; Level 1 and 2 systems may also lead to improvements in safety and operations. In the long term, the adoption of Levels 4 and 5 ADS may supplant certain driving tasks and reduce the need for human drivers, leading to lower freight costs and productivity improvements, but also to periods of transitional unemployment for some affected workers. If workers experience displacement as a result of automation adoption, DOL offers existing programs that have a strong track record of helping workers adapt to new technologies and market conditions.

As technologies mature and business models are better understood, reexamination of this topic will provide valuable insight into the impacts of driving automation on the Nation's transportation workforce.

Appendix: Driving Automation Research, Development, and Commercialization Activity in the Commercial Motor Vehicle and Transit Bus Industries

This appendix provides a brief overview of known research, development, and commercialization activity in the commercial vehicle and transit bus sectors as of early 2019. It is not intended to be comprehensive or to suggest U.S. DOT endorsement of any activity, but rather to give context for the analysis used in this report.

Automated Commercial Trucks

Companies Involved

Many companies have publicly announced efforts to develop and test commercial motor vehicles with driving automation, including investment from traditional truck manufacturers and suppliers, as well as technology companies, start-ups, and venture capital firms.¹⁸⁰

Automation Level

While approaches vary, most companies active in this space are working toward development of Level 4 systems. The level of automation may vary depending on the stage of the trip (e.g., highways, local roads, or private facilities). Some companies are exploring platooning concepts where there would be a lead truck with little or no driving automation and a following truck that uses automation to maintain a set following distance behind the lead vehicle. For example, Peloton has tested platoons with following trucks with SAE Level 1 automation, and both Peloton and Locomotion are working to develop platoons that would use following trucks with SAE Level 4 automation.¹⁸¹

Operational Design Domain

Testing of trucks with ADAS and ADS is primarily taking place on highways, after successful completion of testing on closed tracks. In many cases, onboard operators are used to manually operate trucks during the beginning and end of a trip, though some companies have used driving automation to operate in closed environments, such as truck yards and warehouse facilities.¹⁸²

Operator Roles

Concepts in development use a range of strategies in terms of operator roles. While most testing has included an engaged operator in the vehicle cab sitting in the driver's seat, some tests have included an

¹⁸⁰ S. Clevenger, "TMC Takes Stock of Latest Developments in Automated Driving, Platooning," *Transport Topics*, March 20, 2019, <https://www.ttnews.com/articles/tmc-takes-stock-latest-developments-automated-driving-platooning>; Aarian Marshall, "The DOT Says 'Drivers' Don't Have to Be Human," *Wired*, October 4, 2018, <https://www.wired.com/story/dot-says-drivers-dont-have-to-be-human/>.

¹⁸¹ Peloton, "Peloton Announces its Vision for the Trucking Industry: Drivers Lead, and Technology Follows," *PR Newswire*, July 17, 2019, <https://www.prnewswire.com/news-releases/peloton-announces-its-vision-for-the-trucking-industry-drivers-lead-and-technology-follows-300886373.html>; Locomotion, "Paving the Way to Autonomy," *Medium*, March 27, 2019, <https://medium.com/@locomotionai/https-medium-com-locomotionai-paving-the-way-to-autonomy-97ef4e06dc59>.

¹⁸² Darrell Etherington, "Starsky Robotics' autonomous transport trucks also give drivers remote control," *TechCrunch*, February 28, 2017, <https://techcrunch.com/2017/02/28/starsky-robotics-autonomous-transport-trucks-also-give-drivers-remote-control/>.

operator in the cab but out of the driver's seat, and some tests do not include an operator in the cab at all. Some tests have also made use of remote monitoring or teleoperation.¹⁸³

Revenue Operations

Some companies are already using trucks with ADS and ADAS in pilots that include deliveries to customers. By the end of February 2017, Starsky had made a delivery on a 140-mile route, completing 85 percent of the journey in automated mode.¹⁸⁴ Beginning in October 2017, Embark began a pilot transporting Frigidaire refrigerators between California and Arizona, operating its trucks as an SAE Level 2 system.¹⁸⁵ In March 2018, Waymo announced that it would launch a pilot in Atlanta, Georgia that would use its trucks to transport freight to Google data centers.¹⁸⁶ In January 2019, TuSimple announced that it had 12 customers who were receiving deliveries from its trucks and that it was making three to five deliveries in Arizona each day.¹⁸⁷ Starting in May 2019, TuSimple began delivery pilots for both the U.S. Postal Service and United Parcel Service (UPS).¹⁸⁸ In August 2019, Kodiak Robotics announced that it was making deliveries to customers in Texas,¹⁸⁹ and that same month, Starsky Robotics partnered with the digital broker Loadsmart to demonstrate automated dispatch and delivery of a shipment.¹⁹⁰

Automated Transit Buses

Companies Involved

Driving automation for transit buses is at a relatively nascent state, though transit bus manufacturers, such as New Flyer and Proterra are engaging in research activities related to driving automation.¹⁹¹

¹⁸³ "Starsky Robotics – Voluntary Safety Self-Assessment," Starsky Robotics, December 19, 2018, https://uploads-ssl.webflow.com/599d39e79f59ae00017e2107/5c1be1791a7332594e0ff28b_Voluntary%20Safety%20Self-Assessment_Starsky%20Robotics.pdf.

¹⁸⁴ Etherington, "Starsky Robotics' autonomous transport trucks also give drivers remote control."

¹⁸⁵ "Embark, Frigidaire®, and Ryder Partner to Pilot Automated Driving Technology," Press Release, *BusinessWire*, last modified November 13, 2017, <https://www.businesswire.com/news/home/20171112005077/en/Embark-Frigidaire%C2%AE-Ryder-Partner-Pilot-Automated-Driving>.

¹⁸⁶ Waymo Team, "Same driver, different vehicle: Bringing Waymo self-driving technology to trucks," *Medium*, last modified March 9, 2018, <https://medium.com/waymo/same-driver-different-vehicle-bringing-waymo-self-driving-technology-to-trucks-e55824b55b8f>.

¹⁸⁷ "TuSimple, Leading Fully-autonomous Truck Company, Announces Business Expansion with New Self-driving Routes, Customer Growth and Partners," Press Release, *TuSimple*, last modified January 7, 2019, <https://www.tusimple.com/wp-content/uploads/2019/02/TuSimple-CES-Press-Release-2019.pdf>.

¹⁸⁸ S. O'Kane, "UPS has been quietly delivering cargo using self-driving trucks," *The Verge*, August 15, 2019, <https://www.theverge.com/2019/8/15/20805994/ups-self-driving-trucks-autonomous-delivery-tusimple>.

¹⁸⁹ "Self-Driving Truck Startup Kodiak Robotics Expands Into Texas and Begins First Freight Deliveries," Press Release, *Kodiak Robotics*, August 6, 2019, <https://www.prnewswire.com/news-releases/self-driving-truck-startup-kodiak-robotics-expands-into-texas-and-begins-first-freight-deliveries-300897021.html>.

¹⁹⁰ "Loadsmart completes first-ever automated dispatch and delivery with Starsky Robotics' autonomous truck," Press Release, *Loadsmart*, August 8, 2019, <https://www.prnewswire.com/news-releases/loadsmart-completes-first-ever-automated-dispatch-and-delivery-with-starsky-robotics-autonomous-truck-300898381.html>.

¹⁹¹ "New Flyer Announces Official Opening of the Vehicle Innovation Center set for October 12, 2017: North America's First Innovation Lab for Bus and Coach Technology," Press Release, *New Flyer*, October 10, 2017, <https://www.newflyer.com/2017/10/new-flyer-announces-official-opening-vehicle-innovation-center-set-october-12-2017-north-americas-first-innovation-lab-bus-coach-technology/>; "Emphasizing Safe, Intelligent Transportation, Proterra Begins First Autonomous Bus Program in the United States," Press Release, *Proterra*, May 2, 2017,

Some suppliers and technology firms are developing products that could be transferred from other vehicle types to transit buses, but many challenges remain.¹⁹² There are many companies developing and testing smaller automated shuttles.¹⁹³ Many automated shuttle pilots and demonstrations are being conducted across the United States and around the world.

Automation Level

Transit bus automation research to date has focused on applications that use driver assistance and Level 1 automation, such as lane centering, precision docking, and automatic emergency braking.¹⁹⁴ Some longer-term projects are considering Level 4 or 5 driving automation—in particular international projects, such as Volvo’s work in Sweden and Singapore.¹⁹⁵

Operational Design Domain

Testing of transit buses with driving automation has included both closed course and open road operations. In some cases, testing has occurred in dedicated lanes. Automated shuttles have been tested in a range of operating environments, ranging from closed test facilities to public roads in mixed traffic. Some pilots have included signalized and unsignalized intersections.

Operator Roles

All transit bus testing to date has included an onboard operator in the driver’s seat, and nearly all automated shuttle testing has included an onboard operator who is able to take control of the vehicle in the event of an emergency or system failure. In January 2019, EasyMile announced that it was operating its first shuttle without an onboard operator in France; the shuttle is monitored and can be controlled by a remote operator.¹⁹⁶

Revenue Operations

Some transit bus pilots have provided revenue service. Some automated shuttle pilots have provided rides to the general public over the course of a year or longer, but these pilots typically do not collect fares.

<https://www.proterra.com/press-release/emphasizing-safe-intelligent-transportation-proterra-begins-first-autonomous-bus-program-in-the-united-states/>.

¹⁹² FTA, *Transit Bus Automation Project: Transferability of Automation Technologies Final Report*.

¹⁹³ Cregger, *Low-Speed Automated Shuttles*.

¹⁹⁴ Gregg and Pessaro, *VAA Demonstration Evaluation Report; “Fiscal Year 2016 SRD Program Grant Selections,”* FTA, last modified January 2017, <https://www.transit.dot.gov/research-innovation/fiscal-year-2016-srd-program-grant-selections>.

¹⁹⁵ Linda Poon, “Reno’s Road to the Future of Autonomous Buses,” *CityLab*, May 2, 2017, <https://www.citylab.com/transportation/2017/05/proterra-eyes-the-future-of-autonomous-buses/524937/>; “Volvo Demonstrates Autonomous Bus,” Press Release, *Volvo*, June 18, 2018, <https://www.volvogroup.com/en-en/news/2018/jun/volvo-demonstrates-autonomous-bus.html>; “Joint News Release by the Land Transport Authority (LTA) & NTU - On the Road to a More Sustainable and Reliable Transport System,” *Land Transport Authority*, October 19, 2016, <https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=2bc42aac-6b74-4e58-bca3-e2e819c66d20>.

¹⁹⁶ “Another Milestone for EasyMile: The First Fully Driverless Service,” Press Release, *EasyMile*, January 8, 2019, <https://easymile.com/another-milestone-for-easymile-the-first-fully-driverless-service-of-our-ez10-driverless-shuttle/>.

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