Jobs and Automated Freight Transportation: How Automation Affects the Freight Industry and What to Do About It

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A White Paper from the National Center for Sustainable Transportation

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16. Abstract

The expansion of automation in the U.S. economy is increasingly tangible and will presumably entail positive and negative impacts that are not yet well understood. In the freight sector, there is uncertainty about how and when automation will impact labor. Beyond this, there are further unknowns about what the impacts will be on such freight subsectors as warehousing, long- and short-haul. It is expected that penetration rates of freight automation will vary across subsectors. In some subsectors, new jobs will be created and/or working conditions will improve. Other subsectors will see declining job quality and/or job losses that require workers to transition to new roles or sectors entirely, when possible. Changes in job opportunities and quality will vary within sectors and subsectors, by region, and/or by firm. This study offers an overview and recommendations in three directions. First, despite the uncertainties and based on past and present examples of automation, it provides some insights about strategies that may help impacted workers within and outside of the heavy freight sector transition. Second, it discusses examples of existing public policies that can support a transition for automation-impacted workers. And third, it provides insights on how different freight subsectors are likely to be impacted by automation.

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Glossary

ADAS	advanced driver-assistance system
ADS	Automated driving system
AFL-CIO	American Federation of Labor and Congress of Industrial Organizations
AMR	autonomous mobile robot
ATA	American Trucking Association
AV	automated vehicle
DOL	Department of Labor
DOT	Department of Transportation
FTA	Federal Transit Administration
PIV	power industrial vehicle
SAE	Society of Automotive Engineers
USPS	United States Postal Service
WARN	Worker Adjustment and Retraining Notification
WIOA	Workforce Innovation and Opportunity Act

Executive Summary

This study conducted a general review of the potential impacts of automated technologies in the freight sector, with a particular emphasis on driving occupations. A key initial finding is that significant uncertainty remains about the developmental state of these technologies, their adoption trends, and use. Overall, whether in the short- or medium-to-long–term, these technologies will lead to changes in current occupations. These changes can result in a range of impacts, from positive effects in the improvement of safety, security, quality of jobs, and quality of life, and the generation of new and better jobs, to negative effects where entire occupations disappear. Moreover, whatever the change is, training efforts, transition programs, and other support systems for affected workers will be required to mitigate the impact on those negatively affected and maximize the opportunities for the segment of the labor force that can benefit from the new opportunities. In addition, achieving mass adoption and implementation of vehicles with automation levels 4 or 5 (as defined by the Society of Automotive Engineers, Figure 5), in which vehicles will drive themselves with no driver intervention, will take time, and the gradual nature of the disruption can provide opportunities to adapt.

In summary, with respect to driving jobs, this work, consistent with other studies finds that several factors are expected to mitigate the impacts in the trucking and transit industries:

- **Job displacement might be mitigated by attrition in the freight industry.** There is still uncertainty about when, where, and whether job displacement will occur in the freight industry. Considering that truck drivers, for example, have an older profile compared to other occupations, with about 25% older than 55 years of age (US Census Bureau, 2019), it is possible that retirements could happen before the technology implementation, and the gradual adoption could be an opportunity to prepare and train the next labor force. The industry would have to adapt to the changes, and training can be in the form of providing new skills or otherwise facilitating the transition to additional occupations. Additionally, for some directly affected workers, there may not be related opportunities, and training might not be valuable if the quality of remaining/emergent jobs decline. In the short-term, levels 1 and 2 driving automation are not expected to cause driver displacement. (Levels 1 and 2 assist an active driver in steering and/or braking and acceleration). At the same time, it is important to consider the current needs of drivers in the industry and how strategies to boost employment could attract a new generation of drivers who could be negatively affected in the medium to long term.

- **There is potential for new job development.** The new technologies disrupting the trucking sector may enable the creation of new jobs and occupations across the transportation, business, and logistics industries. While these new jobs can offer opportunities for transitioning for new employees, they may not be accessible to current workers, and there is no guarantee that they will be high-quality high-paying jobs.

- **Limited retraining programs are available through the Department of Labor (DOL) and state partners.** These programs are insufficient to meet the needs of all types of freight workers. While this is not the first time that new technologies have disrupted industries and affected the job market, and there are a number of established policies and programs that can help support dislocated workers. These programs must be updated to account for changes in technology, consider the capabilities for training and transitioning, overcome current access limitations to the programs, and increase capacities to support a potentially large affected labor-force if the more optimistic scenarios do not materialize.

In addition to looking at driving jobs, this study focused on the impacts of automation in the warehousing subsector, where automation has already started. The warehouse sector predicts that in the short-term, there will not be major job losses, but instead a change in the quality of the available jobs. One reason for this prediction is that the sector works with small profit margins and high volatility, leading to a risk-averse strategy and caution with respect to the adoption of new technologies. The sector has so far been slow in the uptake of new technologies, and this is predicted to continue, and, with the increasing demand for e-commerce, aggregate employment levels will continue to rise. Nevertheless, these increases in employment may be reduced by the increasing use of labor-saving technologies, and in the long term, the increased use of technology is predicted to lead to a reduction in labor. There are contrasting views on the matter, with the sector pointing to safety and productivity improvements due to automation but workers' organizations pointing to decreasing job quality. If one of the case studies discussed in this work is an indication, online retailers have been able to improve efficiencies through automation, practically reducing by more than 90% the human labor required for every dollar sold, but at the same time, this increased efficiency has provided the sector the opportunity for incredible growth, resulting in a significant net increase in human labor. It is worth mentioning that even though automation can improve safety and working conditions, the efficiency of automated systems, especially for repetitive simple tasks, could lead companies to increasingly monitor workers efficiency rates, and manage and target them. And as automation can reduce costs, wages would be affected.

These issues, especially job quality, urgently need to be addressed by policy and other instruments. Other important aspects relate to the management of the distribution of costs and benefits accrued due to the adoption of new technologies. Similarly, changes brought by automation can have a physical and psychological impacts on workers that must be determined, so at to mitigate their negative effects. Finally, policy makers, worker organizations, philanthropy, employers, and other entities should work together to identify how new job opportunities can be provided for displaced workers, such as through further training, or transition paths. The introduction of technology is neither good nor bad, but the ways in which it is implemented will have major consequences for the workers in the warehouse industry.

Overall, there are positives and negatives associated with the use of automated technologies in the freight industry with varying effects on jobs. Looking ahead, it is important to consider policies and take action to aid workers impacted by automation. For example:

Key recommended policy strategies for further investigation:

- **Bring everyone to the table.** California's Future of Work Commission brought labor and industry to the table. This approach is quite commonplace, and the DOL and other states commonly bring stakeholders from labor, industry, advocacy, and government together to discuss labor issues and strategize how to meet the needs of a diverse set of stakeholders. Other initiatives include the High Road Transition Collaboratives under the Community Economic Resilience Fund and the High Road Training Partnerships. These more innovative efforts focus on fostering solutions that can leverage technological advancements that will result in shared economic prosperity and social good. All these types of big-picture and long-term solutions will take experimentation and iteration to be successful, and key stakeholders need to be engaged up-front in designing the solutions. Engagement processes like these can leverage the experiences, expertise, and perspectives of worker and industry perspectives, especially those that could be directly impacted, either positively or negatively, by the new technologies. Engagement should be a dynamic process of partnership-building and investments and not a one-time effort.
- **Leverage current and partial automation technologies to improve worker safety.** Automation looks different in different contexts. Autonomous tuggers and autonomous pallet jacks can remove physical burdens from warehousing workers and make workers less susceptible to injury. Similarly, level 1-2 vehicle automation offers safety benefits that protect drivers from preventable accidents, e.g., monitoring fatigue and providing emergency braking. It's possible some workers will benefit from these technologies and others will not. It is up to regulators to serve as arbiters, weigh tradeoffs, and listen to perspectives to encourage adoption where benefits for workers might be apparent.
- **Expand and target existing workforce social safety nets and make sure they are effective.** Programs like the Workforce Innovation and Opportunity Act (WIOA) Dislocated Worker Program work for only a limited number of workers who meet the strict criteria for participation. WIOA cannot help the many workers in smaller firms, or those that are not classified as employees and operate as independent contractors. It cannot help the many workers who are not granted full-time status despite ability and interest to work full-time. If policy makers want to strengthen the social safety net, strategies and policies must strive to recognize the gaps in the existing system and identify how the future workforce does not look like the one in the 20th century, and what new strategies would ensure a high-road jobs future. The authors recognize that it will take considerable resources to leverage the type of social safety net program that fills these gaps, and assessing these costs is beyond the scope of this research. However, it will be essential for policy makers to consider undertaking data-driven strategies that can inform targets on which workers are most at-risk and develop programs to meet the specific needs of those workers.
- **Expand job training efforts.** A core part of future-proofing the workforce is establishing a pipeline for local workers to capture the value of emerging technologies. Certainly, this is a complex task, for several reasons. First, it remains a challenge to direct public

resources towards specific job-training efforts, and industry training partnerships rather than discrete educational programs can be more effective and adaptive to the real needs of workers. Second, the specific skills that must be developed are not yet clear, considering many of the technologies are still in the development phase, and there is uncertainty about technology limitations. And third, it is still uncertain whether and/or when large displacements of workers will occur (i.e., when, where, and how the new technologies will be introduced, whether this implementation will happen within the current generation of workers, or when they retire). How this unfolds will determine the type of training efforts needed for future workforce needs, hence it is necessary to begin documenting technology progress to anticipate training programs, and more importantly, to recognize that some displaced workers may not seek placements within the freight industry, despite the availability of training programs.

- **Foster and incentivize the use of improvement technologies.** Efforts should be made to incentivize the private sector to invest, implement, and use new technologies that can improve the safety and efficiency of jobs, vehicles, and infrastructure, as well as the safety, efficiency, and quality of jobs and the lives of employees and other road users.

1. Introduction

The automated vehicle (AV) industry envisions a future where vehicles for goods movement and those for travel can be beckoned with a touch to a cell phone, allowing passengers to work, play, or relax while they order goods or travel. This future is rapidly unfolding (although more slowly than initially scoped by technology optimists) and commercial AV taxi service is currently operating in many cities in the U.S. and other countries. Today, mobile robots resembling a cooler on wheels can be summoned to bring hot meals to curbsides. These types of robots and other automated devices have been part of the labor force in factories, warehouses, and distribution centers worldwide for some time. However, due to several barriers (Jaller et al., 2020), the mass adoption and use of driverless heavy-duty trucks may still be some years away, except for in controlled environments such as ports, large factories, or logistics centers. Several companies have received permits to operate their automated truck technologies in regions of the U.S. and have made agreements with shippers to transport their cargoes. Internationally, companies have been moving logs in forests and pallets at industrial facilities (Enride Press, 2020) with autonomous vehicles. In all these cases, driverless technology is helping to improve efficiency, competitiveness, and/or profitability. Still, considerably more testing is necessary to assess safety outcomes under rare circumstances or edge cases, to validate the safety, and to quantify other benefits AV technologies have shown in various limited-use cases.

Automated vehicle and equipment technologies for freight come in various forms, from the small delivery robots previously mentioned to large heavy-duty trucks and cargo movers. Without loss of generality, we refer to these technologies in this paper as autonomous mobile robots (AMRs), despite the term's association with small devices that operate off-road (e.g., inside, curbside). Overall, AMRs are machines and equipment that:

- Move between points without direct human guidance (although some technologies rely on remote operators or teleoperation for guidance);
- Can handle freight in different forms;
- Gather information from their physical environment through sensors; and
- Can communicate with the environment and other devices.

The first versions of AMR technologies were developed in the 1950s (e.g., the guide-o-matic tow vehicle). While the technologies have improved significantly, their shapes and forms are very similar to the incumbent technologies (e.g., automated tuggers, pallet jacks). Today, there is a plethora of AMRs for inside environments, performing multiple functions in warehouses, distribution centers, and manufacturing, and even bringing food to people at their hotel rooms or tables at a restaurant. AMRs have also been developed for applications such as facility surveillance, and the transport of containers in a yard. For large AMRs, different companies have been instrumenting vehicles such as heavy-duty trucks to allow for driverless capabilities, and others are rethinking the concept of trucks to have equipment that can move containers and other cargo over the road, without a cabin, looking more like an automated chassis.

Some AMR technologies can fully automate a freight-related operation (e.g., picking, packing, labelling), while others are supporting technologies for human-led activities (e.g., carrying parcels along delivery routes) or for partially replacing a freight activity such as driving a freight vehicle. These vehicles may still require human interaction for the handling of the products at the origin or destination. Therefore, the labor impacts from these technologies are diverse, and while some have a direct impact on the labor requirements for the purpose of the freight activity, some may also generate new labor requirements for supervision, maintenance, and management, among others. While these technologies will bring about other job needs for their development, manufacturing and research, this paper will concentrate on the labor impacts with respect to the effects on freight-related activities. There is considerable uncertainty in the freight sector about how and when automation will impact labor. On the positive side, automation could create new jobs and improve working conditions, but in the absence of public policy interventions, some subsectors could see declining job quality and job losses that may require workers to transition to new roles or sectors entirely. Thus, the objective of this paper is to explore the potential impacts on freight of automated technologies and provide insights on: (i) strategies to help impacted workers within the freight sector transition based on past and present examples of automation; (ii) how public policy can support a transition for automation-impacted workers; and (iii) how different freight subsectors are likely to be impacted by automation.

The structure of this paper is as follows, Section 2 provides an overview of the workforce in the freight transportation and warehouse subsectors. Section 3 provides a description of several use cases of automation in the freight sector; and Section 4 concentrates on the current regulatory environment and the various labor policies. Section 5 discusses the potential labor displacement in these sub-sectors. Section 6 summarizes the key insights from the analyses, discusses some policy recommendations and other efforts to mitigate the potential impacts of labor displacement, and ends with final remarks.

2. Overview of workforce in the freight transportation and warehousing subsectors

In the U.S., many freight-related occupations include, as a primary responsibility, the handling of goods or the driving of motor vehicles. Table 1 summarizes information available about handling/moving materials occupations, and Table 2 concentrates on driving jobs, including the projected change for 2030, median annual wages, and a brief description of each job. The COVID-19 pandemic has significantly impacted the freight sector, and the data and projections may not reflect the long-term effects in the industry. Furthermore, employment counts are a limited metric, and only a starting point in the conversation about how to steer changes in the labor market, and wages and job quality are also important to consider.

Table 1. Moving or tracking materials, primary warehousing jobs in 2020 in the U.S. Source: "Occupational Employment Statistics," from US Bureau of labor statistics (2022)

Occupation	Employment 2020	Change 2020-2030	Median annual wage	Job description
Hand laborers and material movers	6,215,000	7%	$30,010	Feed or remove material to or from machines, clean vehicles, pick up unwanted household goods, and pack materials for moving.
Cleaners of vehicles and equipment	367,200	9%	$27,640	Wash automobiles and other vehicles, as well as storage tanks, pipelines, and related machinery.
Hand laborers and freight, stock, and material movers	2,821,700	9%	$31,120	Move materials to and from storage and production areas, loading docks, delivery trucks, ships, and containers.
Machine feeders and off bearers	63,000	6%	$33,000	Process materials by feeding them into equipment or by removing them from equipment.
Hand packers and packagers	599,700	0%	$28,050	Package a variety of materials by hand possibly including labeling cartons, inspecting items for defects, and keeping records of items packed.
Stockers and order fillers	2,223,000	4%	$29,190	Receive, unpack, and track merchandise. Stock clerks move products from a warehouse to store shelves. They keep a record of items that enter or leave the stockroom and inspect for damaged goods.
Refuse and recyclable material collectors	140,500	12%	$39,100	Gather garbage and recyclables from homes and businesses to transport to a dump, landfill, or recycling center. Many collectors lift garbage cans by hand and empty them into their truck.
Total Subsector	12,430,100			

It is important to mention that owner operators, which can represent a significant percent of the carrier companies may not be represented in these figures. Similarly, additional workers associated with the truck activities are not included, for example, workers in trucking are critical but captured outside of this table (see Table 2 below). Handling/moving materials occupations typically include those that deal with loading, unloading, picking, packing, unpacking, sorting, and cleaning materials in warehouses; driving jobs are related to operating trucks, buses, and taxis, and may also include delivery and sales functions. In 2020, there were approximately 145 million people employed in the U.S according to the Bureau of Labor Statistics (BLS). Approximately 12.4 and 4.6 million of those were occupied in handling materials and driving motor vehicles, respectively.

Table 2. Operating vehicles, primary freight driving jobs in 2020. Source: "Occupational Employment Statistics," from US Bureau of labor statistics (2022)

Occupation	Population size	Median annual wage	Job description
Heavy and tractor- trailer truck driver	1,951,600	$47,130	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 driver	1,035,800	$37,050	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 them. May load and unload vehicle.
Delivery truck drivers and /sales workers	458,200	$34,340	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 truck driver	150,000	Not available	Self-employed heavy truck and tractor-trailer drivers.
Other motor vehicle operator	1,306,990	Not available	Transit, intercity, ambulance, bus, school bus, special client, taxis, and others
Total Subsector	4,902,590		N/A

*Figures extracted from US Government Accountability Office (2019). There may be classification issues.

As automation typically focuses on repetitive activities, some of the occupations in Table 1 and Table 2 may be susceptible to displacement, should machines such as AMRs be able to perform part of or all the work, which represents one of the main topics of discussion in this study. Although certain technologies have the potential to displace human workers when the technology goes beyond satisfying the slack in the labor market, some industries have been struggling to find workers to fill certain positions (in many cases because inadequate working conditions and low pay). For instance, the trucking industry is currently lacking a significant number of drivers, and projections indicate that this situation may worsen, as discussed in Section 5.

3. Examples of freight automation

This section illustrates historical and current cases of automation, concentrating on how automation can impact job quality. Additionally, the section discusses opportunities that have been identified to help the transition and/or compensation of automation-impacted workers.

Containers and longshoremen

Containerization is a classic example of how a new technology displaced workers in the longshoremen occupation. Containerization is interesting because it negatively affected the jobs in this particular industry, but generated gains in others. For example, in the 1950s, ports such as New York and London required a large number of workers to manually handle packages, barrels, crates and bags (Rodrigue, 2020). The introduction of containers enabled these facilities to see significant efficiencies, reducing labor needed to process the cargo, reducing the time vessels were at the ports, and enabling a higher throughput (Monaco, Kristen; Olsson, 2015). In the early 1960s, due to containerization, productivity at U.S. West Coast ports increased 34 percent for a labor cost savings of nearly 7.5 million work hours (Sharpsteen, 2011). In over just a few decades, the number of longshoremen at the ports of New York and New Jersey decreased from about 50,000 to 35,000 (Rodrigue, 2020). Additional factors increased the number of displaced longshoremen (Levinson, 2016), though Gomtsyan (2016) indicates that the benefits to other industries due to containers helped reduced unemployment in those cities affected. This highlights the need to consider the implications of job offsets and net gains or losses in the labor market. While some technologies can result in net gains across industries and sectors, policy makers should avoid focusing on sector-wide net gains alone, because it excludes disruptions in a particular sector, a particular community, or in the lives of affected workers.

The role of automation in retail efficiency

There are several examples of companies using automation at their facilities, but changes in retail and distribution practices have prompted companies to increasingly adopt new automated warehouse and distribution technologies. These technologies have transformed some key activities such as picking, reducing workers physical efforts, and improving productivity. These changes and others have favorably impacted some workers but may create challenges for others.

Amongst the companies implementing these technologies, Amazon has made significant investments in robotics (Guizzo, 2012). Achieving the company’s distribution efficiencies would not have been possible with human labor alone as in most cases, since robots can outperform human productivity in some repetitive tasks. In 2017, the company indicated that their workers were not replaced but rather re-trained to perform tasks complementary to the robots, or even that some were trained to manage robots (Wingfield, 2017). Monotonous and less mentally challenging tasks such as lifting heavy bins (replaced with robotic arms), walking (replaced with AMRs), picking from a conveyor belt, and other tasks are now performed by more than 200,000 robots (by 2019 across Amazon warehouses in the U.S.), while human workers supervise or find ways to make the robots more efficient. The company has expressed that their perspective is to employ humans for their problem-solving skills to deal with activities that improve the rate of orders dispatched. Overall, the use of robots has significantly increased productivity rates from approximately 100 items per hour to 300 or 400, though rates vary across fulfillment centers (Scheiber, 2019). Human workers are at a disadvantage under these high productivity rates, pushing the performance expectations that are then made of workers.

A recent report (Gutelius & Theodore, 2019) discusses some additional concerns about the impact that these new technologies have on job quality. The report is based on an in-depth analysis of warehouse operations where robots are used. Key concerns include work intensification, worker health, and potential reduction in the skills required to perform a job. The report expresses concerns about the increasing productivity rate of work in warehouses, with potential health and safety impacts, which may lead to burnout and higher employee turnover.

Beyond the impacts previously discussed, it is hard to assess the net impact automation has had on labor from the displacement perspective. While it is true that the number of robots in Amazon's fulfillment centers has been increasing, it can be argued that robots have allowed the company to improve its logistics efficiency and achieve continuous growth, which at the end is reflected in the increased number of new employees at those facilities. In 2017, the media expressed concerns about warehouse workers' potential job losses due to automation (Boyle, 2017; McKinsey Global Institute, 2017; Winick, 2017). However, in the example of Amazon, since introducing robots in 2012, the company added 80,000 warehouses employees by 2017, for a total of more than 125,000 warehouse workers and 566,000 overall (Wingfield, 2017), including full-and part-time employees. These net increases reflect sector wide growth not necessarily appreciated by labor markets at a specific warehousing facility.

Focusing exclusively on net jobs is reductive, but job loss metrics can also provide a high-level view of sector wide benefits. For example, between 2012 and 2017, there was a decrease of about 170,000 jobs in the retail industry in the U.S., with the growth of e-retailing as a contributing factor. While the changes in the traditional retail sector had already started before the introduction of automation, new technologies may have fueled the growth of e-retailing and its market share of overall retail sales. Between 2012 and 2021, the retail industry experienced a loss of 670,000 jobs, while one e-retail company alone (Amazon) hired almost 1.5 million people (Coppola, 2022). Figure 1 shows the changes in the number of new employees and robots in Amazon, with the number of new employees in the retail industry every two years, from 2011 to September of 2021.

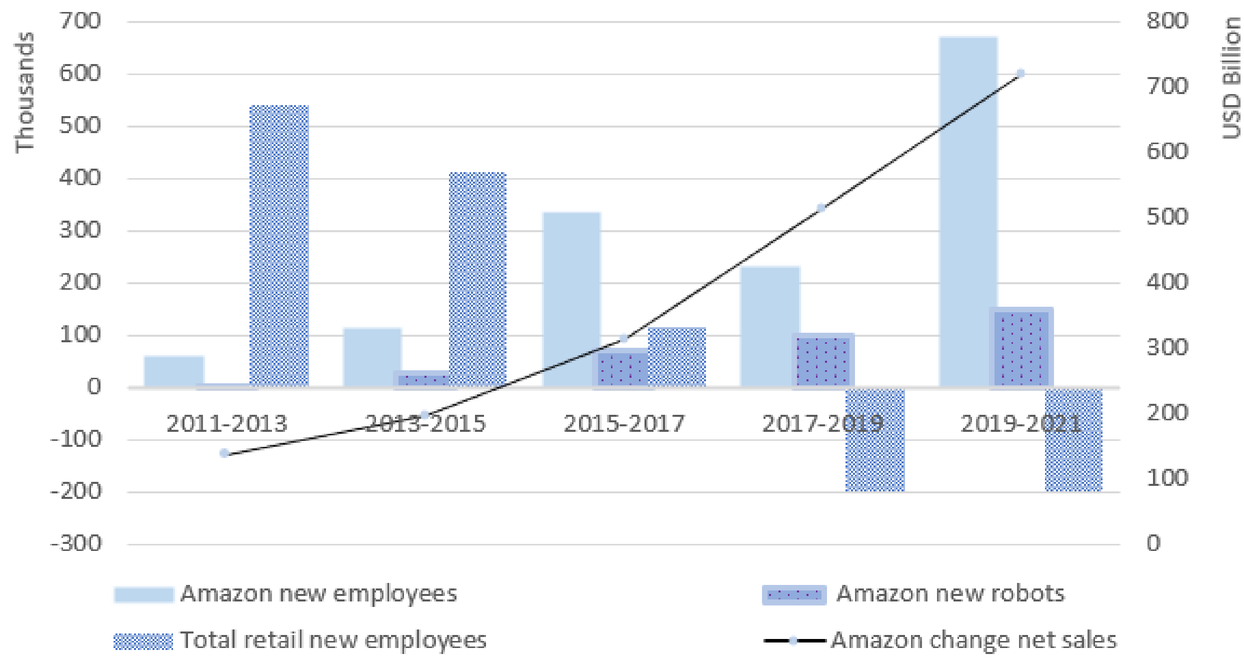

Figure 1. Change in the number of new robots and employees in Amazon, together with new employees in the retail industry in the U.S in contrast with the change in Amazon's net sales. Source: Elaborated with data from Amazon.com Annual reports 2015 to 2021 (Amazon, 2022a) and U.S. Bureau of Labor Statistics.

The number of new employees in Amazon includes full- and part-time employees. Approximately 50% of Amazon's net revenue comes from online retail sales, the remaining comes from Amazon Web Service and retail third-party seller services. The average growth rate in the number of robots in Amazon is approximately 35,000 per year, while the average growth rate of new employees is more than four times that, with 141,180 per year. During the COVID-19 pandemic, the company added more than 650,000 new employees, to reach approximately 1.3 million at the end of 2020, and 1.47 million by September of 2021 (Coppola, 2022). Analyzing the potential impact of robots and employees in the company's revenue, Figure 2 shows the ratio of the average number of employees and robots that Amazon requires to produce $1M in net income. From 2011 to 2013 Amazon only had about 1,000 robots and 117,300 employees and produced $274 million in net income, with reported sales of about $74.45 billion. It required, respectively, 2.13 robots and 631.28 employees to produce $1M in net income. From 2019 to 2021 the company had increased its sales and the number of employees and robots to $718.47 billion, 1.47 million, and 350,000, respectively. In this period, the company required many fewer employees and robots to produce $1M in net income: 44.66 and 6.81, respectively. This is a significant reduction of almost 93% in labor required, indicating high levels of productivity at the company and a loss in new retail for the sector.

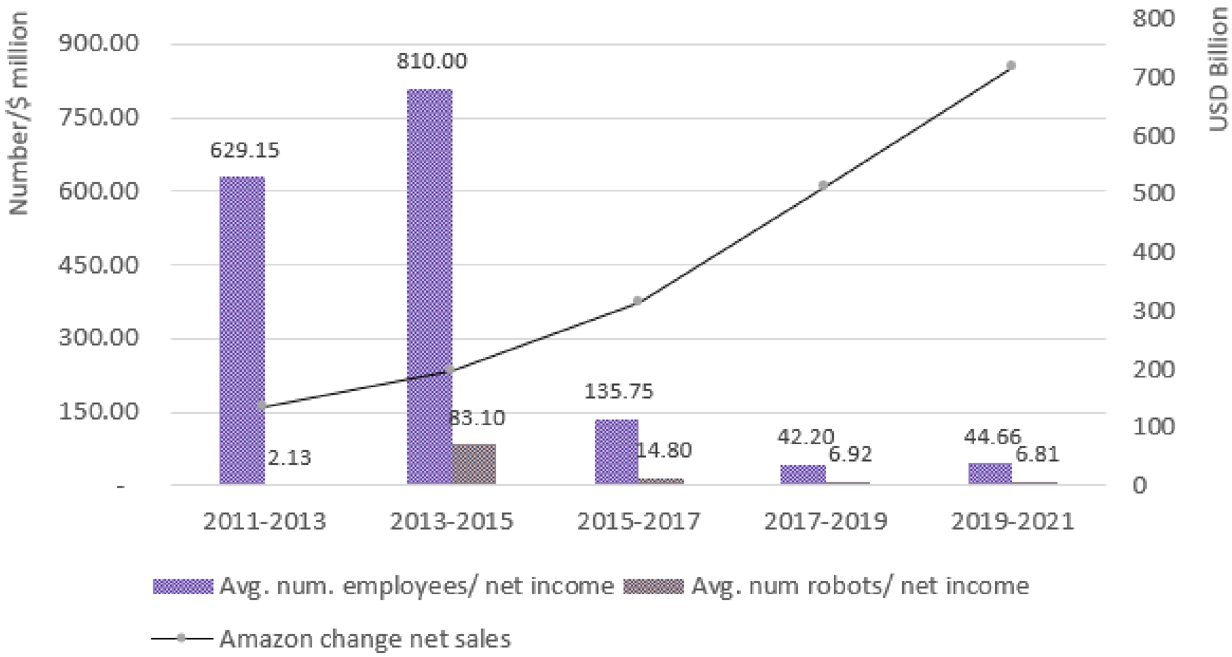

Figure 2. Ratio of the number of robots and employees in Amazon required to produce $1M in net income in contrast with Amazon's change of net sales. Source: Elaborated with data from Amazon.com Annual reports 2015 to 2021.

Figure 1 and Figure 2 do not prove that robots are directly replacing human workers since the rate of new human beings employed is higher than robots, but rather that the sum of the two is helping the company to need fewer and fewer employees and robots to meet its demand. It should be clarified that automation is not limited exclusively to the use of robots, but also includes decision-making support systems typically based on artificial intelligence algorithms supported by super-powerful computers.

The question remains whether robots will effectively replace humans in any significant way in these distribution centers. Undoubtedly, they will replace humans for some tasks, but as the evidence shows, humans of varying skills are still hired in large numbers, and it is not expected that fully autonomous fulfillment centers will exist in the next decade (Boss, 2019; Houser, 2019; Knight, 2021). The technology capabilities are still limited in handling different types of products and there are several situations that arise during the operations that robots are not yet able to deal with, requiring human intervention. The company has announced that it is making efforts to maintain its automation-impacted workforce through a retraining program (Casselman & Satariano, 2019), with the goal of retraining 100,000 employees by 2025.

In summary, robots have been replacing humans for repetitive tasks at Amazon, but the overall effect seems to be of a complementary nature as opposed to substitution, considering that the growth rate of new employees is four times the rate of robots. In terms of efficiency, robots do provide significant improvements, and at least in this example, can reach a 93% reduction in labor intensity, though numbers alone don't tell the whole story. Another important issue is the direct effect that automation can have on safety and other job quality factors for workers who work in conjunction with robots.

The U.S. Postal Service

Another example of the potential effects of AMRs on productivity is in the U.S. Postal Service (USPS), which has been facing serious productivity problems caused by different factors including employee shortages, adverse weather conditions, higher than expected demand, and labor disputes. (USPS, 2019). The company appears to be lagging in its competition with private companies in the parcel sector such as FedEx, UPS, and DHL. The USPS manages a large-scale network of mail sorting centers (200+) that deliver parcels to more than 156 million addresses. The standards of the parcel industry have raised public expectations today to require delivery times of between one and three days throughout the country, which the USPS struggles to achieve. The size of its operation and expected processing speeds have led USPS to consider automating certain operations, especially repetitive ones. The USPS has been testing different types of automation technologies in several experimental pilots. These pilots have demonstrated the potential to both reduce costs and increase productivity.

A report from the USPS Office of Inspector General (USPS, 2018) indicates that automation related efforts began about four decades ago with a pilot to automate some mail transportation functions using electric carts that traveled along wires on the floor. In 2016, USPS installed autonomous tugs in its Pennwood Place plant outside Pittsburgh. The report also announced the installation of AMRs in 25 processing plants in 2018 from multiple vendors. These AMRs, which use sensors and other technologies, can operate independently with limited human interaction, and the pilot was evaluated in terms of operating costs, efficiency, and the ability to provide new services. Indoors, USPS is also using AMRs to move objects from one place to another on defined routes, where the possibility of jamming or incidents with people are reduced and controlled. In addition, the company has been evaluating the possibility of using AMRs to perform residential deliveries. However, outdoors is a more complex and challenging environment, due to the number of unexpected obstacles and situations that can arise that the currently deployed AMRs still cannot deal with.

The USPS's Office of Inspector General (USPS, 2018) indicated the tasks and technologies that emerged as candidates for automation in its operations including hitching containers, sorting and transfer of packages, loading and unloading mail from trucks, and moving tools and spare parts during maintenance. Additionally, the report indicates that some technologies could help with mail and package delivery. This could include hybrid systems in which the carrier is followed by an AMR loaded with packages, or even the case of the "Robovan" that is a van loaded with AMRs deployed to assist the delivery.

As can be interpreted from the USPS report (2018), the purpose of implementing AMRs is to reach high efficiency and improve service, and competitiveness, with a potential downside of job losses. However, the up-front costs are a major barrier. In the report, the company indicates that the procurement costs of AMRs can be quite high, making the implementation nonviable: AMRs can range between $10,000 and $100,000 each, with cheaper prices possible when buying in bulk. The USPS believes that these technologies will be cheaper in the future.

Besides high up-front costs, companies willing to use AMRs to make deliveries face a high cost per delivery. Pilots such as the one performed by Swiss Posts associated most of their operative costs to a handler that walks with the robot due to safety regulations (Swiss Posts, 2017). Regulators typically allow AMRs to travel supervised by chaperones. Legislation rescinding the need for these chaperones would dramatically reduce the costs of operation. In the U.S., by 2020, only one company was granted the right to operate AMR technologies at a commercial level (Ian Duncan, 2020). Although legislation seems to be a bit more favorable to the development of this technology, AMR manufacturers must still demonstrate that their technology is mature enough to navigate real-world streets. The USPS (2018) indicated that AMRs have the potential to cut labor costs in the long-term, and the company announced in 2017 its intention to cut total work hours by 23 million during 2018 (USPS, 2017). In fact, an automation pilot performed by USPS demonstrated significant savings. The pilot consisted of replacing human drivers of power industrial vehicles (PIVs), such as forklifts and other heavy machinery, with AMRs. Figure 3 shows the salary savings of this pilot at the sorting center in Pennwood Place in Pennsylvania between 2016 to 2017. The implementation of an AMR reduced the annual salary costs by $281,289 or 14.8%. The biggest reduction observed was expenditures in overtime hours: $68,173, or 19.3% in comparison with year 2016, before the implementation of the AMR.

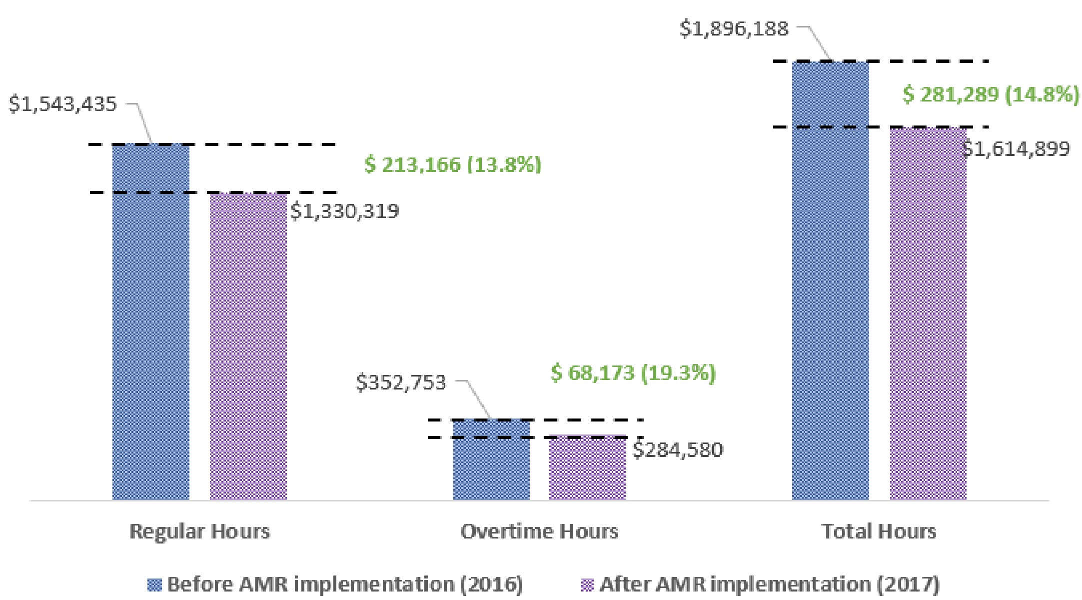

Figure 3. Salary expenditure for PIV drivers at USPS' Pennwood Place sorting center, period 2016-2017. Source: Adapted from (USPS, 2018)

A second factor for reducing payroll costs could come from not filling the vacancies left by retiring PIV drivers, considering that the company claims it has no intention of laying off current employees. In some of the cases mentioned above, robots may replace high quality jobs rather than lower-skilled and lower-paid workers, and employers may opt for underpaid workers supplemented by robots, rather than skilled labor working in tandem with the new technology. USPS also mentions that automation threatens jobs involving repetitive tasks, but labor organizations and policies may protect them from being replaced by AMRs. USPS states that *"…it will be crucial to get employees to accept what the Postal Service is doing and why….*" Achieving this would require education, training, and showing the potential benefits of the technologies to facilitate their work, "…*Machine interaction to produce better results*…." The acceptance of AMRs by postal employees seems to be mixed. For instance, at Pennwood Place, PIV drivers complained of time wasted when they get stuck behind a slow AMR. Moreover, a connectivity disruption caused AMRs to briefly stop working, which caused employees to express disappointment, and confront the realization that they had come to trust the robots (USPS, 2016).

Food delivery robots

There are several last-mile food delivery initiatives using AMRs[1] in the U.S. Although regulations on operating this type of technology in public spaces are stringent for security considerations, some companies have found ways to operate and test their technologies. For example, KiwiBot and Starship have been working in controlled or semi-controlled environments in the U.S., such as university campuses and convention centers. Recently Nuro Technologies was granted approval for grocery deliveries in the United States.

This type of delivery is typically performed in the U.S. by bicycles, automobiles, or even delivery vans. There are several companies offering food delivery services, such as UberEats, DoorDash, or GrubHub. However, for short-distance deliveries (less than 2 miles), these services can be inefficient in terms of time and costs. This is because typically the driver may face high congestion during peak hours, difficulty finding parking spots, and lower remuneration for these micro-segments. On the other hand, small robots can navigate the sidewalks, avoiding street traffic. Contrary to what one might think when seeing one of these robots, they are not yet operating autonomously and require human assistance in normal driving circumstances, in their operation in the field, and when they encounter obstacles during their travels.

The main benefits of using these technologies for this delivery segment are a shorter average delivery time, a higher work intensity compared with human workers, and lower costs. Labor cost savings greatly depend on the automation-level of the AMR. Automation-level refers to the degree of replacement of human labor by machines. The higher a device's autonomy, the lower the need for human intervention. In the context of this example, the higher the automation level means the larger the number of robots that a supervisor can manage/supervise simultaneously. Currently there are no regulatory requirements to dictate how many humans can operate what type and how many AMRs, leaving operators responsible for determining how much labor each device will require to safely administer.

[1] Also known as Autonomous Delivery Robots (ADRs)

Improving the automation level typically implies large investments in research and development, so although autonomy is desired, it may not always be efficient. Figure 4 illustrates the labor reductions for different average delivery times: 50, 55, 60, 65, and 70 minutes. The lower the average delivery time, the higher the number of AMRs, bikers, and supervisors. The curves in Figure 4 are functions of the total labor requirement of bikers and robots, and the automation level, by which the robots' labor requirement is divided. The orange curves represent the cumulative labor reduction for each case. Note that improving the automation level beyond 5 (bots per supervisor) yields only marginal reductions; in all cases, at this level, the cumulative labor reduction is at least 95%.

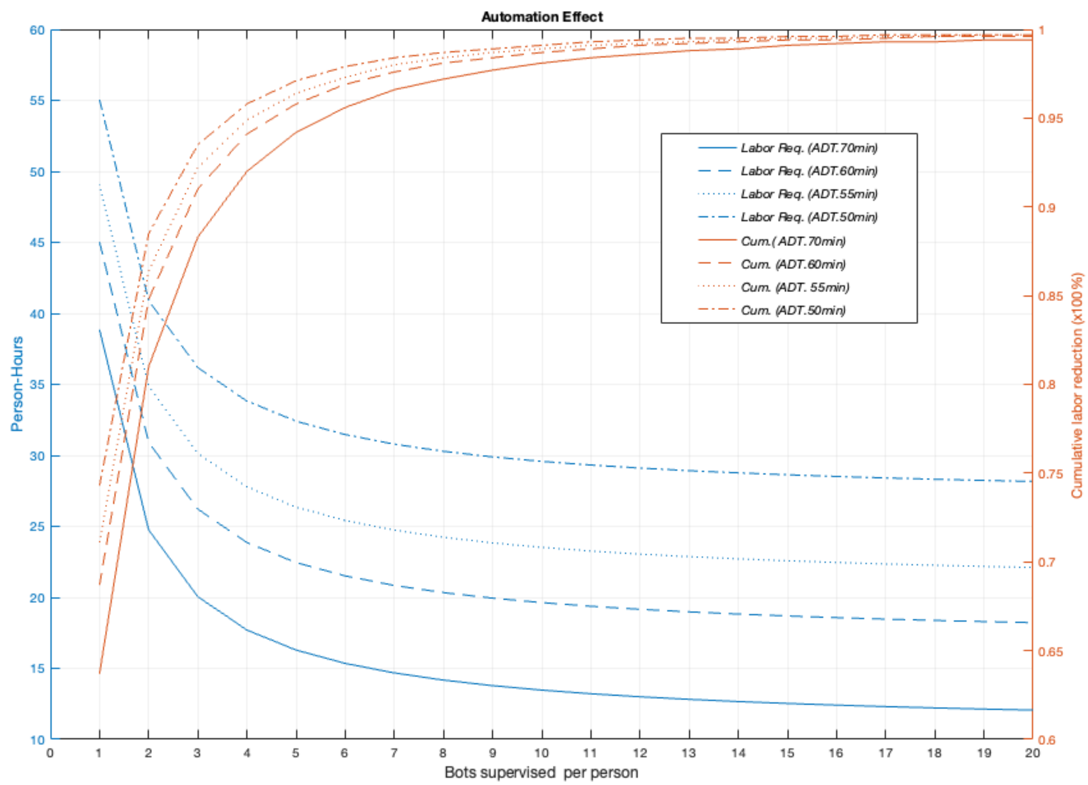

Figure 4. Labor reduction due to automation effect. Blue lines on the right side show the decrease in labor for different average delivery times for the same sample of orders. Orange lines represent the cumulative labor reduction.

In short, this technology has enabled new services, higher service levels, and efficiencies that could not be achieved with traditional systems given traffic conditions and labor costs. But it also requires jobs that did not exist before in this type of industry, such as robot supervisors, maintenance personnel, programmers, and field assistants. On the other hand, in the short term, it does not seem possible that AMRs will achieve full autonomy, and displacement of delivery workers may not be acute until technical barriers and costs come down.

4. Overview of U.S. automation policies: technology regulations and programs to support impacted workers

This section discusses examples of the type of technology control policies and U.S. Government programs that could support workers impacted by automation.

Background on automated vehicle regulations in the U.S.

AMR regulations

Improving safety outcomes is a stated motivation behind the development of nearly every AV operator, but regulators are navigating new terrain with AMRs that will operate on roadways, sidewalks, and bike paths. Curbside AMRs may be able to be safe to operate on sidewalks, thanks to their small, lightweight size, and their multiple sensors to anticipate road incidents. However, regulators seem yet to be convinced, and in some cases have imposed low-speed and weight regulations to mitigate any unintended consequences for other road users, especially vulnerable users (e.g., children, elderly, and people with disabilities).

Developers of AMRs also claim to be hyper-focused on safety, but mistakes will occur, accidents will happen. AMR technologies have the potential to improve road safety, but not every company is as committed to safety as the next, nor as competent to deliver on safety promises. Regulators and industry will likely need to work together to establish performance metrics that are specific enough to ease the worried minds of the public, but flexible enough to allow for innovation. This type of flexible policy mechanism will strengthen the long-term market of the AMR industry. Accidents, especially lethal accidents, can tarnish the reputation of the whole industry, so baseline regulations can protect industry-wide investments. Theoretically good policy will help the most innovative thrive, while also rooting out the bad apple companies, willing to take greater risks at the expense of public safety.

There is a balance to achieve between regulations that are too loose and enable bad actors, and too stringent that may be considered a barrier to the worldwide implementation of automation technologies (Jaller & Otero-Palencia, 2019). In some cases, stringent regulations have prompted operators to switch to places with more flexible regulations (Nichols, 2017). In some regions, AMRs must move along the sidewalk at low speeds (3 to 10 mi/h), with limited weight (50 to 500 lbs.), and for the moment they are limited to controlled geographies, with specific insurance liabilities and other requirements. For instance, the Amazon Scout (a six-wheeled AMR) had to operate in the presence of a “chaperone” (Scott, 2019) in Washington, and FedEx faced a similar situation. While this might be a job creator, this is likely only a short-term requirement.

Despite the regulations and technical challenges, companies keep showing interest in this technology, and identifying potentially profitable opportunities. For instance, FedEx launched an ADR with the intention of delivering parcels from popular stores to nearby home customers or businesses (FedEx Corp., 2019) considering that "…on average, more than 60 percent of merchants' customers live within three miles of a store location, demonstrating the opportunity for on-demand, hyper-local delivery...."

Automated vehicle regulations

In the U.S., equipment and vehicle performance is regulated by the federal government and states regulate vehicle use and licensing. Additionally, auto manufacturers must follow federal vehicle safety standards set by the National Highway Traffic Safety Administration. To streamline the development of automation vehicle technologies and foster innovation, there are some exemption procedures for autonomous vehicle manufacturers. The U.S. has taken a hands-off approach, which may be criticized by safety advocates, and, while this approach appears industry-friendly, some industry voices see regulations as inevitable and want to establish the guidelines as soon as possible (Alliance for Automotive Information, 2022). This push for regulation from industry is aimed to improve certainty, and risk-proof their investments, while they undertake long-term product planning efforts. The US Department of Transportation (DOT) has only issued voluntary guidance. The most recent, Automated Vehicles 4.0, was released in 2019 and emphasized a set of guiding policy principals (US DOT, 2019).

The federal government's approach has raised some questions about the states' role in addressing additional safety and security issues. Some states have taken steps to institutionalize the approach to manage AV technology development and testing at the state level and allow fully automated deployment with limited controls. Arizona and Nevada are among the first to take this approach and have had a somewhat hands-off approach to certifying AV companies to operate in their state. Nevada was among the first states to green light truck platooning technology, and both Arizona and Nevada have allowed testing without a safety driver for more than five years now.

In California, the AV testing conversation began in 2013, but official regulations emerged in 2018. As of this writing, three companies are approved for full commercial deployment, one is Nuro an AMR developer, and the others are passenger service operators, Waymo and Cruise. These three have a license to operate vehicles under 10,000 lbs without a safety driver inside the vehicle (LeBeau, 2018).Several other companies have received testing permits (California DMV, 2019).

Security Regulatory Actions

Safety can be defined as protection from unintentional harms, while security is protection from malicious actors (Kurani, 2019). Regulators are increasingly concerned about privacy and cybersecurity, given the growing number of devices and sensors in everyday life. While AVs don't represent a new issue in this regard, the stakes may feel, or may in fact be, higher given the safety critical software and hardware involved in safe AV operation. Moreover, there are concerns about the privacy and risks of cyber-attacks. The USDOT has been investigating this issue, investing $25 million in 2012, and more recently partnering with National Laboratories to update guidance for automotive cybersecurity (US DOT, 2022).

Much like in a regime to regulate safety, good public policy on security must strike a balance between minimum cybersecurity protocols and stringent regulations that may delay or restrict the implementation of automation technologies. Joint work of developers, authorities, industry, organizations, and other stakeholders will enable better identification of safety and security performance measures to assess the potential risks and establish strategies to protect the people. Good public policy will not undermine progress but serve as a booster, motivating the arrival of new initiatives and investors and reducing overall risks.

Existing federal and state labor policies

In the U.S., there are several federal and state programs and policies that have been developed to help support dislocated workers, and some have directly addressed the potential impact of automation in segments of the freight industry, such as changes in international trade, or automation at port facilities. Table 3 summarizes some of the programs and policies as discussed in the "Driving automation systems in long-haul trucking and bus transit: preliminary analysis of potential workforce impacts" report by the U.S. DOT (2021).

Table 3. Examples of federal and state labor policies

Program/Policy	Description	Objectives
Workforce Innovation and Opportunity Act (WIOA)	A key law guiding training programs offered by the US Department of Labor (DOL). Brings federal investment programs in skills development and training for dislocated workers[2].	• Help access employment services, education, training, and support • Connect employers with workers
WIOA Dislocated Worker Program	Provide grants to states for services to dislocated workers (CRS, 2021). At the local level, services are delivered through community colleges and American Job Centers.	• Fund local entities for training and related services. • Focus on statewide rapid response and local activities. • Provide job search assistance, skill assessment, career planning, case management, and training. • Rapid response activities are proactive, business-focused, and flexible strategies designed to quickly support dislocated workers. • National dislocated worker grants, formerly National Emergency grants, are awarded to states or entities affected by major economic dislocation (US Department of Labor, 2022).

[2] Dislocated workers are, for example, those who have been terminated, laid off, or received notice of termination or layoff from employment as a result of a permanent closure of, or substantial layoff at, a plant, facility, or enterprise; those who were self-employed but became unemployed because of changes in local general economic conditions or natural disasters; or those who were providing unpaid services to family members whose income changed (More information at https://www.govinfo.gov/content/pkg/PLAW-113publ128/pdf/PLAW-113publ128.pdf). (US Congress, 2014)

Program/Policy	Description	Objectives
Worker Adjustment and Retraining Notification (WARN) Act	The WARN Act does not mandate training resources but can impact dislocated workers. This Act requires employers to provide a 60-day notice to affected employees, states, and localities, when planning plant closings or mass layoffs. Only specific and qualified employers are under WARN.	• Provide notice so that impacted workers can seek alternative employment, retraining, or adjust to job loss. • Inform localities so that they can prepare for and/or adjust to the changes in the labor market.
Trade Adjustment Assistance Program	Program designed to benefit workers affected trade impacts (e.g., increased imports, offshoring) (US Department of Labor, 2021)	• Provide benefits in the form of training, case management, job search allowances, relocation, wage supplements, and income support.
State Level Workforce Development Efforts	California's AB 639 defines a stakeholder engagement process to check on the impact of port automation on state efforts to reduce greenhouse gases, and on job losses (California Legislative Information Office, 2019). Additionally, Executive Order N-17-19 convened the Future of Work Commission (FWC) under the Labor and Workforce Development Agency (LWDA) (California Governor Office, 2019).	• Help agencies and industry to develop strategies to contend with the impacts from automation and market pressures. • FWC to support worker transition, and provide a set of recommendations and principles for future jobs and emerging industries (Labor & Workforce Development Agency, 2022).

5. Potential labor displacement and other impacts due to automation

Automation in trucking

Major advances in technologies for automated driving have been made over the last decade. The extent of automation is described by the Society of Automotive Engineers (SAE) levels of automation (Figure 5). For example, adaptive cruise control and lane-keeping systems, which are forms of advanced driver-assistance systems (ADASs) and are considered SAE level 1, have become common. Even some level 2 implemented ADASs, which use a combination of both speed and directional control, are offered by multiple manufacturers. In both levels 1 and 2, the human in the driver's seat is still driving the vehicle, with assistance. In contrast, at higher levels, various degrees of automation are achieved, and many companies are currently developing and/or testing such advanced functions. In fact, in 2019, the USDOT estimated that more than 80 companies were in testing phases for automated vehicles (Chao, 2019), with tests being conducted or soon to be conducted in 40 U.S. states

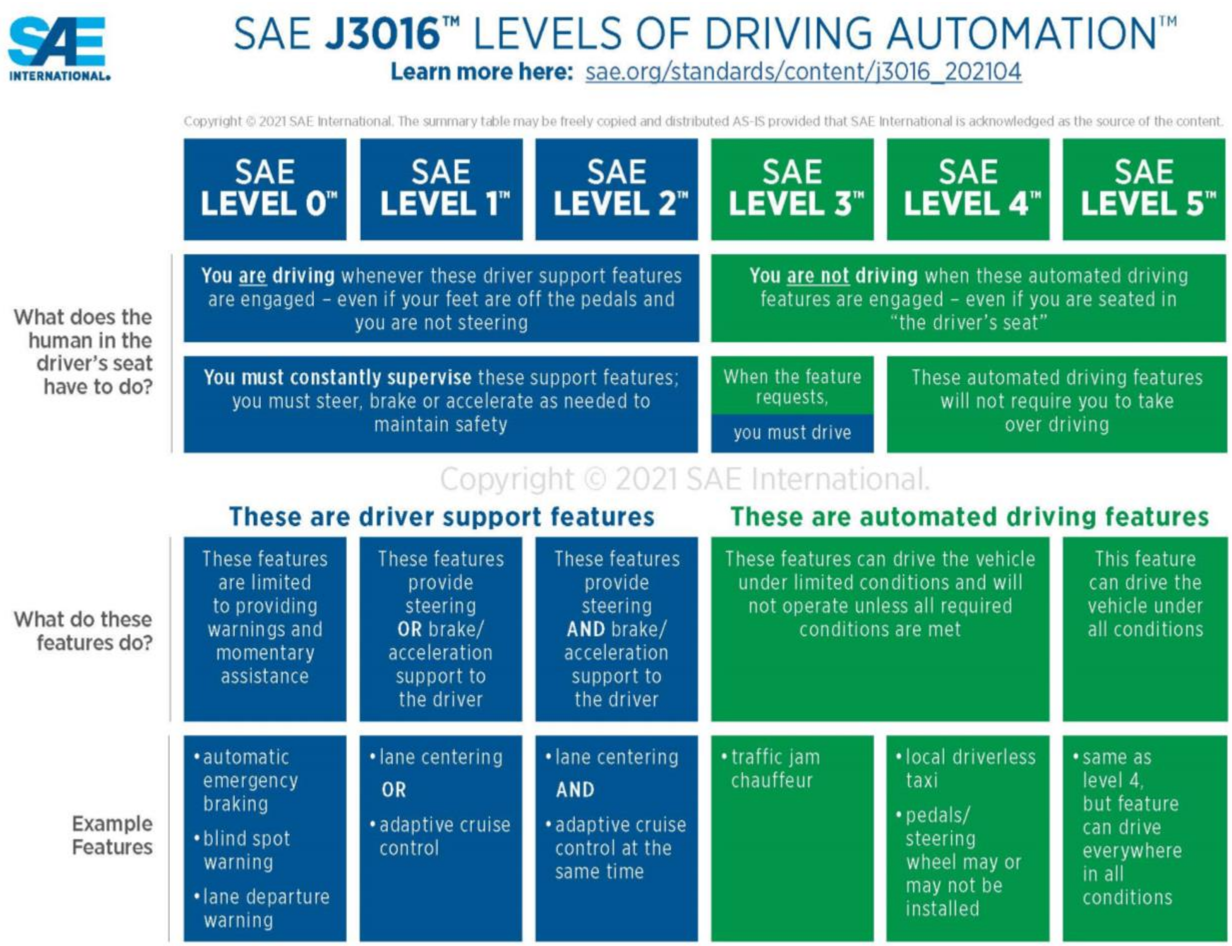

Figure 5. SAE automation levels. Source: SAE website.

In 2021, the U.S. DOT, DOL, Department of Commerce, and the Department of Health and Human Services (HHS) carried out "…a comprehensive analysis of the impact of advanced driver-assistance systems (ADASs) and highly automated vehicles technologies on drivers and operators of commercial motor vehicles, including labor displacement." (U.S. DOT, 2021) This study looked at the impacts of automation on the workforce in both long-haul trucking and transit buses. They found that in the long-term, automation is likely to displace many driving jobs, though these conclusions may be dependent on when the technologies for full automation are commercially available, and the study did not fully assess the potential new jobs to be created.

Level 1 and level 2 systems are expected to improve safety and could provide other benefits such as fuel savings, or operational improvements, without having a major impact on the labor market. Higher levels of automation aim to remove the driver, resulting in major cost reductions in operations through salary savings. Wages, benefits, and bonuses account for 43 percent of the marginal costs for trucking firms and have been the source of the biggest cost increase since 2012 for motor carriers. Thus, the removal of drivers is seen as a potential saving opportunity for these companies. Additionally, other new jobs may be created to develop and then run and maintain these new technologies, the costs of which are difficult to predict.

The second highest cost for the trucking industry is fuel costs, accounting for an average of 22 percent of marginal costs in 2017. Automation is predicted to decrease fuel costs by optimizing controls such as brakes to minimize fuel usage. Close following, such as truck platooning, can result in significant fuel saving for the following vehicles. A further potential benefit of automation is on safety improvements. Studies suggest that driver assistance technologies provide safety benefits, for example through additional cameras or sensors that can improve driver awareness and mitigate blind spots to avoid accidents.

A final benefit of automated trucking is that vehicles could have higher utilization rates, resulting in more savings. Vehicles that have level 3 to 5 automation (or automated driving systems [ADS)] could operate without a human onboard, and so would not need to stop for rests (e.g., abiding to hours-of-service rules) or meal breaks, providing higher levels of operational flexibility.

These analyses have not considered the powertrain of the vehicles, but if automated vehicles also use zero emission technologies, there would be increased benefits for the environment and public health.

Driving jobs

Overall, different industry associations indicate that there is a driver shortage (ATA, 2019) and difficulties in driver retention (Miller, 2018), which result from multiple factors such as overcapacity of vehicles in the industry, low wages, and challenges in recruitment and driver retention (OOIDA, 2019). While automation could potentially mitigate the shortage gap, it is important to consider the role of higher wages and better working conditions to address some of the root causes of the shortage (Burks & Monaco, 2019). There may be concerns about the potential displacement of drivers as automation evolves, and automation should be considered as a way to use technology to improve the trade and quality of trucking jobs. In addition, it should not be assumed that all drivers would be capable or willing to retrain to use the new technologies (Bloomberg News, 2018). Regardless, the diversity of jobs within the trucking industry will result in a wide range of impacts from the advancement of automated driving technologies. In the trucking industry there are three market segments:

- Long-haul trucking, or the long-distance movement of cargo by truck. Drivers in this segment spend long periods of time on routes. Typically, they work alone, taking breaks during their trips, or with one team member sleeping in the sleeper cab while the other team member is driving.
- Short-haul trucking mostly consists of time in urban areas and shorter periods of uninterrupted driving on the highways. Drivers in this segment spend less of their time driving than those in long-haul due to the additional needs of customer service and cargo handling. These drivers can return home daily and are not required to sleep in the truck.
- Regional trucking involves a mix of short- and long-haul driving. These drivers generally return home every day but tend to spend more time driving on the highway than short-haul drivers. Regional routes move goods from one freight terminal to another and then take cargo back to their origin point. Trips are generally completed within a day to stay in compliance with the hours-of-service rules from Federal Motor Carrier Safety Administration.

At least initially, long-haul drivers may be the most affected by automation. This is because highways are a less-complex environment to test these technologies, and much initial testing of automated technologies has focused on these long periods of uninterrupted driving. However, tests of “last-mile” deliveries in urban settings are also underway (Gittleman & Monaco, 2019). Unfortunately, there is no clear data on how many drivers operate long-haul routes and therefore could be most impacted by automation. Some researchers estimate that in the heavy-duty trucking sector, about 60 to 65 percent of driver jobs will not exist when levels 4 and 5 of automated driving are implemented, though the authors did not consider the size of the long-haul market (Groshen et al., 2019).

Other studies have used other methods to estimate the impact of automation on drivers. Gittleman & Monaco (2019) used the Census Bureau’s Vehicle Inventory and Use Survey (VIUS) (from 2002, so it may not represent current market conditions). They found that many heavy trucks operate at a short range. Roughly half were found to operate at a 50-mile or lower range, with a quarter functioning at the over 201-mile range. This long-distance segment is most likely to be impacted by automation, with drivers in the for-hire sub-segment disproportionally affected, resulting in 19 percent of the workforce impacted, which raises to 25 percent if “in-house,” or private carriers, are included.

Another study also identified the long-haul drivers to be the segment most likely to be impacted, and in particular those working for the largest trucking firms, which likely have the resources to invest in these automation technologies (Viscelli et al.,2018). Across three potentially impacted segments including truckload, less-than-truckload, and parcel services, the study estimates that 294,000 long-haul trucking jobs are at risk.

Retraining needs

Training will be required to prepare drivers to operate vehicles with automation levels 1, 2, and 3. Drivers will need to learn how to use these technologies safely and effectively. This will require reskilling efforts to provide workers with the needed skills as roles and responsibilities evolve. Current training programs do not include automation technologies. New training requirements could be incorporated into training programs (e.g., commercial driver license requirements). The U.S. DOT sets the standards for these tests via the Federal Motor Carrier Safety Administration. However, requirements may vary by state as commercial driver licenses are issued by states (US DOT, 2020b). In February 2022, FMCSA's Entry-Level Driver Training Final Rule set new minimum standards requiring a theory and driving curriculum (US DOT, 2020a). Training requirements for a commercial driver license are usually met by completing a program at a truck driver training school.

It is unclear how these training requirements will change in the future, as is it still unknown which technologies will be adopted, or when. The skills required to operate the technologies, such as the ability to engage and disengage different system functions and interpret the system will likely need to be taught. Furthermore, the ability of these new systems to carry out functions that would usually be human operated (e.g., automatic emergency braking), may increase safety concerns. Training is required to understand and build trust in technology, as well as to raise awareness about the technologies' limitations.

Retraining will be required to enable workers to search for new jobs if they are displaced by levels 4 and 5 automation. For example, new roles as remote supervisors or operators will require training on how to operate the vehicle from a remote location. As these positions currently do not exist, it is hard to predict exactly what training will be required, but it could include training operators to be engaged and attentive in case intervention is necessary, as well as understanding how the technologies work and their limitations. Another unknown is with respect to the ability of the system to absorb displaced drivers in new positions, as the number of drivers displaced could be much higher.

Other perspectives on the use of advanced driver-assistance systems (ADASs)

In its 2021 report on driving automation systems in long-haul trucking and bus transit, the U.S. DOT documents some union concerns and support over the use of ADASs (US DOT, 2021). Concerns relate to the "deskilling" of the vehicle operations occupations, and compensation impacts (Greco, 2019). Different organizations highlighted the importance of understanding and guaranteeing that technologies are used appropriately, that they include designs that consider the interactions between the humans and the machine, and that training is provided. Organizations "documented in the report include the Transport Workers Union of America, and the American Federation of Labor of Congress of Industrial Organizations (AFL-CIO). Comments address support and concerns and cite various existing regulations (Regulations.gov, 2018). For example, the AFL-CIO noted that “strong unions and worker engagement are essential to mitigate harms inherent in rapid changes to industries.” (TTD, 2019).

On the transit side, considering that the structure and ownership of most transit agencies is different from that of trucking and other freight segments, the impacts and their pace may be different. For example, procurement processes, the level of investment risks, market competition, and labor force structure may affect the implementation of automation in transit driving (Machek et al., 2018). Another important aspect of transit and the implementation of driver- or staff-less vehicle operations is the requirement to comply with other regulations, including but not limited to the American with Disabilities Act (US DOT, 2015), or the evaluation of impacts on workers when making procurement investments (Transit Cooperative Research Program, 1995). While these are not an inherent obstacle to automation, it is imperative that the implementation of new technologies guarantees the rights of users and abides by the provider’s responsibilities.

Other considerations and factors affecting adoption and use

Even considering the potential benefits of automation, some factors could limit the speed and extent of adoption in trucking. ADASs are expected to increase the cost of vehicles, and this leads to slower adoption, in particular by smaller firms and owner-operators who do not have the revenue to invest in these technologies (Camden et al., 2017). Larger firms may choose to transition to ADAS-equipped trucks but over a longer period, as human-operated vehicles are removed from service. The rate of change from human-operated trucks to automated trucks would depend on the cost advantage provided by these new technologies. Therefore, full automation is thought to be something that will occur gradually, over a long timeframe. This will not change the number of jobs impacted in the long term, but it will give younger workers the ability to anticipate these changes and search for alternative opportunities. It may also allow job losses to occur through retirements rather than layoffs. It is important to note that even under this long-term transition, there will be some level of displacement, and for some workers, it will be a net loss, with no chances of retraining or transition to other sectors. Some of the factors affecting the adoption and use of the new technologies are discussed next.

Cost of technology

While technologies could provide savings, these need to be considered in the context of the investments required to adopt them. Such investment costs not only include the cost of new vehicles themselves, but also of developing, implementing, operating, and maintaining these new technologies. In fact, for trucking, at automation levels 1, 2, and 3, a human operator is still required to be present in the vehicle, and so the potential savings will be greatly reduced, providing less savings to cover the costs required to implement the technology. The potential savings are higher at levels 4 and 5 of automation, where the need for a driver is eliminated, but in these cases the costs of adoption and implementation are less clear.

Training costs

In addition to the costs directly related to the new technologies, there will be additional costs related to training requirements. The current workforce will need training on the new technologies, which represents another cost for companies. Not only will training be required on how to operate the new automated technologies, but also additional skills will be needed by those responsible for maintenance, for example. Truck mechanics who typically work with mechanical issues will now need to be able to work on maintaining and repairing these complex technologies; such repairs and maintenance costs will be more expensive than the traditional maintenance requirements, and not all current workers will be able or willing to be retrained for these tasks. Additionally, the number of new positions may not compensate for the loss of drivers from higher levels of vehicle automation.

Cost scaling

As mentioned, the uptake of these new technologies will depend on balancing the potential benefits through increased productivity and savings, with the costs of implementation. This equation will not be the same in every company and may vary largely by firm size. For example, large firms could negotiate bulk technology discounts, resulting in lower upfront costs needed for adoption. This high initial vehicle purchase expense could be a barrier for small firms and owner-operators, who may be more likely to rely on small-business loans or personal loans to buy vehicles.

Wages

Automation levels 1, 2, and 3 are unlikely to lead to major changes in the wages of drivers. The skills required to drive a truck with these technologies are very similar to the skills for driving non-automated trucks, with the only additional skill being interacting with the new technology. However, skills required are not the only determinant factor in compensation. Adoption of levels 4 and 5 of automation are significant, due to the lack of a human driver. This implementation will occur over a long period due to the logistical challenges, testing requirements, and the upfront costs of technology adoption, among other factors. In such an extended transition period, where drivers are gradually phased out, a higher driver supply than driver demand with lower wages resulting from this imbalance could occur. It is hard to accurately predict supply and demand for drivers in the future, whether displaced drivers can transition to other freight sectors or industries, and what the working conditions and wages will be. But drivers switching to new jobs may experience a reduction in pay due to the transition costs, starting new positions at a lower wage, having to transition to jobs that pay less than driving, or even having to retire earlier than planned. Groshen et al. estimated that losing a vehicle driving job (not specific to heavy-truck driving) results in a lifetime reduction of $80,000 of income per worker (Groshen et al., 2019).

Quality of life, job quality, and equity

One major advantage that automation could provide is an improved quality of life. For long-haul drivers, this could happen through improved safety due to the adoption of new technologies and new distribution schemes where drivers may not need to be on the road for long periods of time, removing the need for them to sleep in the truck on long journeys. For example, automation may enable new operations where drivers may only be needed to drive the vehicles in the first and last segments of the journey. In such scenarios, the driver may meet or deliver the vehicles at the highway exits to, do local deliveries, or perhaps even work in an operations center to remotely supervise the automated trucks that are doing long-haul drives. This could lead to an overall better work-life balance, and more desirable employment opportunities for truck drivers (Morris, 2019). As mentioned above, there will be displaced drivers that can access these new jobs, but others will not, thus these opportunities will not be universally available to the pool of impacted drivers.

Automation, despite its potential benefits in safety and efficiency, can also affect the quality of the job and the life of some workers, for example new monitoring technologies, such as algorithms that analyze worker performance and wearable devices that track workers' movements, walking speeds, and routes. These can push workers to perform at higher speeds, leading to improved efficiency, but can also worsen working conditions and reduce worker autonomy and satisfaction. In addition to changing the quality of jobs, technologies could change the content of jobs. Technologies are designed to split what is currently considered one job into multiple tasks, each of which could be automated. This removes the skill-level required to be part of the workforce, with technologies replacing humans in tasks involved in decision-making. One potential shift that could result from this is the increased use of temporary workers, which can reduce the number of direct hires and make labor supply more adaptable. Temporary workers have fewer protections and tend to be paid less, with increasing job insecurity due to their temporary status.

The uptake of these new technologies is unlikely to have even impacts across different jobs and demographics, with Hispanic and black workers potentially experiencing a higher burden. There is also likely to be greater impacts on workers who cannot meet the new high expectations of an intensified workplace such as older workers who do not reach the new targets or who are not familiar with the new technology.

6. Summary of insights, recommendations, and final remarks

Automation has the potential to displace workers in occupations that feature repetitive tasks and low mental challenge such as driving tuggers, sorting items with regular shapes, or packing parcels. Automation can be a direct threat to some workers, even highly skilled and specialized workers and will impact freight subsectors in different ways and timelines.

Summary of insights

In warehousing, a major concern for policy makers is the issue of dramatic job losses due to the adoption of new technologies and despite these concerns. However, the warehouse industry predicts that in the short-term there will not be major job losses, but instead a change (possibly a decline) in the quality of the available jobs (UC Berkeley Labor Center Report 2019). One reason for low job losses is that the industry works with small profit margins and high volatility, leading to a risk-averse strategy and caution with respect to the adoption of new technologies. Additionally, due to the increasing demand for e-commerce, aggregate employment levels will continue to rise, resulting in a potential net gain in jobs (of unknown quality). It is important to recall that aggregate numbers mask the negative effects on those displaced and their communities, because individual workers can rarely capture system-wide gains when labor demands shift. When adopted, the new technologies can bring some benefits such as reductions in physical tasks as heavy lifting and safety improvement, but the resulting expectations of workers to increase their work pace and their workloads is likely to intensify work demands. These higher demands on the workforce are predicted to lead to new health and safety issues, thus resulting in a decline of job quality.

The adoption of new technologies is being pushed by the warehouse industry to reduce labor costs and to meet the demands of a changing market with increasing speed requirements and higher real estate costs. Smaller companies will need to consider technology adoption to be able to compete with large retailers. The warehouse industry could clearly make major operational improvements through automation and will do so, both in the short and long terms. What is crucial is that these efficiency gains are shared with the workers, and that workers are included in the process to improve the outcome of increased automation. That is, technology should prove beneficial to the company and the workers as well. Policy makers must consider potential changes in job quality, and how to quantify the costs and benefits from the implementation of the new technologies, and whether these costs and benefits are fairly distributed in the labor force. The assessment of costs and benefits should go beyond an economic and financial analysis and must consider physical and psychological impacts to workers.

Historically, the implementation and use of new technologies (e.g., automation) has displaced some jobs in the industrial, manufacturing, and transportation sectors. Then and now, there are some factors that can affect the level of job displacement and its impacts on workers. Examples of these factors are: the time at which those technologies (e.g., level 4 and 5 automation) are developed and implemented; natural attrition and the level at which new jobs will absorb all potentially displaced jobs; whether affected jobs or the new jobs will improve job quality or not; and, the programs, efforts, and funding available at the federal and state levels for training programs. Such programs should be updated as new technologies emerge and funding should be expanded to overcome previous limitations and coverage.

In the trucking industry, automation is considered a mechanism to increase efficiency and reduce costs. Other considerations include the view of automation as a solution to driver shortages and retention, while the root of these issues might be in terms of low pay and quality of the job. Consequently, automation and the implementation of new technologies should be a mechanism to improve the quality of jobs and lives of workers.

Looking ahead: Recommendations to aid workers impacted by automation

Key policy strategy: Bring everyone to the table

Assembling stakeholders for discourse, as has been done by California's Future of Work Commission, is not a new strategy. The DOL and other states commonly bring stakeholders from labor, industry, advocacy, and government together to discuss these issues and come up with strategies that meet the needs of each community. Other more innovative initiatives include the High Road Transition Collaboratives under the Community Economic Resilience Fund and the High Road Training Partnerships. These later groups seek long-term solutions that will require experimentation and iteration; for these to be successful they should be vetted by different stakeholders.

Key policy strategies: Leverage current and partial automation technologies to improve worker safety

Automation looks different in different contexts. As mentioned previously, autonomous tuggers and autonomous pallet jacks can remove physical burdens from warehousing workers and make workers less susceptible to injury. Similarly, level 1-2 vehicle automation offers safety benefits that protect drivers from preventable accidents, e.g., monitoring fatigue and providing emergency braking. Some workers may benefit from these technologies and others may not. It is up to regulators to serve as arbiters, weigh tradeoffs, and listen to perspectives to encourage adoption where benefits for workers might be apparent.

Key policy strategy: Expand and target existing workforce social safety nets and make sure they are effective

Programs like the WIOA Dislocated Worker Program work for only a narrow group of workers who meet the criteria for participation, but this program leaves many holes in the safety net. Many workers are not classified as employees and operate as independent contractors; many are not granted full-time status despite their ability and interest in full-time work. Program updates will be needed to address the nature of the future workforce. Strategies and policies must recognize these factors to meet the needs of workers of today and the future who are not covered by social safety net programs. Furthermore, regulators can look at data such as that provided in this report and the referenced publications to inform identify which workers are most at-risk and target programs to meet the specific needs of those workers, as well as consider industry standards

Key effort: Job training

A core part of future-proofing the workforce is establishing a pipeline for workers to capture the value of emerging technologies. This is a complex and challenging task that requires the investment of public resources towards specific job training efforts. One reason for the complexity is that many of the technologies are still being developed, leading to multiple unknowns regarding what skills they will require. Addressing these unknowns will necessitate concerted efforts between different stakeholders and the development of partnerships to effectively train on the right skills, and not only on the perceived ones. A second challenge is the uncertainty about whether and when large displacements of workers will occur. In this regard, the uncertainties about when, where, and how the new technologies will be introduced, and whether this implementation will happen within the current generation of workers or when they retire will determine the types of training efforts needed.

There are already some indications that the private sector is anticipating the potential effects of the new technologies and has initiated concerted efforts. One such indication is the Partnership for Transportation Innovation and Opportunity, which is an association of major automakers, and freight stakeholders including Ford, Daimler, Toyota, Waymo, May Mobility, FedEx, Amazon, etc. This partnership aims to direct public and private resources towards empowering workers to be prepared for automations. Similar efforts are also underway in the trucking industry. The public sector has to catch up with guidelines and programs to address the training needs and partner with the private sector and different organizations. Potential disruptions brought about by new technologies will not be addressed by isolated and independent efforts, and all stakeholders will have to collaborate. A recent example was the collaboration between the automated trucking provider TuSimple and Pima Community College in Arizona to certify truckers on self-driving operations (Pima Community College, 2019). At the federal level, the USDOT could enhance its efforts to partner with colleges and schools to improve training and certification, through its Intelligent Transportation Systems Professional Capacity Building Program.

In the case of actual job dislocation, retraining will not be enough for individuals, but will provide systemic gains if the trainings can be targeted to produce high-quality jobs. More public policy intervention beyond trainings will be required to ensure that the freight sector can transition in a way that ensures sustained economic growth and social benefits. However, identifying other social safety net policies may also be necessary to avoid broader economic ripple effects.

Automation will change existing jobs and introduce new ones, e.g., mobile robots, drones, and automated trucks may require remote supervision for operations and safety. Although it is difficult to predict all the requirements of these jobs due to the uncertainty that exists around the limitations of the technology, it is necessary to begin to document the technological progress to anticipate training programs and assess whether existing workers will be able to transition (and be trained) for these new jobs or will be displaced with no opportunities.

Key Policy Considerations:

- **Be inclusive and comprehensive.** While there are federal and state regulations oriented to protect workers, it remains unclear which workers in the transportation, freight, and logistics sectors are not protected. And while new technologies offer considerable opportunities to make economic gains for individual companies and offer potential working condition improvements for some occupations, sector-wide and economy-wide impacts and their subsequent effects on unprotected workers are difficult to predict.

- **Robust and dynamic stakeholder engagement.** Ensure that federal and state lawmakers and regulators implement an inclusive and comprehensive stakeholder engagement process. Engagement must guarantee participation of participants from diverse stakeholder groups within the transportation sector. The engagement process must consider the experiences, expertise, and perspectives of the different stakeholder, especially those that could be directly (positively or negatively) impacted by the new technologies. More importantly, engagement should be a dynamic process of partnership-building and investments and not a one-time effort.

- **Foster and incentivize the use of improvement technologies.** Efforts should be made to incentivize the private sector to invest, implement, and use new technologies that can improve the safety and efficiency of jobs, vehicles, and infrastructure, as well as the safety, efficiency, and quality of jobs and the lives of employees and other road users.

- **Expansion and innovation in dislocated worker support.** Expand and innovate federal and state worker dislocation and rapid response support. Existing and new programs should assess how different segments in the freight sector may be most vulnerable to job displacement and should be prepared for targeted support efforts**.**

Final remarks

This paper has discussed the potential impact of automation on jobs, providing an overview of selected examples in various freight subsectors. We have identified potential approaches to addressing the impacts of automation on labor, including: participatory assessments of impacts and solutions; leveraging and expanding programs and regulations; improving worker safety; efficiency and job quality through automated technologies; and training. Today, considerable uncertainties remain, which make the full effect of these technologies difficult to parse, thus this type of work must be revisited as technologies mature and penetrate the industries. Nevertheless, we hope that the work provides insights into the following key questions: How are different freight subsectors likely to be impacted by automation? Which subsectors are most and least vulnerable to job losses and declining job quality, and why? Where might new jobs be created, and what skills might be required for these jobs? For which subsectors will the transition to new employment be most difficult? What barriers exist to prevent workers from transitioning successfully to new, better positions or jobs? And lastly, how accessible and feasible are these new jobs/positions for displaced workers?

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Data Summary

Products of Research

This white paper is mostly the result of the comprehensive analysis of different reports and documents in the areas of freight, logistics, and automation. The study only used statistics to enhance the qualitative discussion and provide a reference for the size of the employment in the potentially affected industries. The study did not conduct quantitative analyses; thus, no dataset products were generated from this study. Quantitative information in this white paper in the form of Tables 1 and 2, and Figure 1-3 were generated using data from the referenced sources. The entirety of the data used is contained within the tables and figures, and no additional data was used in this study.

Data Format and Content

No data files were generated as part of this study.

Data Access and Sharing

The data used for the figures and tables is of public nature and can be accessed by the reader at the sources referenced in the white paper.

Reuse and Redistribution

Dr. Miguel Jaller and the other co-authors of the work (identified in this white paper) hold the intellectual property rights to the figures generated by the research. The data used for the figures is of open access in public reports.