DRIVERLESS?

Autonomous Trucks and the Future of the American Trucker

STEVE VISCELLI

SEPTEMBER 2018

A REPORT FROM THE
UC BERKELEY CENTER FOR LABOR RESEARCH AND EDUCATION
AND WORKING PARTNERSHIPS USA

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Acknowledgements

About the Author

Steve Viscelli is a sociologist at the University of Pennsylvania. He is a Robert and Penny Fox Family Pavilion Scholar, a Senior Fellow at the Kleinman Center for Energy Policy, and a lecturer in the Department of Sociology. In 2016 he published *The Big Rig: Trucking and the Decline of the American Dream* (University of California Press), about the work and fortunes of long-haul truck drivers.

Suggested Citation

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Executive Summary

Will autonomous trucks mean the end of the road for truck drivers? The $740-billion-a-year U.S. trucking industry is widely expected to be an early adopter of self-driving technology, with numerous tech companies and major truck makers racing to build autonomous trucks. This trend has led to dozens of reports and news articles suggesting that automation could effectively eliminate the truck-driving profession.

By forecasting and assessing multiple scenarios for how self-driving trucks could actually be adopted, this report projects that the real story will be more nuanced but no less concerning. Autonomous trucks could replace as many as 294,000 long-distance drivers, including some of the best jobs in the industry. Many other freight-moving jobs will be created in their place, perhaps even more than will be lost, but these new jobs will be local driving and last-mile delivery jobs that— absent proactive public policy—will likely be misclassified independent contractors and have lower wages and poor working conditions.

Throughout this transformation, public policy will play a fundamental role in determining whether we have a safe, efficient trucking sector with good jobs or whether automation will exacerbate the problems that already pervade some segments of the industry. Trucking is an extremely competitive sector in which workers often end up absorbing the costs of transitions and inefficiencies. Strong policy leadership is needed to ensure that the benefits of innovation in the industry are shared broadly between technology companies, trucking companies, drivers, and communities.

The findings below are based on in-depth industry research and extensive interviews with the full range of stakeholders: computer scientists and engineers, Silicon Valley tech companies, venture capitalists, trucking manufacturers, trucking firms, truck drivers, labor advocates and unions, academic experts, and others.

294,000 or 2.1 million?
The need for scenario-forecasting analysis

Prior studies and news stories have suggested that nearly all of the roughly 2.1 million heavy-duty truck drivers in the United States could lose their jobs to automation. However, that number includes many industry segments that are unlikely to be automated in the near future, such as local pickup and delivery and carriers using specialized equipment. This report finds that the jobs most at risk of displacement are long-distance driving jobs with few specialized tasks, representing about 294,000 drivers.

1. Today, wages and working conditions in trucking vary widely by industry segment

While truck driving is often portrayed as one of the few remaining middle-class jobs that doesn't require a college degree, Figure 1 shows that the quality of trucking jobs varies significantly across different segments of the industry, which can be split into long-distance and local driving.

Long-distance drivers move goods from factories to distribution centers or retail stores or between distribution centers. Many are working at "for hire" trucking firms, and an important distinction here is whether they are driving a full truckload for a single customer or if their load is a combination of freight from different customers (known as "less-than-truckload").

Drivers for less-than-truckload firms and parcel companies such as UPS typically have higher wages, better benefits, and stable careers (unionization rates are high). By contrast, full truckload companies tend to pay lower wages, churn through workers new to the industry, and often misclassify their workers as independent contractors (unionization rates are low). Unfortunately, these practices set the competitive standard in key parts of the industry.

Local driving jobs, particularly those driving light-duty trucks, pay significantly less than long-distance jobs. The large majority are local delivery drivers who perform a wide range of assignments, delivering anything from express packages to flowers. They take home salaries that can be half of what long-distance drivers make. The other major category of local driving jobs are at the ports, where drivers work long hours for low wages. When port drivers are contractors rather than employees, they can work the equivalent of two full-time jobs and earn less than minimum wage.

FIGURE 1: Current configuration of truck-driving jobs

Full truckload driver
Average earnings: $47,000 – $54,000

Parcel driver
Average earnings: $60,000

Delivery driver
Average earnings: $36,000

Port driver
Average earnings: $29,000 – $35,000

Less-than-truckload driver
Average earnings: $69,000
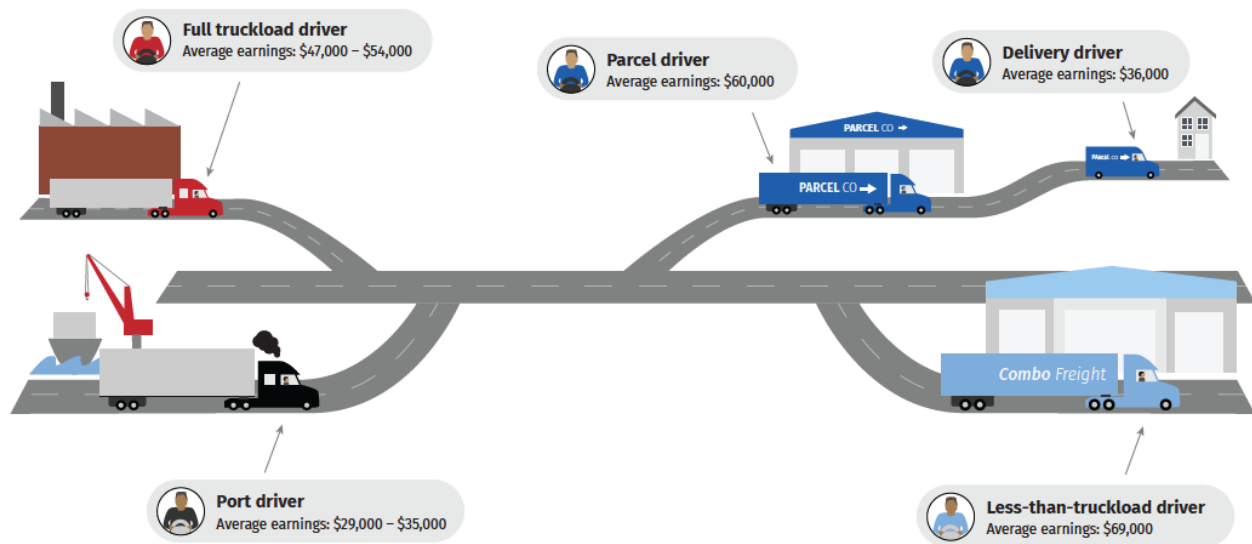
2. Without policy intervention, automation will likely eliminate high- and mid-wage trucking jobs, while creating low-quality driving jobs

Based on an analysis of a range of potential scenarios for the adoption of self-driving technology (see *Potential Adoption Scenarios, page iv*), here are the four ways that automation is most likely to change trucking:

Autonomous trucks are best suited to long-distance highway driving, while humans will still be needed to navigate local streets and handle non-driving tasks.

Many industry experts and developers expect that self-driving trucks will soon be able to drive autonomously on the highway, but that it will take far longer (perhaps several decades) before driverless trucks will be able to routinely navigate local streets packed with cars, pedestrians, cyclists, road work, and other unexpected challenges. Humans will also be needed to handle the many non-driving tasks—coupling tractors and trailers, fueling, inspections, paperwork, communicating with customers, loading and unloading, etc.—that drivers currently perform.

Therefore, the most likely scenario for widespread adoption involves local human drivers bringing trailers from factories or warehouses to "autonomous truck ports" (ATPs) located on the outskirts of cities next to major interstate exits. Here, they will swap the trailers over to autonomous tractors for long stretches of highway driving. At the other end, the process will happen in reverse: a human driver will pick up the trailer at an ATP and take it to the final destination (see Figure 2).

FIGURE 2: Most likely automation scenario, absent policy intervention

Local drivers
Low pay means old, polluting trucks & inefficient operations

Delivery drivers
Low wages, likely to be misclassified as independent contractors

Autonomous Truck Port

Autonomous Truck Port

Autonomous tractor
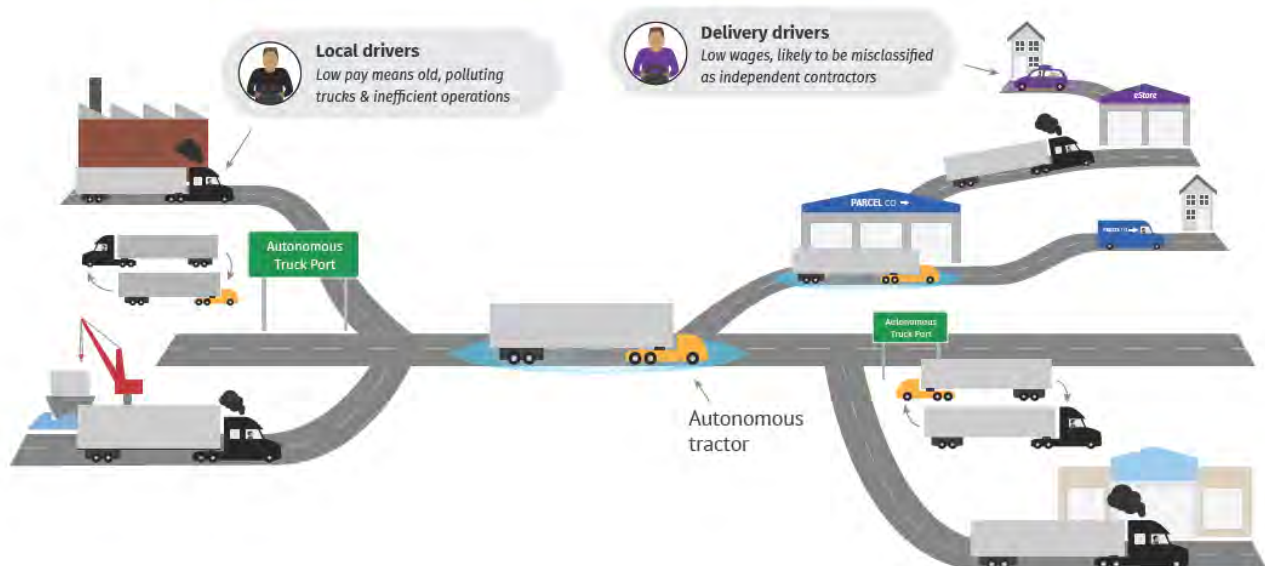
Potential Adoption Scenarios

This study is based on an analysis of six potential scenarios for how self-driving technology could be used in the trucking industry. The scenarios are the result of interviews with engineers, developers, trucking firms, and drivers, along with reviews of industry trade literature.

- **Human–human platooning:** A series of human-driven trucks would be electronically linked, with the lead truck controlling speed and braking in the following truck(s). This approach would let the trucks travel much closer together on the highway, improving aerodynamics and fuel efficiency. Each truck would still have a human driver to maintain the lane and navigate local streets.

- **Human–drone platooning:** Similar to the human–human platoon, except that a single human driver would lead a platoon of autonomous drone trucks on the highway. The human driver would be available to operate the lead truck, manage unexpected situations, or make repairs and ensure safety if a truck broke down mid-route. As in the exit-to-exit scenario below, local drivers would bring loads to an autonomous truck port (ATP) near the highway, where they would swap trailers with the drone trucks for the highway platoon.

- **Highway automation + drone operation:** Human operators would remotely control trucks on local streets and in complicated situations, and then trucks would drive autonomously on the highway. This approach would rely on highly trained dock staff to handle tasks currently performed by drivers, such as inspection and coupling.

- **Autopilot:** Similar to autopilot in airplanes, a human would handle loading and local driving, then sleep in the back of the truck while the computer drove on the highway.

- **Highway exit-to-exit automation:** Human drivers would take care of non-driving tasks and navigate complicated local streets, then swap trailers with self-driving trucks at an ATP next to the highway. The autonomous truck would handle the long-distance freeway driving, then hand off the load at an ATP near the destination.

- **Facility-to-facility automation:** In situations where warehouses and shipping facilities are located near major interstates, autonomous trucks may be able to handle industrial roads (where there are few pedestrians and complex intersections) and drive directly from origin to destination.

Absent significant changes in the policy or economic context, this report concludes that highway exit-to-exit automation is the most likely scenario to be widely adopted in the future. However, human-led platoons represent a model that has fewer technological challenges, a strong economic case, and better jobs for long-distance drivers.

Automation could replace most non-specialized long-distance drivers—about 83,000 of the best trucking jobs and 211,000 jobs with moderate wages but high turnover rates and poor working conditions.

As shown in Table 1 (page v), the most likely automation scenario evaluated in this report could result in the loss of an estimated 294,000 trucking jobs. Specifically, self-driving trucks will be best suited for use in industry segments with long stretches of highway driving, minimal need for drivers to perform other tasks, and large firms with the capital to buy (and expertise to integrate) new technologies.

Two parts of the long-distance industry best fit this bill:

TABLE 1: Truck driving jobs and potential impact of autonomous trucks

Key segments of the trucking industry	Average annual wage	Number of drivers	Turnover	Independent contractors	Unionization rates	Potential impact of autonomous trucks
LONG DISTANCE DRIVING						
Full truckload	$46,641–$53,690	211,000	High	Common	Low	Significant job loss
Less-than-truckload	$69,208	51,000	Low	Uncommon	High	Significant job loss
Parcel	$59,660	32,000	Low	Uncommon	High	Significant job loss
LOCAL DRIVING						
Ports	$28,783 (contractors) $35,000 (employees)	75,000	Low	Predominant	Low	Uncertain
Pickup and delivery	$35,610	877,670	Varies	Mixed, potential to shift towards contractors	Varies	Strong job growth
POTENTIAL NEW SEGMENT (PROJECTED)						
Autonomous truck ports	?	100,000+	?	?	?	Strong job growth

Notes: See Section 4 for sources on wages and employment.

Truckload

Truckload drivers typically work for large trucking companies, hauling full trailers over long distances directly from one customer location to another. These drivers rarely perform work such as loading and unloading or caring for special kinds of freight. These characteristics make their jobs more likely to be automated. An estimated 211,000 long-distance jobs in this segment are at risk of displacement from autonomous trucks. As described above, working conditions in this segment are arduous, and turnover is high. Wages are lower than in the unionized segment of trucking and private, in-house fleets, but higher than local delivery driving, the lowest-wage segment of the industry.

Less-than-truckload and parcel

In parcel and less-than-truckload operations, shipments from different customers are combined together at trucking company terminals, driven to another facility near the destination, and then

sent out for delivery. The long-distance drivers who haul these combined shipments on the highway rarely do much more than driving, which makes their jobs also vulnerable to automation. Up to 51,000 less-than-truckload drivers are at risk of displacement by autonomous trucks, plus another 32,000 parcel drivers. These are some of the best jobs in the industry, and drivers earn some of the highest incomes in trucking, in part because of high unionization rates. Because these drivers are able to make a career out of trucking, they tend to be older than the average driver and much older than the average U.S. worker.

Over the next several decades, e-commerce growth and lower freight costs could create many new driving jobs, perhaps more than will be lost to automation. Without policy intervention, however, these new jobs will likely have low wages and poor working conditions.

The combination of automation decreasing the cost of moving freight by truck and consumers ordering more goods online and expecting rapid delivery will likely increase the need for local drivers to:

- Move loads to and from autonomous truck ports;

- Shuttle goods from large centralized warehouses outside cities to smaller local depots—the approach being adopted by firms such as Amazon to enable rapid last-mile delivery;

- Deliver packages and other goods to customers' doors.

However, without proactive public policy, these new driving jobs are likely to be far worse than the jobs that are lost. Drivers bringing loads to ATPs are likely to face conditions similar to those currently experienced by port drivers, such as low pay, long periods of unpaid waiting, and independent contractor misclassification. The port driving sector is rife with stories of drivers putting in 16-hour days but losing money after paying off truck loans, company charges, and other fees. And if local drivers can only afford old and inefficient trucks, more communities are likely to suffer from the high pollution and asthma rates common in neighborhoods near ports.

Delivery drivers, meanwhile, typically take home less than half the pay of better-paid long-distance drivers. Retailers seem increasingly likely to subcontract to small firms with low pay or to adopt the Amazon Flex model of treating delivery drivers as independent contractors who do not receive benefits, must use their own vehicles, and lack the right to organize for higher wages and better working conditions.

Splitting trucking into local human driving and autonomous highway driving is likely to foster the "digitization" of freight matching, with the potential for intense downward pressure on driver earnings.

Currently, long-distance trucking firms rely on complex systems to match drivers with a series of loads, seeking to minimize miles driven without freight, while complying with limits on how

long drivers can be behind the wheel. Splitting trips between autonomous trucks that can almost constantly be on the highway and local human drivers who go home each night vastly simplifies this load-matching problem. This approach is likely to lead to the "digitization" of freight, with app-based marketplaces where local drivers can select from available loads.

Digitization could significantly reduce the number of miles driven without freight, saving the trucking industry billions each year. However, the destructive competition of a digitized load-matching system could put intense downward pressure on local drivers' earnings. To a significant degree, the impact of this approach on drivers will depend on public policy and job-quality standards.

3. Proactive industry and public policy action will be needed if automation is to deliver broad economic, environmental, and social benefits

The way we move goods is going to change dramatically in the coming decades, but how new technologies make their way onto our roads—who benefits, who may be left behind, the impact on our environment—will be shaped by the response of governments, businesses, and workers across the industry. Effective public policy can ensure that trucking evolves into a productive, high-road industry. Policymakers, collaborating with workers and industry leaders, have an opportunity to tackle some of our biggest challenges: creating good, family-supporting jobs, improving road safety, and reducing traffic congestion and carbon emissions. The following three main pillars should drive that collaboration.

Develop an industry-wide approach to worker advancement and stability

Policymakers should create a Trucking Innovation and Jobs Council, bringing together diverse stakeholders across the sector—workers, employers, technologists, and policymakers—to support a 21st-century trucking workforce. The Council would develop and implement an action plan for how industry stakeholders would fund, design, and carry out policies and programs to accomplish two goals: (1) the development of good career pathways and training/job-matching programs for incumbent, dislocated, and future workers; and (2) the creation of safety-net programs to support transitions within and out of the industry, including work-sharing initiatives, supplemental and flexible unemployment insurance, and retirement packages.

Ensure strong labor standards and worker protections

Policymakers should establish a framework of strong labor standards that can shape the impact of autonomous trucks, ensuring high-quality trucking jobs now and into the future. Specific policies include addressing independent contractor misclassification and wage theft; expanding early warning systems in the case of layoffs; and exploring new ways to establish good jobs in the industry and strengthen workers' right to organize. Some of these policies have long been needed;

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the goal is to enact them now so that low-wage business models do not become the norm in the industry's growth segments.

Promote innovation that achieves social, economic, and environmental goals

In order to ensure the best social, economic, and environmental outcomes for drivers, local communities, and our transportation infrastructure, policymakers need to play an active role in regulating the industry and the development of new technology. Examples of specific policies include engaging stakeholders to develop a shared innovation agenda and leveraging public research funding to implement it; allowing state and local governments to experiment with new policy responses; and ensuring that public dollars and policies do not subsidize the displacement of workers.

✦ ✦ ✦

What might an alternative, shared innovation agenda look like for the adoption of autonomous trucks? This report identifies an adoption scenario with good outcomes for workers, job quality, and public health and safety: human-led platooning, coupled with clean and electric trucks. Figure 3 illustrates this scenario, where drivers lead platoons of autonomous trucks on highways and have the experience and knowledge to deal with equipment problems, poor weather, and rapidly changing road conditions like accidents, construction, traffic, and erratic drivers. This model would yield many of the best environmental benefits of automation through increased fuel economy and the use of clean trucks for the growing segment of local driving. The policy menu outlined above would also raise labor standards and help train and support workers through the transition. The result would be a robust, sustainable 21st-century trucking industry that broadly shares the benefits of innovation among technology companies, trucking companies, drivers, and communities.

FIGURE 3: Alternative automation scenario, with policy intervention

Local drivers
Higher wages & driving clean electric trucks

Delivery drivers
Employees with good wages, rights and benefits

Autonomous Truck Port

Drone platoon pilot
High-skill, high-wage jobs

Glossary

The meaning and usage of many common terms vary significantly across the industry. The definitions given here are intended only to help the reader understand how I will use these terms in this report, which may differ from specific legal or regulatory definitions and/or informal usage within particular firms or industry segments.

Backhaul – A load originating where another load is destined that helps a trucker get back to where he/she wants to be. Typically not as profitable as the primary load, backhaul is often used to describe an undesirable load a trucker hauls to cover costs over distances they would need to travel regardless of whether they have a load (e.g., on their way home).

Brokerage – A business that arranges freight transportation by motor carriers but does not transport freight itself or take legal possession of freight.

Class 8 Trucks – Trucks with a gross vehicle weight of more than 33,000 pounds. This would include heavy tractor-trailers, which typically have a gross vehicle weight up to 80,000 pounds.

Container – A shipping container. A heavy-duty steel container in 20' or 40' lengths that can be loaded onto ships, rail cars, or onto a chassis for hauling by tractor. The predominant method for transporting imports and exports.

Contractor – A driver working as an independent contractor who is responsible for a large portion of the fixed and operating expenses of their tractor and who works under contract for a motor carrier. Contractors may own trailers but typically do not. Unlike independent owner-operators, contractors operate under the authority of a motor carrier which typically finds and prices all of the loads hauled by the contractor. Often contractors are misclassified employees.

Deadhead – Traveling without freight.

Dedicated – Freight service organized to serve the regular shipping needs of a particular—usually high-volume—customer. Dedicated service can entail meeting special requirements of shippers and almost always involves significant numbers of loads moving between particular origins and destinations. Dedicated service is typically a long-term (multi-year) relationship, and within their own fleet, motor carriers often differentiate drivers assigned to service a dedicated account.

Dray or Drayage – Transportation of freight over short distances. Also known as cartage. Often refers to container movements from ship and rail yards.

Dry Van – A standard non-refrigerated "box" trailer. Typically 53' long, but also in other lengths, such 48'. The most common trailer in the industry used to carry a majority of freight. Freight in a dry van is usually on pallets or in boxes.

Dry or Dry Van Freight – Anything that can be hauled in a dry van but is often hauled in refrigerated trailers.

For-Hire Motor Carrier (For-Hire Carrier) – An individual or firm with an FMCSA operating authority to offer freight transportation services to the public for a fee.

Hours of Service (HOS) – The federally mandated rules set by the Federal Motor Carrier Safety Administration (FMCSA) that regulate, among other things, how many hours drivers may drive and work over certain periods of time.

Independent Owner-Operator – The owner of a for-hire motor carrier who also works driving equipment they control. Independent owner-operators are responsible for all of the fixed and variable expenses of their operation and operate under their own legal authority to provide freight services to customers (which could include shippers, freight brokers, or other motor carriers).

Intermodal – Transportation of freight in which containers or trailers are transferred between different types of vehicles without unloading the freight. Typically used to refer to a combination of ship or rail and truck movement using containers.

Less-than-Truckload (LTL) – Freight service moving shipments generally less than 10,000 pounds. These services often consolidate multiple shipments into a single truckload-size shipment for long-distance transport and then break consolidated shipments down again for final delivery. Consolidating and breaking down of LTL shipments often happens at motor carrier-controlled terminals. Such operations typically use different drivers for local pickup and delivery and long-distance transport (known as linehaul).

Less-than-Truckload Carrier (LTL Carrier) – A for-hire motor carrier providing LTL service.

Linehaul – Transportation between facilities owned by the same firm, most commonly freight terminals with an LTL, mail, or parcel operation. Used in some segments to refer to truckload service on regular or dedicated accounts or, simply, over long distances.

Local – Freight services less than 150 miles from origin to destination.

Motor Carrier – Generally refers to a commercial vehicle transporting freight or passengers. For the purposes of this report, I use the term in the common usage meaning a motor carrier with an operating authority or motor carrier (MC) number issued by the FMCSA.

Parcel Service – Freight services that move packages or individual shipments of freight weighing roughly 150 pounds or less (e.g., UPS or FedEx).

Private Carrier – A trucking fleet that hauls goods that it produces or sells. A private carrier provides in-house services and does not require an operating authority.

Over-the-Road (OTR) or Long-Haul – Service that transports freight more than 150 miles from origin to destination.

Refrigerated (also Reefer or Temperature-Controlled) – Used to refer to freight that must be transported at a particular temperature. It can also refer to van trailers used to haul that freight or firms that haul it (called refrigerated carriers). Refrigerated vans (also called reefers) are often used to carry dry freight.

Regional – Can refer to carriers or transportation services that are longer than local (more than 150 miles) but concentrated such that drivers and equipment do not regularly move outside of particular regions, e.g., Northeast, Southeast, Upper Mid-west, etc.

Segment (or Industry Segment) – A portion of the trucking industry distinguished by freight or service type. There are numerous recognized segments based on whether carriers are private or for-hire, size of shipments, distance goods are moved, the type of trailer required, etc. The most common segment distinctions would include, among others: private/for-hire, truckload/less-than-truckload, over-the-road/local. Within the OTR, for-hire truckload segment are segments defined by the type of trailer used to haul freight (e.g., dry van, refrigerated, flatbed, tanker, etc.). Segments sometimes have relatively distinct business models for firms and different labor market and operational characteristics relative to drivers.

Sleeper Cab – A tractor with sleeping accommodations for a driver. Typically used initially in long-haul operation but often ends up as cheap, used equipment in inefficient local operations, such as port hauling.

Tractor – The power unit of tractor-trailer.

Truckload (TL) – For-hire freight service that moves shipments larger than 10,000 pounds, generally large enough to fill a truck to capacity, based either on legal allowable weight or trailer volume. Truckload freight generally moves point-to-point from shipper to consignee (receiver), without passing through a motor carrier facility.

Truckload Carrier (TL Carrier) – A for-hire motor carrier providing truckload service.

SECTION ONE:

Introduction

On October 25th, 2016, American news media heralded the first delivery made by an autonomous truck. That truck—developed by the startup Otto, which became part of Uber's Advanced Technologies Group before it was shuttered this summer—hauled a trailer full of Budweiser along I-25 in Colorado from Fort Collins to Colorado Springs. *An 80,000-pound truck drove 120 miles without a driver behind the wheel*. It certainly captured the imagination.

Since that demonstration, trucking has become the odds-on favorite as the first significant market for self-driving technology. In the span of less than a week in March 2018:

- Uber announced a pilot program in which its autonomous trucks would move actual freight on a regular basis;
- Embark (already moving freight in partnership with Ryder) announced that one of its autonomous trucks had driven from California to Florida;
- Starsky Robotics claimed the first autonomous trip in the United States on public roads without a driver in the vehicle at all;
- Waymo announced that its autonomous trucks would begin hauling cargo into one of its Atlanta facilities.

Autonomous trucks, with their promise of increased safety, improved productivity, and lower cost, seem just around the corner, leaving one inevitable question: what about the truck drivers who lose their jobs?

Popular press and industry experts have published numerous articles and reports suggesting a "jobs catastrophe" resulting from autonomous trucks.

Over the past two years, dozens of news articles have forecast "the end of the trucker." Reports from think tanks and consulting groups have suggested that autonomous trucks and other self-driving vehicles could result in several million lost jobs within a few decades.[1] Prominent commentators have suggested the imminent need to retrain large swaths of the workforce for new jobs and to consider minimum basic incomes guaranteed by government as unemployed truckers join the tens of millions of other workers sure to be displaced by automation in the coming decades.[2]

What will the consequences of autonomous trucks actually be? And how should these consequences be faced? This report argues that recent debate on both these questions has missed the mark— badly.

The Uncertainty of When Self-Driving Trucks Will Arrive

Over the past year, I've discussed self-driving trucks with scientists and engineers across the United States. Through these conversation and other research, I've learned that self-driving technology has made rapid improvements, but the technology still has a long way to go. A number of significant hurdles need to be overcome before autonomous trucks become commonplace on our highways. Predictions of when this technology will be ready for widespread adoption are "guesstimates" at best.

We can all imagine a future in which robots not only haul beer on the highways, but also deliver it right to our lawn chairs, yet that future is likely many decades away. In fact, it is unlikely we'll see any significant labor impacts from autonomous trucks in the next decade. If the technology continues to develop rapidly, however, we could see impacts that spread at a fair rate across the industry.

This report looks at what might happen in the next 25 years, a timeframe that allows policy to be researched, debated, and instituted for impacts that will affect existing workers and populations. Effective policy for trucking—with its complexity, importance for the economy overall, and generally polarized policy positions—will take a long time to develop, so the time to start is now.

Job Loss and Job Quality

This report estimates that the adoption of autonomous truck technology threatens around 294,000 jobs, and a significant number of the jobs at risk are among the best trucking jobs. Though many of the other jobs at risk are not good-quality, stable work from which truckers can make a career, they still pay better wages than most comparable jobs. The loss of both the really good trucking jobs and the better-than-the-alternative trucking jobs will hurt workers.

Rather than the "suddenly jobless" scenario that has been suggested, however, autonomous trucks, e-commerce, and economic growth are together poised to create many new trucking jobs. Twenty-five years from now there will likely be many more jobs moving goods than there are today.

The question is whether or not most of those jobs are going to be good jobs, with healthy working conditions and living wages. Historically, trucking has provided jobs with middle-class wages and security for workers. The quality of future freight-moving jobs, like that of most jobs in the United States, will depend on whether we have policies that protect workers and ensure the benefits of economic growth are equitably shared.

If current conditions seen in much of the trucking industry prevail—and it's likely they will, if policy doesn't change—the jobs created by autonomous trucks will pay far less than the jobs we might lose. The risk of autonomous trucks is not that there won't be enough jobs for American truckers, it's that there won't be enough good jobs.

Here's the good news: the technology of autonomous trucks itself won't determine whether the trucking jobs of the future are good or bad—policy will. Trucking has long had the potential for cut-throat and destructive competition and the negative repercussions on workers that follow. Workers need a policy that ensures they are protected from abusive practices and receive an honest return for their hard work. Because truckers work on our public highways and streets, we all benefit when trucking jobs are good and truckers are experienced, safe, and efficient. In fact, policies protecting workers from the costs of automation will also promote a clean, safe, and efficient trucking industry.

We need to reorient the debate around autonomous trucks to recognize these facts. Rather than trying to predict the specific damage autonomous trucks might do to workers, we must figure out how this technology can help us achieve a safer, more efficient industry, with better pay and improved working conditions for truck drivers. Bringing about that reality demands a thoughtful, long-term approach to the policies that will shape the use of autonomous trucks. This report argues that such an effort is worthwhile and suggests where we might begin.

Section 2 provides some basic background on the trucking industry and the development of autonomous trucks. Section 3 lays out a series of scenarios for how different kinds of autonomous trucks might actually be used, based on published reports and extensive conversations with technology developers. Section 4 suggests which trucking jobs might be affected by those scenarios and what the labor market impacts might look like. Section 5 concludes the report by suggesting a set of policy steps to help ensure that tomorrow's trucking jobs are good jobs.

SECTION TWO:

The Trucking Industry and the Development of Autonomous Trucks

Before the scenarios and job-impact analysis will make sense, we need to cover some background about trucking and self-driving trucks. This information will help us understand the important challenges the industry faces and the potential impacts of autonomous trucks.

Why Focus on Trucking?

The Department of Commerce reported that in 2015, there were 15.5 million workers in driving-related occupations that could be affected by autonomous vehicles or approximately one in nine workers in the United States. Workers who drive on the job are employed in a wide range of occupations, from truck and taxi drivers to electricians, firefighters, and home care aides. While self-driving technology might change many jobs, it won't eliminate most of them because driving is such a small part of what those jobs entail. In 2015, about 3.8 million workers (2.8 percent of the workforce) were engaged in jobs identified as primarily motor vehicle operators, including truck, bus, and taxi drivers.[3] While these workers almost always do more than just drive, much of their time at work is spent driving so their jobs may be at higher risk from automation.

This report focuses on the largest single job category of motor vehicle operators, and arguably, the jobs most immediately facing automation in the next several decades: heavy and tractor-trailer truck drivers. There were about 1.87 million such drivers in the United States in 2016, according to the Bureau of Labor Statistics (BLS), comprising a little less than half of all jobs that were considered primarily driving. In addition, a number of self-employed truck drivers do not figure in the BLS data. All told, there are probably a slightly more that 2 million heavy and tractor-trailer truck drivers. As Section 4 below suggests, about 300,000 of these jobs are at risk of automation not only because they involve lots of driving, but specifically, lots of *uninterrupted highway driving*.

Truckers and the Trucking Industry

Unlike anything since the CB radio craze and *Smokey and the Bandit,* autonomous trucks have drawn attention to the lives and fortunes of America's truckers. Hauling nearly 71 percent of the nation's freight, U.S. trucking is a $740-billion-per-year industry.[4] Virtually all the physical goods we consume move by truck at some point, sometimes several times. As a result of changes in all the stuff we buy, where and how it's made, and how we buy it, the trucking industry varies considerably in terms of how it moves freight and what that means for drivers. In order to understand how autonomous trucks will affect these workers, we need to look more closely at two important factors previously neglected in the analyses of autonomous trucks' labor impacts:

1. What the process of moving freight looks like in different parts of the industry;
2. How the labor market works in different parts of the industry.

These two factors are critical to understanding what kinds of trucking jobs are likely to be automated and what it will mean for workers to lose those jobs.

SEGMENTS OF THE TRUCKING INDUSTRY

Freight movement by truck varies in a number of key dimensions, most of which are important for both the likelihood of automation and the quality of the jobs at risk. For readers unfamiliar with the industry, these differences and the terms used to describe them can be bewildering. An introduction to the basic lay of the industry is useful before discussing autonomous trucks.[5]

The trucking industry can be divided up into "segments" that haul different kinds of freight using different kinds of equipment, in different size shipments, over different distances, at different speeds, and for different kinds of customers:

Long-haul (generally 150 miles or more)

For-hire truckload (dry and refrigerated)

"For-hire" carriers haul freight for client companies; for example, they bring Johnson & Johnson products to a Walmart distribution center. "Truckload" means shipments fill a trailer, by either space or allowable weight. Truckload freight goes directly from customer location to customer location, rather than first going to a freight terminal (as in less-than-truckload service, described below). For-hire truckload carriers include firms like Swift Transportation and C.R. England.

For-hire truckload service uses "dry" or "refrigerated" trailers. Dry vans are the standard box trailers you see on the interstate. If freight needs to be temperature controlled, it will go in a "reefer"—essentially a dry van with insulation and a refrigeration unit.

Private carriers

Some companies operate their own in-house fleets, like a paving company that moves stone to a mixing plant or Budweiser deliveries of beer to a corner grocery. In addition to having their own

private fleets, firms like Budweiser or Walmart may also contract additional trucking services from for-hire carriers.

Less-than-truckload and parcel linehaul

In contrast to truckload, "less-than-truckload" (LTL) companies like YRC move smaller loads that don't fill an entire truck. Typically, a local pickup-and-delivery driver brings a load from the customer to a freight terminal, where it's combined into larger shipments based on destination. Then a linehaul driver hauls the combined load to another company-controlled terminal near the freight's destination, where it's broken down and sent out for delivery on local trucks. "Linehaul" means the driver is moving between facilities owned by the same firm.

Parcel service moves packages using a process similar to LTL. Parcel is dominated by the twin giants FedEx and UPS.

Specialized and flatbed

Besides the standard dry vans and reefers, there are other types of trailers for specialized loads, such as flatbeds, tank trailers, and dozens of others. Specialized trailers carry cars, gases, trash, and more; super-long flatbeds transport oversized loads like windmill turbines and bridge trusses. For the purposes of this report, I will lump all the companies using those trailers—and there are tens of thousands of these carriers—into the commonly used category of "specialized."

Local (less than 150 miles)

Local pickup and delivery

In LTL and parcel operations, these drivers move packages and shipments between the customer and the freight-company-owned terminal, where they are combined in trailers for linehaul drivers to move over longer distances.

Port and intermodal hauling

Port drivers haul shipping containers between shipyards and a range of destinations, including warehouses, distribution centers, stores, and other transportation facilities.

For freight that travels most of the way by rail, intermodal trucks move the freight the remaining distance on the road.

Other local service

In contrast to long-haul, local service makes shorter trips, generally anything less than 150 miles.

THE QUALITY OF TRUCKING JOBS

As I will discuss in detail in Section 4, the quality of trucking jobs varies widely. In some segments of the industry, such as LTL and specialized hauling, the skill and experience of truckers is rewarded with good working conditions and pay—sometimes very good pay. In other segments of the industry, conditions are dismal.

Poorly treated long-haul drivers may live for weeks, sometimes months, out of their trucks without returning home. Due to the sedentary nature of the job, the constant presence of diesel exhaust, truck-stop food, lack of exercise, and other workplace hazards, these workers suffer tremendous health consequences.[6]

Many long-haul truckers are treated as independent contractors but are really misclassified employees. They shoulder the expenses of owning and operating the truck they drive but get no real benefits in terms of pay or control over their work. Turnover is a chronic problem in some of these segments. As a result, drivers in these segments are likely to be less-skilled, less-safe, and less-efficient drivers. In the general freight and refrigerated long-haul for-hire segments, for instance, turnover is very high (more than 100 percent every year at some of the largest carriers).

Despite the difficult conditions for many drivers, trucking still provides some of the better-paid blue-collar jobs in the United States, with heavy-duty truckers earning a median income of a little more than $42,480 a year in 2017, according to the Bureau of Labor Statistics.[7] That's far more than other workers in transportation, such as taxi drivers ($24,880), bus drivers ($33,010), and other delivery drivers ($29,250).

Long-haul drivers can make considerably more than the average trucker. According to data from the American Trucking Associations, the average long-haul for-hire dry van driver made $53,000 in 2017, up from $48,000 in 2013. Unfortunately, the analysis in Section 4 suggests that the best-paying jobs like these—as well as LTL linehaul jobs, which pay even better—are most at risk.

Local jobs, such as port hauling, pay far less than long-haul jobs, and workers often bear the cost of owning and operating the equipment they drive as misclassified employees, a practice that is the norm in this sector. These workers cannot afford new equipment, which means that dirty old trucks, no longer reliable enough for long-haul work, are common on local jobs, with the attendant pollution and health consequences, such as increased childhood asthma in neighborhoods near ports.

Though workers in these local jobs usually get home nightly, they often work the equivalent of two full-time jobs, sometimes for less than minimum wage. These poor-quality and low-paying jobs are the result of declining regulation in the industry and the spread of abusive labor practices as employers seek higher profits and insulate themselves from risk in the face of destructive competition. Absent policies to protect workers, jobs like these are the most likely to be created in the coming decades as the industry automates.

What Is an Autonomous Truck and Who Is Making Them?

For the purposes of this report, I will distinguish between self-driving, driverless, and autonomous trucks. By self-driving, I mean that a vehicle can drive itself but may not be able to operate without a human behind the wheel (Tesla's current vehicles, for instance, are self-driving). Self-driving would be the broadest category. By autonomous, I mean a vehicle that can drive itself without a human ready to take control in at least some environments, such as highway driving. On the far end of the spectrum, driverless trucks have no human in the vehicle at all.

Since the primary concern of this report is the potentially significant labor impact of self-driving trucks, I focus on autonomous trucks, which may or may not be driverless. When a trucker is no longer needed behind the wheel, there is the potential for significant productivity gains and thus potential labor impacts, such as job losses.

In contrast, in the near term we can envision self-driving systems, including capabilities like adaptive cruise control and lane maintenance. A number of developers, such as Freightliner, are working on features that may improve safety and relieve driver fatigue but do not increase productivity to the point where there would be significant job losses. Some functions might be automated, but these improvements do not result in a fully autonomous truck. Meanwhile, other firms are working to build trucks that never require a driver in them.

The most common way to explain where certain systems fall in terms of automation is the automation scale used by the Society of Automotive Engineers. On a scale of zero to five, Level 0 means that no functions of the vehicle are automated, while Level 5 means the vehicle can operate without human intervention—or without a human even in them—in all driving conditions. In Levels 1 to 4, the lines are a little blurry, and debate will undoubtedly ensue as the technology develops. Fortunately, for the purposes of this report, we don't need to resolve this challenge with great precision.

A Level 2 system has multiple automated functions. Level 3 vehicles can operate themselves completely in certain environments but must be monitored at all times by a driver prepared to take control—a monitored autopilot, if you will. While Level 2 and 3 automation will be considered briefly, with regard to safety and other issues, they are only of interest here because of that technology's potential as a path to Level 4 automation.

Level 4 vehicles can operate on unmonitored autopilot or autonomously in certain environments. Level 4, most importantly, means trucks can operate on highways without a driver behind the wheel (an autonomous truck) or, potentially, without a driver in the vehicle at all (a driverless truck). Level 5 means the vehicle can operate in *any* conditions or environment without requiring a human—they could be driverless.

While Level 2 and 3 systems could have significant safety and fuel efficiency benefits, the scenarios in Section 3 focus on Level 4 and 5 systems, because they will have significant labor impacts.

At present, most of the systems that are immediately aimed at Level 4 or 5 driving rely on relatively similar combinations of technology. They use a wide range of sensors, including lidar (laser radar),[8] video cameras, traditional radar, ultrasonic sensors, and various motion sensors, such as accelerometers. These sensors feed a tremendous amount of data to a computer on the truck, which then creates a three-dimensional map of the truck's environment and the objects around it. Some developers are also exploring the use of more detailed "base maps" that reduce the amount of information the truck needs immediately from the sensors. The computer then uses all that information and GPS data to make decisions about where and how to drive, using algorithms to predict the consequences of its own and other vehicles' behavior.

SECTION TWO: The Trucking Industry and the Development of Autonomous Trucks

FIGURE 2.1
Key technology used in self-driving trucks
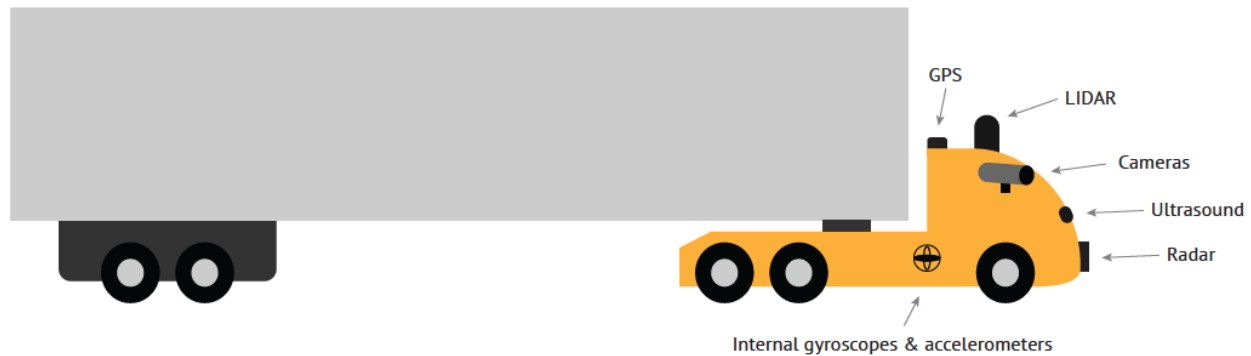
Work on self-driving cars began in the 1970s in Japan and was taken up at universities and automakers in United States and Europe in the 1980s and '90s. For decades, the U.S. government, in particular, has funded basic research out of interest in military applications. The best-known efforts are the Defense Department's Defense Advanced Research Projects Agency (DARPA) Grand Challenge, first held in 2004, and the Urban Challenge, held in 2007. These competitions offered teams substantial cash prizes to build self-driving vehicles that could complete courses in desert terrain and then a simulated urban environment. Since then, engineers and computer scientists at leading U.S. universities and around the world have accelerated work on self-driving hardware and software.

Now that self-driving technologies hold more immediate commercial promise, some of the world's most resource-rich companies are working to bring them to market. These private efforts began in earnest with Google's driverless car program in 2010. Today, self-driving technology is being developed by dozens of major firms in the tech sector as well as numerous vehicle manufacturers and suppliers. Among those working on self-driving cars are Silicon Valley giants—like Apple, Waymo (formerly Google's driverless car project, now owned by Google's parent company Alphabet), Uber, Lyft, and Tesla—and major automakers, including Daimler, Audi, BMW, Volkswagen, Volvo, GM, Ford, Honda, and Toyota. Numerous suppliers, such as Delphi and Bosch, are likewise working to develop self-driving technology, many in partnership with tech firms, like Nvidia, Samsung, Intel, and Microsoft. In fact, it's hard to find any major vehicle manufacturer not working on self-driving technology and increasing their investment in that work.

While private efforts and demonstrations dominate headlines today, as we consider the responsibility of government to influence how this technology affects workers, the public, and the environment, we should not forget that this technology was, until recently, largely developed by public dollars.

Beyond highlighting the public role in creating this technology, this brief history should help skeptics understand that self-driving vehicles are not the fantasy of a few mad scientists or a Silicon

Valley vanity project, but rather a long-standing, well-funded set of interrelated efforts by thousands of scientists and engineers across academia, industry, and government, whose efforts have already developed the basic technologies required for self-driving vehicles. Today, billions of dollars are being invested annually to achieve the goal of autonomous vehicles.

Why Autonomous Trucks May Come Before Other Self-Driving Vehicles

Trucks are different from cars and will require different self-driving technology—including different placement of sensors, longer braking distances, and more space to turn, as well as more physically robust components—but the most difficult technological challenges are shared by both types of vehicles. Significant investment in the specific development of self-driving trucks is more recent. Until just two or three years ago, work on trucks with significant automation in the United States was confined to just one start-up (Peloton) and small projects within major truck makers, aimed primarily at collision avoidance and lane-maintenance, including the notable efforts of Freightliner (owned by Daimler). Internationally, Volvo, Daimler, and others were taking on more ambitious projects in self-driving commercial vehicles. As a result, autonomous vehicles, including trucks, are already operating profitably in controlled environments, such as seaports and mines in both Canada and Europe.

Autonomous trucks are now seen as a lead sector for autonomous vehicle adoption in the United States. Total funding for new truck technology development, including autonomous trucks, was estimated to reach $1 billion in 2017, up 1,000 percent in just three years.[9] Major projects for Level 4 autonomous trucks are now underway by Waymo as well as a number of startups, including Embark and Starsky Robotics.

A simple economic argument recognized since at least 2013 explains why self-driving trucks will be adopted before driverless cars.[10] The purchase of a truck is a business decision that is often thoroughly evaluated by fleets, and given the potential labor savings of Level 4 and 5 autonomy, the returns on investment could be extraordinary.[11]

In addition, numerous inefficiencies related to human truck drivers—such as mandatory rest breaks and the need for drivers to return home, even only for a couple of days every few weeks—not only raise costs but make truck freight slower. Just as importantly, the largest segment of the industry, for-hire long-haul truckload, has high turnover and difficulty recruiting new drivers due to poor working conditions and low pay. Eliminating the need for drivers would be a tremendous boon for companies in that segment. Unlike cars, there is already incredible demand for the potential benefits of autonomous, even driverless, trucks.

It is conceivable that autonomous trucks could double the productivity of long-haul trucks for highway segments. They could also substantially reduce fuel costs, which comprise another 30+ percent of total costs for many carriers. Relative to these gains, the cost of self-driving technology is expected to be small. Like other researchers who have interviewed experts and developers, I found that, despite some uncertainty, the expectation is that self-driving technology would add less than

SECTION TWO: The Trucking Industry and the Development of Autonomous Trucks

FIGURE 2.2
Potential savings to the U.S. freight transportation industry from autonomous freight vehicles

In 2013, the investment firm Morgan Stanley conservatively estimated that autonomous trucks would save the industry $168 billion. Analyses like these suggest a strong economic argument for trucking as a lead sector of autonomous vehicle technology.

$35bn
Fuel efficiency gains

$70bn
Labor savings

$168bn
Autonomous freight vehicles total savings

$27bn
Productivity gains

$36bn
Accidental savings

Source: Morgan Stanley. Autonomous Cars: Self-Driving the New Auto Industry Paradigm. Morgan Stanley Blue Paper. November 6, 2013.

20 percent to the cost of a new tractor.[12] It is important to note, however, that such affordability is dependent on dramatic reductions in the cost of some of the more expensive parts of the systems currently under development, such as the powerful lidar most of these vehicles depend on.

Autonomous trucks could also operate around the clock, essentially doubling the performance of a human-driven truck. The value of a self-driving car, on the other hand, is unclear for individual buyers who will be riding in the vehicle, regardless of whether they are driving or not.

From a technological standpoint, autonomous trucks have another advantage over cars. Self-driving cars will be operated primarily in congested urban areas and on local roads, which present a far greater challenge in terms of object recognition and decision making by artificial intelligence. In contrast to passenger cars, an autonomous truck that can operate only on the highway might be highly profitable.

In light of the above considerations, trucks are now seen by many experts and those in the industry as one of the clearest opportunities for early adoption of self-driving technology. Existing reports, however, overestimate the readiness of this technology for actual trucking operations, when adoption will begin, and how rapidly it will spread. As a result, many analysts conclude that job losses could come within a few years and spread across the industry in just a decade or so. Such rapid deployment and adoption of self-driving technology is extremely unlikely.

Even the most optimistic developers believe we are still at least several years away from autonomous trucks operating even in limited highway operations in anything other than testing programs with

drivers still behind the wheel. Important challenges in both hardware and computer science need to be overcome before autonomous trucks are able to operate safely and reliably.

The cost of components, including some very expensive sensors, must drop significantly before autonomous trucks will be economical. Some potential self-driving technology may require improved infrastructure maintenance or new infrastructure, ranging from better lane markings to more robust wireless communications networks. Once autonomous trucks are demonstrably safe, there may also be important regulatory debates to ensure safety. For instance, if drivers and autonomous trucks will work together, there are questions about how this collaboration will affect rules that limit drivers' work hours to ensure that they don't drive fatigued. Given the slow speed at which trucking regulation typically is debated and implemented, addressing such an issue will likely take years.

Then, before autonomous trucks can be adopted on a widespread basis, they will need to demonstrate reliability and feasibility within the operations of actual trucking firms. A change in equipment and operations this fundamental is not something trucking carriers will do without lengthy consideration. Trucking equipment, both tractors and trailers, are used in harsh conditions for hundreds of thousands, even millions of miles. Equipment critical to the safety and reliability of these systems, such as computers, sensors, wiring, etc., will need to withstand cold temperatures, near constant vibration, ice, salt, and more, over long periods.

Also challenging for developers is the relatively low number of units sold by truck manufacturers. In 2016, some 250,000 class 8 trucks (the largest trucks) were sold.[13] The number of autonomous trucks sold per year would be significantly smaller because most class 8 trucks don't operate over long distances. Sales of passenger cars and light trucks, on the other hand, totaled around 17.5 million in 2016.[14]

Finally, when autonomous trucks can be safely and legally operated, they will only perform one task: driving. Most truck drivers do far more than just drive. Reports suggest there are 3 or 4 million driving jobs at risk, but they use broad categories to represent "driving occupations."[15] As other experts have clarified, in nearly all the jobs that fall under such broad headings, driving is one task among many others, and driving may not even represent a majority of the work in many of these jobs.[16] In fact, for many of the trucking jobs I identify below as the most likely to be automated, driving may only represent about 50 percent of drivers' total work time.[17]

Instead of assuming that an autonomous truck can operate in all freight operations and that all drivers are equally at risk, we need to identify more precisely which jobs may be affected. Thus, we need to understand in more detail the ways in which autonomous trucks might be used. A range of self-driving technologies is currently under development, and each has its own particular challenges, potential benefits, applications, and likely job impacts. Section 3 lays out different scenarios for how the technology described might be used in practice. Section 4 explores which segments of the industry might be able to use it, if the scenarios in Section 3 are correct.

SECTION THREE:

Scenarios for the Use of Autonomous Trucks

We don't know exactly what autonomous trucks will be able to do, but looking at the technology that various firms are developing can help us understand the potential impacts in the near-to-medium term (0–25 years, by my definition). While technologists and experts consider a few scenarios far more likely than others, it is worth looking a wide range of alternative scenarios for a number of reasons.

First, this analysis is not intended as a prediction of exactly how autonomous trucks will be used. Rather, it is intended to begin a serious conversation about how we can forecast and shape the potential impacts of autonomous trucks to maximize the benefits of these technologies and ensure that these benefits don't come disproportionately at the expense of workers who are displaced or have their pay or working conditions deteriorate.

Second, uncertainties about the technology's future are significant and evolving. Over the past several years, firms and experts have viewed a number of ideas about how autonomous trucks might develop as more or less likely. Real uncertainty exists around key aspects regarding the mix of capabilities, reliability, and costs of all of the different possible autonomous truck technologies currently under development.

Third, given the diversity of operations and customers within freight transportation, it is likely that over time, a number of different applications of autonomous truck technologies could be successfully brought to market to suit different segments of the industry. Just as no single trucking process or equipment moves all freight today, no single technology or process will move all freight in the future.

To develop the following scenarios, over the course of the past year I have studied the existing popular coverage as well as industry and scholarly literature on self-driving technology. I also interviewed numerous experts and discussed potential technology with stakeholders in the industry—including Silicon Valley tech companies (Uber ATG[18] and Peloton among others), truck manufacturers, truck drivers, venture capitalists, computer scientists, engineers, labor advocates and unions (including NGOs and the International Brotherhood of Teamsters), academic experts, and others—to finally derive at these six scenarios for the use of autonomous trucks.

WHY SCENARIO FORECASTING?

The primary method used below is scenario forecasting, which describes a series of likely or possible futures. Scenarios are good for thinking about the likely outcomes of disruptive technological development when a complex set of factors make modeling and trend extrapolation based on existing data impossible or likely to be unreliable. In this case, the choice of scenario forecasting is justified by the disruptive nature of autonomous trucks, the complexity of the existing truck freight transportation industry, and the presence of significant trends, such as e-commerce, with uncertain implications for the adoption of autonomous trucks. Scenarios also make clear the importance of considering the labor process involved in moving freight and the way that process and possible alterations to it will make autonomous truck adoption more or less desirable.

The scenarios below identify the major self-driving technologies that have been publicly identified and suggest how they might be used. The hope is that they can be the basis of stakeholder engagement aimed not at predicting the future, but shaping it. Scenarios are commonly used in transportation planning when a number of competing goals might need to be balanced and public policy can clearly affect that balance through regulation, infrastructure investment, and other roles.

We need to move beyond trying to predict the inevitable outcome of autonomous truck development and recognize the importance of identifying the benefits we want to bring about. We don't need precognition; we need a road map that will help us understand how to encourage the development and adoption of autonomous trucks to meet the goals we set.

AUTONOMOUS TRUCK PORTS

A number of the scenarios described below involve trucks that can only drive on highways because local driving, with the presence of pedestrians, intersections, etc., is simply too complex. One of the ways to solve this problem is to hand off trailers between human-driven trucks and autonomous trucks near the exits of the interstate highway system. Such operations could use a facility I call an "autonomous truck port" (ATP). As illustrated in Figure 3.1 (page 15), ATPs would be strategically located truck parking lots (or "drop lots") at interstate exits outside of congested urban areas. These staging areas would provide space to park and couple trailers but could also have driver facilities and fueling or charging options for trucks.

Having trucks stop at ATPs would allow for the use of the most fuel-efficient technology on either side of the port, whether local driving (e.g., electric) or long-haul driving (e.g., sleek aerodynamics). These facilities would also facilitate off-peak deliveries to keep trucks out of rush-hour traffic. They could be publicly owned land with private services or privately owned entirely.[19]

The use of ATPs would have tremendous impacts beyond the physical operation and efficiency of the truck itself. It would cut down on the coordination required between shippers and carriers. Instead of having to find freight service from point to point, the service could be provided by a local truck that is getting freight through an app, which would greatly increase the efficiency of matching freight to drivers and potentially lower costs for smaller shippers, in particular. This sort of task could be accomplished using an Uber-style application, with real-time pricing. A local truck might bring

SECTION THREE: Scenarios for the Use of Autonomous Trucks

FIGURE 3.1
What an autonomous truck port could look like

the freight to an ATP, where an autonomous tractor would take over, for instance. Since there would be a large volume of tractors and trailers continually moving through the same facilities, in theory there would be little reason that a particular autonomous tractor could not go to many or nearly all other ATPs. Tractors and trailers could be mated based on timing of their arrival to the ATP.

KEY TRENDS TO CONSIDER: THE DIGITIZATION OF FREIGHT MATCHING AND E-COMMERCE

Key trends that will shape the impact of autonomous trucks and, in turn, be shaped by the development of autonomous trucks include the digitization of freight matching and the growth in e-commerce and last-mile delivery.

Digitization refers to the matching of freight with trucks by means of a platform similar to that used by transportation network companies, such as Lyft and Uber, to match passengers with drivers. There have been a number of attempts to digitize freight in recent years using better information technologies.

At present, the matching of freight to trucks happens through numerous processes ranging from long-term contracts to Internet load boards. The largest shippers often contract well in advance for freight services from large trucking carriers, but many shippers are dependent on brokers who match supply and demand on a short- and medium-term timeframe. Substantial friction persists in the transactions involved in matching freight and carriers and in the interactions between firms. This

problem is most often handled by freight brokers who take a significant chunk of load revenue for their efforts. And, despite technological advances in the industry, this work is done by thousands of workers who call customers looking for freight and matching it with trucking carriers that need loads for particular trucks. Today, it often takes several hours, multiple emails and phone calls, and maybe even a few faxes, to mate a load with a truck.

The idea underlying the digitization of freight is that if you can get more loads and more trucks into a transparent process, then you can more efficiently match them in terms of time of availability and location. The value of even a few percent improvement in the system of matching freight and trucks overall could reduce the miles traveled empty to pick up to load (known as "deadheading") and waiting time that could be calculated in the billions of dollars annually.

However, the challenge of creating a functional market around these platforms is far more complicated than some new entrants imagined, and a number of these digital brokers have stumbled in recent years. Nonetheless, the basic idea of more efficient matching of supply and demand is widely seen as having real merit by nearly everyone in the industry.

Another key issue to consider is the explosive growth in e-commerce and in last-mile deliveries *and* returns. While most of this growth has thus far been handled by the U.S. Postal Service, UPS, and FedEx, new models are emerging to meet surging demand. Numerous last-mile delivery services have begun for groceries and other product categories. Likely to be most important in this area is the development of Amazon's own delivery services, known as Amazon Flex and Amazon Delivery Service Partners (DSP). Like most other new last-mile delivery services, Amazon Flex hires independent contractors who use their own vehicles to carry packages from Amazon fulfillment centers to customers. Amazon DSP, just launched, is a franchise-like model for Amazon to subcontract its delivery service out to small, nominally independent companies.

The biggest problem with the digitization of freight and the growth of last-mile delivery is a concern that has plagued trucking since its earliest days: destructive competition. There may be little profit to be made in moving digitized and last-mile freight, and the vast majority of costs may be borne by workers in the form of lower pay and risks associated with owning and operating equipment. As we see in for-hire long-haul truckload and port hauling, without rules to stop them, the response by companies to digitization will be to use poorly paid employees and, whenever possible, independent contractors who provide their own vehicles.

THE LIMITS OF THE ANALYSIS: UNDERSTANDING THE JETSONS FALLACY

Current estimates of job loss from autonomous trucks often commit the "Jetsons Fallacy," and this report may, as well.[20] *The Jetsons* was a cartoon, first aired in 1962, that depicted a family of 100 years in the future. They had flying cars, a robot maid, machines that made meals instantly, smart watches, and holograms. In fact, *The Jetsons* predicted many cutting-edge technologies that are commonplace today. What *The Jetsons* didn't get right were the social norms and behavior of the future, and the way technology would transform and intersect with them.

George Jetson, the father, is a bumbling patriarch and solo breadwinner. Jane, his wife, is a dutiful homemaker, who sneakily snatches George's wallet to head off to the local shopping mall. George and Jane live in a nuclear family, with two cute kids. When the family uses its instant food machine nightly, everyone gathers around the family dinner table, except Jane, who stands next to the machine pushing buttons as if she were at a stove. The machine's performance—or rather, Jane's inability to get it to perform—is a frequent source of arguments. As Jane operates the machine, her husband and children engage in intimate, thoughtful conversation about the day's events and their lives, oblivious to the ubiquitous screens, video phones, and smartwatches around them.

In short, while the capabilities of the technologies weren't far off, how they would affect people's behavior wasn't even close. *The Jetsons* kept family and social life constant and simply substituted one tool for another. It mapped the technology of the future onto an idealized 1950s American family, without understanding that new technologies—like processed or fast food and smartphones—would combine with other economic and social changes to transform the way we live.

To an even greater degree than it affects life at home, technology directly transforms the way we work. Automation in the workplace is fundamentally about increasing productivity by changing which tasks are performed by humans and which tasks are performed by machines. But in changing the division of tasks, automation often transforms the labor process more generally. The Jetson Fallacy for autonomous trucks would model future scenarios that assume autonomous trucks will replace human-driven trucks without meaningfully affecting the process of moving freight, including where, when, and how much of it moves.

Let me give one example to illustrate this point. Walmart is widely considered to have the most sophisticated logistics system of all big-box retailers. The firm gains tremendous advantages from that system and is constantly exploring innovative ways to improve the efficiency of its trucks and truck movements. Once autonomous trucks are able to successfully go from facility to facility (for example, from Walmart's distribution centers to its stores), Walmart will very likely be one of the earliest adopters among private carriers. The Jetsons Fallacy in this case would be to assume that Walmart would simply substitute autonomous trucks for those operated by human drivers who perform the regularly scheduled deliveries of goods from distribution centers to stores. In these very well-paid jobs, drivers make one to two trips, taking full trailers of new goods from distribution centers to stores and returning with empty trailers or trailers carrying damaged or returned merchandise. Sometimes these drivers will pick up a load of new goods headed to the distribution center on their return trip.[21]

In fact, while Walmart might adopt autonomous trucks for regular service from distribution centers to stores, it might also make far more radical changes to its logistics system. Why? Because Walmart's logistics system was built around the limitations of human-driven trucks. One of the greatest insights that Sam Walton had was that truck efficiency was critical to making the most of a distribution center-based model.[22] In order to maximize the trucks' efficiency, Walton's strategy was first to identify areas where he wanted to locate stores and then place a distribution center within one day's roundtrip drive for Walmart's trucks. For many of reasons, from speed of restocking inventories, to asset utilization, to labor costs, this was a great distribution model.

SECTION THREE: Scenarios for the Use of Autonomous Trucks

The limitations of human-driven trucks were foundational considerations in designing Walmart's overall logistics system. If autonomous trucks, which don't have to stop to sleep, can travel twice as far in a day, what will Walmart do? Most likely it will consolidate distribution centers, spacing them further apart and allowing Walmart to reduce inventory costs.

In similar ways, the limitations of human truck drivers have been a factor in siting and operating acre upon acre of warehouses, retail space, highways, truck stops, parking lots, and other assets and infrastructure. Autonomous trucks will fundamentally change the capability of trucks and the economics surrounding their use. In combination with trends in e-commerce, last-mile delivery, and the potential for extensive digitization of freight markets, autonomous trucks will remake the movement of goods in the United States.

Finally, it is critical to recognize that while autonomous trucks might make long-haul trucking cheaper and faster, e-commerce has been steadily increasing the number of short trips retailers use to supply more goods faster and in smaller shipments to customers. Predicting the overall impact of autonomous trucks then requires understanding how it will intersect with these other trends—a task whose difficulty should not be underestimated.

Six Potential Adoption Scenarios

In what follows I lay out six potential scenarios of how autonomous trucks might be adopted in the trucking industry.

TECHNOLOGY SCENARIO 1:
Cooperative Adaptive Cruise-Control Platooning

Cooperative Adaptive Cruise-Control Platooning (often simply called "Platooning") has the longest public profile of recent automated driving technologies. The goal of platooning is to allow two or more trucks to save fuel by drafting each other to reduce wind resistance, just as bicycles or cars do when racing. Optimal drafting requires trucks to be fairly close to each other, somewhere less than 70 feet apart depending on conditions.[23] This following distance is significantly less than what is considered safe at highway speeds for large trucks without automated technology, which would

Platooning aerodynamics improve fuel efficiency

Following truck's speed & braking is controlled by lead truck

Lead truck fully controlled by driver
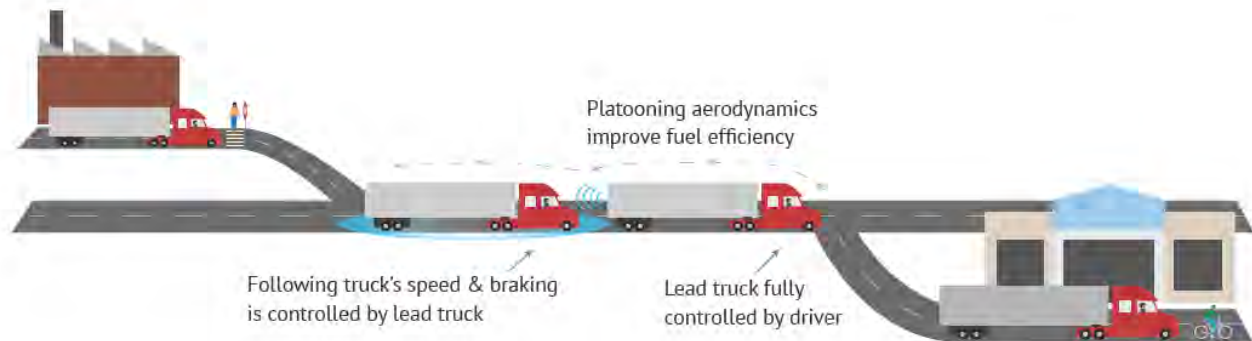
typically be at least several hundred feet. Of course, on highways in many areas of the country today, as a result of surrounding traffic and other factors, freight trucks often end up following one another at distances closer than is safe, without active safety or platooning systems.

Platooning utilizes a combination of sensors, GPS, wireless, and vehicle-to-vehicle (V2V) communications technologies to allow trucks to follow very closely behind one another by linking their acceleration and braking. One leading provider of platooning systems uses a control center to track and match potential trucks, assigning them to a platoon based on location and a number of important factors, such as each truck's weight and estimated braking capabilities. Once linked in a platoon, the lead truck is entirely under the control of a human driver. The trailing truck or trucks follow directions provided via wireless links based on the operations of the lead truck but only for acceleration and braking. The human driver of the following truck is still responsible for steering and maintaining proper position in the lane.[24]

Currently, platooning is envisioned as a practice that will be used only during highway driving and as a means to achieve greater fuel savings, reduce highway congestion, and improve safety. As yet, removing the human drivers in following trucks has not been tested or stated as a near-term goal by U.S. developers or trucking firms. At present, platoons involving only two trucks (one lead, one follower) are proposed for the United States, though demonstrations are planned in Singapore using one lead truck and three following trucks, and three-truck platoons have been demonstrated in Europe. A number of U.S. states have developed or are developing regulations that will allow platoons to operate, the primary regulatory obstacle being restrictions on following distances between vehicles.

A wide range of trucking operations that travel significant distances on interstates could adopt this technology in the near future, if communications equipment could be integrated with truck technology in a cost-effective fashion. The most likely adopters are large truckload carriers, which have lots of trucks on the road that might be close enough to make platooning efficient, and less-than-truckload carriers, which have multiple trucks leaving terminals on regular schedules, making coordination of platooning trucks easier.

The most likely way for trucks to be linked to a control center and across firms is through existing 4G LTE cellular communications. Widely available cellular communications provide the ability to coordinate platooning between trucks from different carriers. In the approach of Peloton, the leading U.S. developer of platooning, a Network Operations Cloud provides "platoon authorization," and drivers make the decision to form or dissolve platoons. In the event that cellular communication is lost, vehicles can retain Network Operations Cloud authorization for a defined time period before authorization is removed.

Platooning may result in significant fuel or energy savings[25] and, thus, cost savings for operators. Along with lane maintenance and collision avoidance, it represents one of the most high-profile examples of a possible incremental adoption path to self-driving trucks.[26] Since the driver in the following truck is still responsible for steering and lane maintenance, there will be no significant productivity gains in terms of labor and, thus, no job losses. However, if platooning is a path to having fully autonomous following drone trucks, as some industry players believe, future higher automation systems using platooning could then provide significant driver productivity improvements and have significant labor impacts, as addressed below.
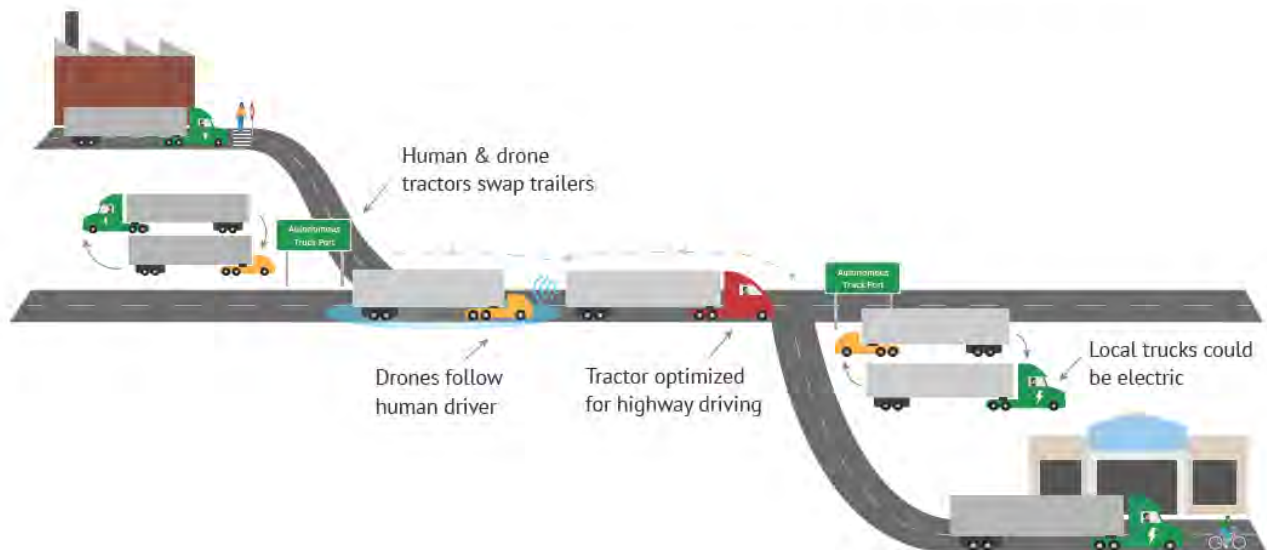
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There are several issues related to job quality and other safety-related aspects of cooperative adaptive cruise-control platooning that will require further consideration. While platooning, the following driver's view of the road ahead is a consideration; this view depends on the inter-vehicle gap. The view of the rear driver at typical platooning distances of 60 feet provides the rear driver with the ability to see surrounding traffic and road signs. A video feed from the front truck provides awareness of traffic ahead. Voice communications between the two drivers increases situational awareness for both. At the same time, following drivers need to track the position of their own vehicle within their lane. While drivers have been trained to maintain a following distance from the vehicle ahead that would allow them to react and brake, the NACFE Confidence Report on Platooning notes that the learning curve for platooning "is not steep."[27]

The level of stress affecting the following drivers after long periods of platooning should be considered. In particular, the health and safety impacts of several-hour stretches of this kind of behavior is something that may require further study. I did talk with a former test driver for Peloton who reported he did not perceive additional stress or fatigue, even at high speeds, during platoons. To the contrary, due to the constant presence and communication with the lead truck, this driver reported finding platooning less monotonous and, therefore, safer. At present, it appears the potential fuel, safety, and congestion benefits of platooning far outweigh the costs. Adoption of this important technology could begin by the end of 2018.

TECHNOLOGY SCENARIO 2:
Human–Drone Platooning

A scenario that was regularly mentioned in the past but has gotten little attention recently is the possibility of a human-driven truck with autonomous truck units trailing in a platoon for interstate driving.[28] In this scenario, a human driver would bring a trailer to an autonomous truck port or ATP, as described above, and uncouple the trailer. The trailer would then be coupled to an autonomous

Human & drone tractors swap trailers

Drones follow human driver

Tractor optimized for highway driving

Local trucks could be electric

tractor. This truck would be fueled and inspected at the ATP. It would follow a human-driven truck onto the interstate (or perform limited autonomous driving to get itself onto the interstate until linked in a platoon with a human-driven truck, perhaps using a special section of roadway where the autonomous truck could get up to speed and engage in the platoon). While on the interstate, this autonomous truck would platoon with the lead truck for acceleration and braking but would also be capable of independently maintaining its lane using the human-driven lead truck as a reference. In this scenario, the following truck would essentially be both remotely operated by the driver of the lead truck and capable of autonomous driving within the platoon, using vehicle-to-vehicle networks, wireless communications, sensors, and artificial intelligence.

From a technological standpoint, this scenario has significant advantages. Having a lead driver would mean that drone trucks could mostly rely on decisions made by the human driver and be left with the much simpler task of lane maintenance. In the event that it were disconnected from the lead truck, the following truck would need to be capable of driving itself to a safe location (for example, pulling over onto the shoulder of the road) or to be remotely piloted from a control center, as discussed in Scenario 4, below.

In addition to reducing the complexity of decision making required of the autonomous truck, having a human driver could reduce, if not eliminate, concerns related to bad weather and security. There would also be a human driver available to perform inspection, maintenance, coupling and uncoupling, fueling, and other tasks, as necessary.

From a cost perspective, this scenario has tremendous potential. There would be substantial labor productivity gains in the long-haul portion of the duty cycle and, thus, significant reductions in drivers needed.

Human-led drone platooning is also the only scenario where driver upskilling would be almost certain for driving activities. This scenario could improve the quality of driving jobs. Because of the significant productivity gains, a platoon pilot—like the highly skilled and experienced drivers who haul multi-trailer combinations today—would be of much more value to carriers. Rather than de-skilling drivers and making them less needed, this scenario would add additional high-skill tasks to the drivers' work. These drivers would be responsible for more freight and equipment. While the importance of their conscientious efforts and skill would increase, labor costs would decrease considerably compared to the overall cost.

Drivers in this scenario would likely be better trained, more highly skilled, and better rewarded. If these drivers could run from ATP to ATP, they could even be put on more regular routes, allowing drivers to be home more often and spend less time living on the road and out of their vehicles. All these improvements could combine to make for fewer, but much better, long-haul trucking jobs. At the same time, a significant number of local jobs would be created to bring trailers to and from ATPs. Unfortunately, these local jobs would be at risk of the same problems found in existing jobs at ship ports today, as discussed below.

There would also be better energy savings than in multiple-driver platoons because the following units could be reconfigured to be lighter and more aerodynamic. These drone long-haul trucks

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could be specifically engineered for high-speed highway driving, right down to the tires, axles, and other features, making these trucks much more fuel efficient. In addition, because the local trucks bringing trailers would not need to drive highway miles, they too could be optimized, with features such as electric or alternative fuel powertrains, tractors without sleeper berths (a.k.a. day cabs), optimal tires, etc.

This scenario would be most important for the general and refrigerated freight segments as well as LTL and parcel linehaul operations. There is potential for some job losses in the long term, but this scenario could greatly improve the efficiency and safety of trucking operations and the quality of many jobs. While the technological challenges in this scenario are fewer than in other scenarios, this particular scenario does not seem to be a serious goal of most Silicon Valley autonomous truck projects at present (though it is an obvious next step for Peloton and its partners). The need for facilities where local drivers could bring trailers to be assembled into platoons could be accomplished with existing facilities, such as those used to break down multi-trailer trucks, or new facilities, like ATPs, could be built with public or private funding.

TECHNOLOGY SCENARIO 3:
Exit-to-Exit Autonomous Trucks Plus Drone Operation

The "exit-to-exit autonomous trucks plus drone operation" scenario has received attention over the past year in the United States, largely as a result of Starsky, a Silicon Valley startup. In this scenario, trucks would be autonomous on interstates and then piloted remotely by human operators while driving in local areas and under conditions where autonomous driving might not be possible (e.g., in bad weather that would make some sensors unreliable). Remote piloting is envisioned as being done by operators stationed at centers where they would use workstations to receive information from the truck and remotely pilot the vehicle much like the military pilots aerial drones. Such systems are in use already in controlled industrial settings, including mines and ports. However, deploying this technology on public roadways across broad geographic areas and with communications networks of varying reliability presents significant challenges. For example, what happens when remotely piloted trucks lose their wireless signal?

Remote drivers navigate local streets

No need for human-driven tractor allows longer trailer

Tractor not optimized for highway since it also drives locally

Proponents suggest drone piloting would improve the work lives of truck drivers, allowing them to work at control centers close to their homes rather than traveling for weeks or months at a time and living out of their trucks. The industry could thus address the most difficult problem associated with driver turnover, potentially resulting in significant cost savings. Productivity gains would be substantial because trucks could be operated on multiple shifts, overcoming the biggest single source of inefficiency in the industry: the "one truck–one driver" model that predominates and results in trucks sitting idle while drivers take their 10-hour mandatory break required by federal hours-of-service regulations. With remote drivers taking regular breaks and with assistive technology, such as lane maintenance and collision avoidance, significant safety improvements might also result. Vehicles without driver cabs could be designed for greater aerodynamics, larger trailers, or lighter weight, resulting in significant productivity and fuel efficiency gains. However, since the same tractor would be used for urban and highway driving, specialization for particular environments (as in the previous two scenarios) would not be possible. Perhaps most importantly in terms of efficiency, drone operation would mean drivers would not need to sit unpaid while waiting as their trucks are loaded and unloaded.

This scenario would likely have some important effects on employment relations and the structure of firms in the industry. The remote piloting of trucks is unlikely to be performed by independent contractors, given the substantial investments and centralized control systems required. Drone operation would also likely result in greater concentration in the industry, due to increased capital intensity and reduced opportunities for small businesses.

In theory, while this technology could be applied in a wide range of driving settings, it would require significant operational changes for most segments. Adoption would be influenced by whether current driver-performed tasks, such as loading, coupling, opening doors, fueling, and inspections, could be performed by other workers at loading docks. Customers would have to be sufficiently large to have trained dock staff on hand. Since not all customers would have such staff, drone-operated trucks would need to be distinguished from non-drone trucks within the load-planning process.

Some experts I spoke with suggested this scenario may face additional security challenges since the system is designed to be piloted remotely by a human. If someone gained control over a workstation or the communications link between the workstation and the truck, the truck could be stolen or used for mayhem. Another challenge to this technology is ensuring that human drivers have all the information to safely pilot the truck remotely in congested areas. Drivers would need to have the necessary situational awareness, which might require expensive simulator-like work stations and significant investment in cameras and sensors on the truck. The cost of such equipment would clearly affect the profitability of remote operations. There will also certainly be ethical issues when the human driver's own physical well-being is not at stake in making decisions that may affect safety.

Another long-term question about this scenario is how drivers would be trained. As suggested below, the segments most likely to be automated are the ones that train the vast majority of new drivers. If drone operation for local driving becomes the norm, it raises the question of how drivers

would learn to drive a truck and whether real-world experience driving a truck would be needed in order to safely operate a truck remotely or whether operators could be trained entirely on drone systems.

In this scenario, the job of truck driver could be significantly improved in a number of ways. The primary concern here in terms of labor will be job losses in some segments and downward pressure on wages from increasing the supply of drivers and eliminating the premium that carriers currently pay to get workers to live on the road (more on this aspect in the sections below). In terms of potential job losses, productivity per truck could go up significantly, and productivity per worker would be affected by removing autonomously driven highway sections, by eliminating waiting times for loading and unloading, waiting to be dispatched, etc., and by doing away with much or all non-driving work. Essentially, drivers' only remaining task would be to remotely pilot the truck for local driving. In some segments of the industry, such as long-haul truckload, tasks representing perhaps 90 percent of drivers' time could be eliminated. This improvement would have a significant impact on the number of jobs required to move freight in these segments.

Several million workers who have been trained to drive tractor-trailers in recent years have left the industry but might return if they were not forced to be away from home, living out of a truck for weeks at a time. Workers who never previously considered trucking for these reasons might also be attracted to the labor market. Working in simulators—which will obviously be safer than operating inside the trucks—and other improved conditions may also help the industry to attract millennials and women, something it has had great difficulty doing. As a result, former drivers, women, men with young children, and younger workers may be more attracted to these new jobs.

While this scenario has a number of hurdles and may not be feasible for most of the industry because of the difficulty of replacing the non-driving labor of drivers, there is a strong possibility that a drone-type of operation from a control center could be used for short periods to "rescue" autonomous trucks that cannot operate because of weather or complex situations beyond their programming.

TECHNOLOGY SCENARIO 4:
Driver-in-the-Sleeper Scenario (A.K.A. Autopilot)

Among the earliest visions for autonomous truck use was one in which driver and machine would take turns driving and operate as a team. This scenario is often suggested as the most likely and desirable use of autonomous trucks by the American Trucking Associations. The ATA suggested this would look like autopilot for airplanes. In highway driving situations, the driver would remain in the sleeper berth, and the machine would drive itself. Then, when situations require a human driver—such as local driving, fueling the truck, or dealing with a shipper—the human driver would take over. Initially some technologists suggested that a primary market for this sort of adoption would be owner-operators, who would get much greater asset utilization from their truck.

While promoting this scenario has a significant benefit at the moment—namely, it may not scare workers away from entering the trucking industry—there are numerous obstacles that make it

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Driver sleeps during highway driving
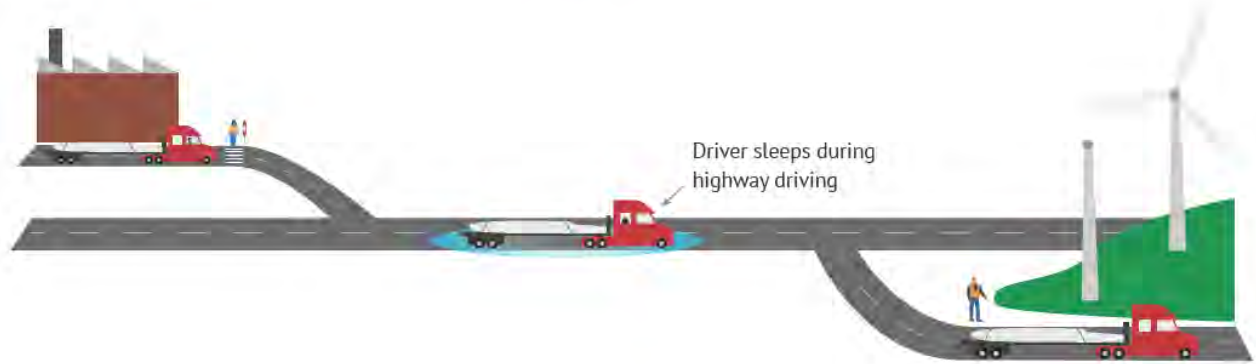
unlikely and highly undesirable for most segments of the industry. It is difficult to sleep well in the back of a moving truck, and relatively few drivers are comfortable enough with a partner driver to get restful sleep. It would likely take a lengthy regulatory process and years of scientific study to understand whether drivers get proper rest and operate safely while working in partnership with an autonomous truck. This is particularly true because, unlike a team of two human drivers, where each is capable of driving the truck and performing non-driving tasks, the partners in a human-autonomous truck team would be responsible for entirely different environments and tasks.

A brief description of a typical load will illustrate the problems of this scenario. The average length of haul (i.e., distance freight is moved) for truckload dry van carriers, the most likely adopters of autonomous trucks, is about 500 miles. In order to most profitably haul a load this length, a human driver might do local driving and perform other tasks required to pick up a load, working at least several hours, including waiting time. Then, the autonomous truck might drive the highway portion of the load, say 450 miles, requiring nine hours or so. The human driver would take over to drive locally and unload again. By this point, the driver would not have completed a full 10-hour break, as currently required by law, and might only have a few hours left to work according to federal rules. However, in order to make the most of the autonomous truck, the driver would drive locally to complete the load and then pick up another load. Requiring the driver to wait while the next load of freight was loaded or unloaded might take somewhere between six and eight hours. Then the autonomous truck would take over again for interstate driving, and the driver might get nine hours of rest time.

Many long-haul drivers today work 80 hours per week or more. They are only supposed to work 60 hours per week, but the federal rules intended to prevent such long hours are regularly violated because of inaccurate self-reporting of non-driving work and waiting time. In this scenario, the driver would have a much more broken-up schedule than common today and would perform even more non-driving work and waiting. In combination with truckers' tendency to work as many hours as possible because they are paid by the mile or the load and not hourly, partnership with an autonomous truck raises very important concerns for both safety and the long-term health of drivers. Truckers might keep that truck rolling almost constantly.

In my experience studying long-haul truck drivers, the only drivers who come anywhere close to this kind of sleep disruption and continual movement are trainers working with inexperienced drivers. Most of these drivers effectively work as a team with the trainee, splitting up the driving of highway and local miles according to the trainees' stamina and abilities and the degree to which the trainer trusts the trainee to drive while they sleep in the back of the truck. Unlike teams of experienced drivers, however, trainers are required to observe the trainees under a number of regularly occurring conditions, such as when the truck is entering or exiting a highway, driving in local conditions, or backing into a parking spot or dock. In fact, the conditions that trainees generally have trouble driving in and need supervision for are pretty much the same as those that autonomous trucks will have trouble with. Trainers often experience extreme fatigue and operate almost continually in violation of federal hours-of-service regulations, often working in excess of 100 hours per week.

This scenario would likely mimic that of trainer-trainee teams and could result in a tremendous "speed-up" of drivers' work lives. This speed-up would result in much cheaper and faster trucking service that would set a competitive standard in the industry. Competitors would need to follow suit to survive. It would inevitably lead to pressure on drivers to ignore their bodily needs, including sleep, in the service of keeping the truck rolling continually, breaking only for loading and unloading. Many long-haul drivers already endure a brutal combination of working hours and conditions that take an enormous toll on their social lives and health; this scenario would almost certainly exacerbate those conditions and their consequences.

With proper regulation, however, this kind of scenario could be beneficial for a few segments of the industry. In fact, this scenario would be most beneficial to some of the remaining true owner-operators in long-haul trucking or for specialized niche companies where drivers are typically highly paid and work routines are not driven by a race for the next load. For freight requiring extensive driver oversight during loading and unloading and those that use highly specialized trailers or tractors, for instance, this model might eventually be successful. Appropriate and desirable applications might include long-distance hauling of vehicles or heavy equipment.

TECHNOLOGY SCENARIO 5:
Exit-to-Exit Autonomous Trucks

The "exit-to-exit" autonomous truck scenario has received a great deal of attention over the past year and is viewed by some major players developing Level 4 autonomous trucks as the most likely way for such trucks to be utilized in the near future. There is a strong economic case for this scenario that, if supported by robust policy, could result in a wide range of benefits for stakeholders inside and outside the industry in long-haul operations. Without appropriate policy, however, this scenario raises important concerns about both job loss in long-haul trucking and about job quality, environmental, and safety issues for local truck operations.

In this scenario, human drivers would haul freight from distribution centers, production facilities, or other modes of transportation, like ship or rail, to an autonomous truck port, as described above. There, the human driver would uncouple from—or "drop"—an outward-bound trailer. That trucker or another worker at the ATP then would supervise as an autonomous tractor couples to that

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Human & autonomous tractors swap trailers

Cabless tractor optimized for highway driving
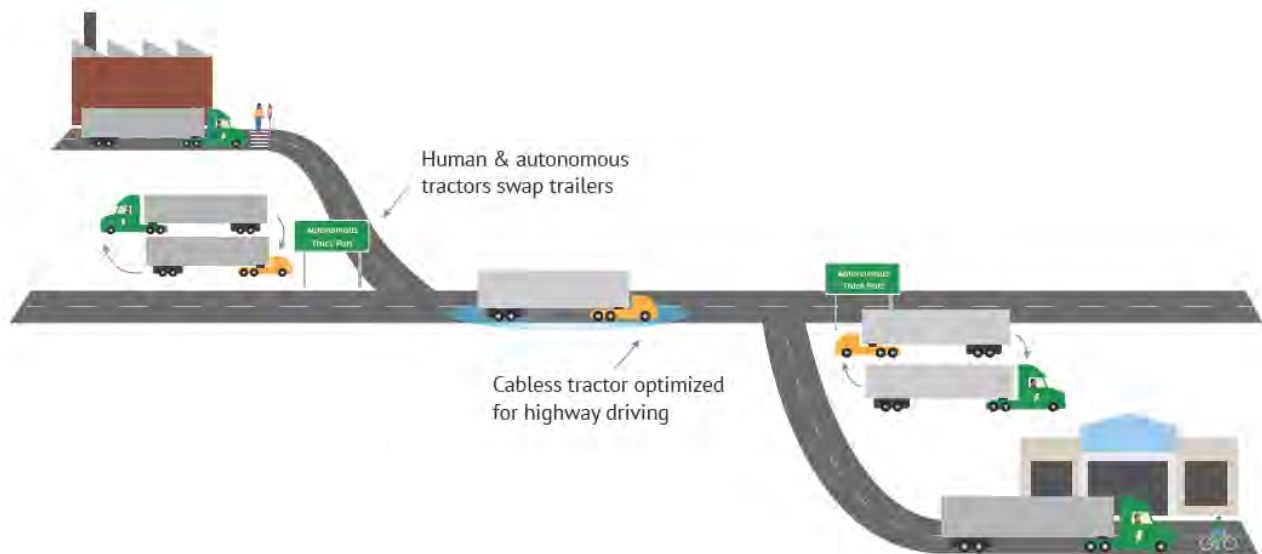
outbound trailer. That worker potentially could also ensure that the autonomous truck is safe to drive, fueled, etc. The autonomous truck would then drive the interstate portion of the freight's trip, while the human driver could take an inbound trailer from the ATP to final delivery in the local area.

Like the drone autonomous trucks in Scenario 2, the autonomous tractor in this scenario could be optimized for highway travel, including gearing, engine size, tires, aerodynamics, and more. This truck could operate with other autonomous trucks in platoons. Over the highway portion of trips, this scenario would eliminate labor costs and cut fuel costs substantially. It would also dramatically increase the overall speed of moving freight as loads would not have to wait while drivers take mandatory breaks to sleep and stop for other reasons. In so doing, this scenario would have a major impact on what is now a substantial constraint on freight moving between 500 and 1,000 miles. It could also bring the trucking industry some much longer distance freight, including many imports that currently move by rail.

This scenario could be the most likely to play a significant role in the immediate future. Indeed, at least two Silicon Valley firms, Uber and Embark, have envisioned such a scenario. Uber modeled a well-known demonstration with a human driver operating a truck until it got to the interstate, then operating the truck autonomously, with the human driver taking over again for local driving. Embark is hauling actual freight using a similar transfer process, where their autonomous trucks pass trailers on to Ryder trucks with human drivers.

Given the intense focus on this scenario and its emergence as the odds-on favorite for near-term adoption, its labor implications will be discussed at length below.

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TECHNOLOGY SCENARIO 6:
Facility-to-Facility Autonomous Trucking

Many facilities that ship and receive large amounts of freight are strategically located very close to major interstates, often within just a few miles. Those few miles of road between facilities and an interstate exit are often in industrial or commercial areas, where roadways are designed for heavy truck traffic and largely used for commercial purposes. In some cases, these roadways are more suitable to autonomous truck operation than interstate highways. Like interstates, there is often no side parking, pedestrians, or bikes. They have fewer complex and congested intersections. Unlike highways, they have relatively slow speeds and are far less congested than some interstates. In the "Facility-to-Facility" scenario, autonomous trucks drive directly between facilities like these without a human driver required at any time. Workers at each facility would handle any required non-driving tasks, such as coupling trailers, fueling tractors, and inspections.

Autonomous trucks navigate commercial streets near highway

Tractor not optimized for highway since it also drives locally

This scenario presents a significantly different set of impacts from that of exit-to-exit autonomous trucks for a number of reasons. It would allow autonomous trucks to replace both for-hire and private drivers working on regular routes between facilities, including linehaul drivers within less-than-truckload or parcel systems. These drivers are typically far more skilled and experienced, and therefore more costly.

Port drivers could be similarly impacted under this scenario. If autonomous trucks result in significant cost savings, as expected, they will capture some long-distance container freight that currently goes from ship to rail (sometimes with a short truck trip in between). This scenario would lead to containers coming right off ships and onto autonomous trucks going longer distances of 500+ miles and directly to destinations. This scenario could be highly disruptive to important existing warehousing districts that currently process imports, such California's Inland Empire.

These potential impacts will be discussed in detail below, but this scenario would have by far the largest negative impact on jobs, essentially eliminating driving jobs in some segments. It would also not have all of the positive environmental benefits of segmenting into local and long-haul trucks for better fuel economy and congestion management (though, in theory, these trucks could operate around the clock and more easily avoid rush hours than human drivers).

Which Scenarios Are Most Likely and Desirable?

This report argues that we should not try to predict the outcome of the development of autonomous trucks, but rather shape it. Still, in trying to shape the inevitable use of autonomous trucks, it is important to understand which scenarios have more or less difficult paths and beneficial effects. Below is a brief summary of the challenges and desirability of each scenario.

TECHNOLOGY SCENARIO 1: Cooperative Adaptive Cruise-Control Platooning

The technology required for platooning is already available, and the case is being made for adoption to major fleets. This scenario could be a reality in a matter of months. At present, policymakers seem receptive to efforts to encourage adoption, and there appear to be few drawbacks.

TECHNOLOGY SCENARIO 2: Human–Drone Platooning

This scenario has relatively few technological hurdles and would result in major productivity gains. In addition, the case for human–drone platooning is very strong from an environmental and job-quality perspective. However, without public policy to ensure otherwise, it would result in the loss of some good long-haul jobs and create local jobs that will likely offer poor pay and poor working conditions. Perhaps because it is the least technologically ambitious, this scenario has not been a major focus of Silicon Valley, which is unfortunate as human–drone platooning may represent an effective outcome that many stakeholders could support.

TECHNOLOGY SCENARIO 3: Exit-to-Exit Autonomous Plus Drone Operation

This scenario may present the most difficult technological challenges: it not only calls for autonomous driving on the highway, but also requires the technology to pilot remotely, which could be costly given potentially expensive control centers and communications systems, as well as the need to replace non-driving driver-performed tasks throughout the labor process. This scenario should be treated as the least likely.

TECHNOLOGY SCENARIO 4: Driver-in-the-Sleeper Scenario (A.K.A. Autopilot)

This scenario would require developing the same basic technology for autonomous driving as the exit-to-exit scenario. The environmental benefits of the "autopilot" scenario would be minimal, but the potential labor impacts could be significant and negative. In the near term, this scenario should be treated as highly undesirable.

TECHNOLOGY SCENARIO 5: Exit-to-Exit Autonomous Trucks

Exit-to-exit is the scenario that most Silicon Valley developers are putting forward as the most likely. It requires overcoming significantly more difficult technological challenges. However, since it is the aim of key developers and easier than Scenarios 3 and 4, it should be treated as a likely outcome. Exit-to-exit autonomous trucks would result in more job loss than human–drone platooning and would create a similar number of local jobs (which, again, would likely have low wages and poor conditions without policy intervention).

TECHNOLOGY SCENARIO 6: Facility-to-Facility Autonomous Trucking

This scenario requires technology to solve the problem of local driving, which may be possible for some limited locations, especially within linehaul LTL and parcel operations. For those use cases, this scenario should be treated as likely, following the successful development of exit-to-exit self-driving.

How Soon Could Autonomous Trucks Be Used?

Everyone wants to know when self-driving vehicles will be ready for widespread adoption. Several car manufacturers are forecasting that they will have self-driving cars in the next two or three years, but exactly what these cars will be capable of is unclear. When talking with experts and developers, I found a range of opinions for trucks. Essentially, the most ambitious timeline suggests that autonomous trucks could be operating in the highway portion of the long-haul duty cycle in a few stretches of highway within three years. This general timeframe fits the prediction of experts surveyed on the subject, who estimate a high likelihood of Level 4 operation on highways beginning between 2018 and 2024.[29] In the opinion of the vast majority of those I talked to, reliable and safe local driving is still decades away.

Again, a number of important technological and cost barriers need to be overcome to achieve these outcomes. I consider the timeline below to be the most aggressive that can realistically be envisioned for self-driving exit-to-exit and limited facility-to-facility autonomous operation.

Here's what the stages might look like:

STAGE 1: Now to three years

Pilot usage of autonomous trucks begins. Waymo and Embark are currently using or planning to use trucks with self-driving technology for interstate hauling of freight, and Starsky says it will begin doing so by the end of 2018. Right now, human drivers are present behind the wheel. These trucks are paired with traditional human-driven trucks and swap trailers with those trucks for local driving, similar to what is described in the exit-to-exit autonomous scenario described above, using something like an autonomous truck port. These trucks might be operational without a driver in pilot programs, perhaps with time-of-day restrictions on highway segments, within three years. Within this time, digitized freight matching begins to have a meaningful impact on the brokerage business for local and regional loads. E-commerce continues its explosive growth and fosters the growth of last-mile delivery jobs.

STAGE 2: Three to seven years

A few advanced for-hire fleets begin ATP-to-ATP autonomous truck programs in partnership with technology and truck leasing firms on I-10 in the U.S. Southwest, building on existing testing regimes. These trucks operate with route and time restrictions. Sophisticated supply chain actors begin to plan for integration of autonomous trucks' greater speed and lower cost in the southwestern and southern United States, south of I-40. Digitized freight matching for local and regional truckloads spreads widely, and long-haul freight begins to be affected. Strong growth in last-mile delivery continues.

STAGE 3: Seven to ten years

Autonomous truck operation between ATPs begins during more congested times on some routes and on additional major freight lanes on I-10 and I-40 and sections of some north-south interstates south of I-40. Total autonomous truck numbers climb to several thousand. Long-haul truckload for-hire rates decline on lanes where autonomous trucks operate. Small and mid-size carriers attempt to compete by lowering wages on those lanes or take losses for backhauls on them. Planning and investment for autonomous truck adoption by the largest for-hire and private fleets is widespread. LTL fleets begin planning for adoption or consider subcontracting for-hire autonomous service for linehaul operation between ATPs in limited areas. Strong e-commerce growth in existing and new product categories continues to support strong LTL demand and moderate truckload demand growth. The most sophisticated supply chains continue reorganizing to meet "right now and free" shipping demand in combination with remaining brick and mortar. Digitized freight matching becomes dominant for local and regional truckload market transactions. Pilot projects begin to demonstrate autonomous truck feasibility in climates with regular snow and facility-to-facility operations.

STAGE 4: Ten to fifteen years

Autonomous truck operation has been established as safe and reliable in most interstate conditions and begins to spread to key freight lanes nationally on a seasonal basis, creating intense competitive pressure and market volatility. Adoption of autonomous trucks or labor cost cuts become critical for survival of medium-to-large dry van and refrigerated truckload carriers in some areas. Significant concentration of truckload carriers begins as the largest fleets successfully transition to automated fleets for dry van and refrigerated truckload shipments. A few private fleets begin to shift to cheaper, faster for-hire autonomous truck service, including customer-directed, dedicated autonomous trucks. LTL fleets begin adopting autonomous trucks for facility-to-facility linehaul. Strong growth in local jobs for final delivery of truckload trailers, growth in LTL and other last-mile delivery jobs continues. Digitized freight matching is now dominant throughout for-hire truckload.

STAGE 5: Fifteen to twenty-five years

Low-cost autonomous truck service largely replaces long-haul truckload in dry van and refrigerated segments with significantly cheaper, faster services. Some private linehaul truckload fleets shift to dedicated, for-hire autonomous trucking carriers as that segment provides faster service that has the dependability of in-house services at much lower cost. Linehaul LTL operations are now done by autonomous trucks. Several hundred thousand new jobs have been created in last-mile delivery jobs as well as local trucking jobs. Human drivers still drive short-haul routes and specialized equipment.

Estimating Job Losses and Likely Job Impacts

In order to understand the potential impact of self-driving technology, we need to know what kind of trucking companies will adopt it and how they will use it. In light of the above analysis, this section assumes that exit-to-exit autonomous trucks are the likely scenario and that limited facility-to-facility use will follow.

Ultimately, three sets of factors will determine who adopts autonomous trucks using those scenarios:

1. Can the truck perform the driving tasks in the required environments? In the exit-to-exit scenario, the truck will drive long distances on the highway. In facility-to-facility, the truck will also drive limited distances on commercial roads.

2. Is it profitable to segment out that driving from the other tasks drivers perform? Is there enough long-distance driving to justify the swapping of trailers at an ATP in the exit-to-exit scenario? Are customer staff available to open trailer doors and inspect the truck in the facility-to-facility scenario? Can would-be adopters raise sufficient capital to buy driverless trucks and build in-house expertise or hire expertise to operate them profitably?

3. Can other impediments to adoption, like risk to brands from accidents and concerns raised by drivers, be resolved?

If the answer to all of these questions is "yes," then firms in that segment are likely to adopt the technology. Table 4.1 (page 33) breaks these factors down by characteristics of the freight, carriers, and customers in different segments of the trucking industry. Green indicates characteristics that make a stronger case for adoption. Yellow indicates a characteristic that weakens the case for adoption. Red indicates a characteristic that will impede adoption. Other characteristics might also affect adoption, but these are major obstacles identified in my conversations and research.

Clearly, the strongest case for adoption is in for-hire long-haul truckload. The next strongest is linehaul service within LTL and parcel operations. It is unlikely that other segments will be easily transformed to adopt autonomous trucks, with one exception. Port hauling could, with the entrance

TABLE 4.1
Characteristics of loads, firms, and customers relevant to autonomous truck adoption by industry segments

	Primary driving environments	Uninterrupted highway driving	Non-driving tasks	Customer facility Type	Route regularity	Union presence	Typical carrier size
For-hire truckload (dry and refrigerated)	Highway	Extensive	Minimal	Large Warehouse	Moderate	None	Medium/ Very Large
Less-than-truckload and parcel linehaul	Highway	Extensive	Minimal	Internal Terminal	High	Moderate	Medium/ Very Large
Port driving	Urban/ Highway	Minimal/ Significant	Minimal	Large Warehouse	Moderate to High	Low	Small
Specialized truckload	Highway/ Complex	Significant/ Extensive	Significant/ Extensive	Varied Commercial	Varied	Low	Small/ Medium
Intermodal	Urban	Minimal	Minimal	Large Warehouse	Moderate	Varied	Small/ Medium
Local pickup and delivery (part of LTL and parcel)	Local/Urban	Minimal	Significant/ Extensive	Commercial or Residential	Varied	Varied	Very Large
Local – other	Local/Urban	Minimal	Significant/ Extensive	Varied	Varied	Varied	Small

🟩 Strengthens case for adoption   🟨 Weakens case for adoption   🟥 Obstacle to adoption

of larger firms using autonomous trucks, capture a significant amount of freight currently shipped long distances by rail. However, a substantial shift would be required in firm strategy, which currently relies heavily on cheap trucks paid for by independent contractors.

How Many Jobs Are At Risk of Automation?

If the analysis above is indicative of the segments where autonomous truck adoption is possible and profitable, how many jobs are at risk?

Answering this question is complicated, because there are no datasets on freight that would allow us to look at all the dimensions in Table 4.1 with any precision. However, by combining different datasets, we can calculate the total revenue at large firms (the most likely to automate) in each

SECTION FOUR: Estimating Job Losses and Likely Job Impacts

segment, the average revenue per driver, and thus, the estimated number of drivers in each segment. As shown in Table 4.2, these data suggest that far fewer jobs—an estimated 294,000—are at risk than other studies have suggested.

TABLE 4.2:
Jobs in segments at high risk of automation

Segment	Total segment revenue of large firms (A)	Estimated revenue per driver job at large firms (B)	Approximate estimated jobs at risk (A/B)	Average annual driver earnings
For-hire truckload dry van	$30.5 billion	$174,000	175,000	$46,641*
For-hire truckload refrigerated	$7.6 billion	$209,000	36,000	$53,690*
Less-than-truckload linehaul	$33.7 billion	$266,000	51,000	$69,208*
Parcel linehaul	—	—	32,000	$59,660**
Total jobs at risk of automation			294,000	

Note: LTL linehaul estimate is based on 127,000 total drivers x .4 for percent linehaul. Calculating revenue per driver isn't possible for parcel linehaul, so a different approach was used. See below for more details on these calculations. For parcel job numbers, see text for information on reasoning. Columns 2, 3, and 4 are author's calculations, see Data Appendix.

* Costello, Bob. 2014. ATA Compensation Survey 2014. Arlington, VA: American Trucking Associations.

** BLS, Occupational Employment and Wages, May 2017, 53-3032 Heavy and Tractor-Trailer Truck Drivers, https://www.bls.gov/oes/current/oes533032.htm.

JOBS AT RISK BY SEGMENT: FOR-HIRE TRUCKLOAD

If the analyses in Tables 4.1 and 4.2 are correct, the firms most likely to adopt autonomous trucks are dry van and refrigerated truckload carriers, particularly the largest firms, which dominate these segments. Data collected by *Transport Topics* and *Commercial Carrier Journal* (CCJ), two leading industry publications, allow us to get a rough estimate of the number of jobs. Both publications collect annual data on all the largest for-hire and private firms and report some combination of the number of trucks they operate, the drivers they employ or contract with, and the revenues they earn in different segments.

Transport Topics publishes a list of the 100 largest for-hire fleets and the 100 largest private fleets. The top of the list on the for-hire side is dominated by the parcel giants UPS and FedEx and the very largest truckload and LTL fleets. In total, the fleets in the top 100 generated more than $232 billion in revenues in 2017 and controlled around 476,000 trucks, though slightly more than half of that revenue was generated by FedEx and UPS alone. CCJ publishes an annual list of the largest 250 carriers, both for-hire and private. Unfortunately, the CCJ Top 250 doesn't have revenue information for many companies, but it does provide driver numbers for employees and contractors for most fleets. In total, the 250 fleets on the list use nearly 761,000 drivers.

Transport Topics also publishes lists of the largest carriers and their revenue in 11 different industry segments, including dry van and refrigerated. Unfortunately, while truck counts are provided for these companies overall, they are not broken down by particular segments.

Bringing these sources together to get revenue counts by segment from *Transport Topics* and drivers from CCJ gives us a good picture of the numbers of driving jobs at risk in the near future. By calculating an estimated average "revenue per driver" in each segment using a selection of firms that only haul freight in one segment, then dividing total revenue in a segment by the estimated average revenue per driver in that segment, we arrive at the number of jobs for firms that haul in multiple segments. The Data Appendix shows the carrier data used to calculate the estimated average revenue per driver in each segment.

Jobs at risk in for-hire dry van

Transport Topics lists 86 carriers as having dry van truckload revenue. At the top of the heap in terms of revenue for the segment is Swift Transportation with more than $3 billion from dry van truckload. Last on the list is Bolt Express with slightly more than $14.5 million dollars in revenue from dry van truckload. While economists conclude that trucking markets are not particularly concentrated, there is clearly a massive difference between the big carriers and the rest: the largest carrier has more than 200 times the revenue of the last on the list. It will undoubtedly be more difficult for carriers with less revenue to transition to autonomous trucks. Perhaps none of the 38 carriers on the list with less than $100 million in revenue will be able to make this change and may eventually go out of business or be bought by larger firms as the segment consolidates.

In total, the 86 firms on the *Transport Topics* list generated about $30.5 billion dollars in revenue in truckload dry van. These firms are primarily regional or long-haul firms. Using the revenues and driver counts for major dry van truckload carriers (see the Data Appendix for the data used for this calculation), I estimate that large truckload dry van fleets average $174,000 per driver in revenue in this segment. Dividing the total revenue of the 86 largest fleets in the dry van segment by this estimate of per driver revenue suggests that these firms use approximately 175,000 drivers (both employee and contractor) to haul dry van freight.

Jobs at risk in for-hire refrigerated

The refrigerated segment is much smaller than the dry van truckload segment. The 32 firms on the *Transport Topics* list of the largest carriers in the segment brought in around $7.6 billion. At

the top of the list was C.R. England, with $1.3 billion in revenue from refrigerated. Last on the list was Celadon Group, which brought in $30 million in refrigerated revenue. Using the figure of $209,000 per driver in revenue,[30] we can estimate that these firms used some 37,300 drivers in the refrigerated segment.

JOBS AT RISK BY SEGMENT: LESS-THAN-TRUCKLOAD AND PARCEL LINEHAUL

The other groups of drivers most at risk are linehaul drivers in parcel and less-than-truckload operations who transport full trailers from one carrier or private facility to another controlled by the same company.[31] Once autonomous trucks are capable of driving directly to and from terminals close to interstate exits, they will likely take over the long-haul portions of LTL and parcel service done by these linehaul drivers.

Jobs at risk in LTL linehaul

LTL is far more concentrated than truckload. LTL generates about $33.7 billion for the 27 fleets on the *Transport Topics* list of LTL hauling firms, ranging from a high of $6.35 billion for FedEx to a low of just $53 million for Anderson Trucking. Revenue and driver counts for the CCJ Top 250 suggest that LTL firms generated $266,000 per driver in revenue. The total revenue reported for the segment by *Transport Topics* suggests these firms used about 127,000 drivers to haul LTL freight. Based on my conversations with drivers and other stakeholders, there is a fairly wide range of the percent of drivers within LTL operations who drive linehaul. Some large LTL carriers may employ up to 45 percent of drivers in linehaul, the rest of the drivers would do primarily local pickup and delivery work, which is less likely to be automated. Other LTL firms may only use 20–25 percent of their drivers in linehaul work. To be conservative for a rough estimate, I used an overall average of 40 percent of drivers in linehaul,[32] which suggests that about 51,000 linehaul drivers are at risk.

Jobs at risk in parcel linehaul

Like LTL carriers, parcel carriers may move to autonomous trucks to replace linehaul jobs. UPS controlled a total of 31,808 tractors in 2017, according to the CCJ Top 250. UPS's almost $2.74 billion in revenue from LTL suggest that it utilizes roughly 8,850 tractors in that segment. If UPS uses the remainder of its tractors for linehaul parcel operations, some 22,958 tractors could be automated.

FedEx controlled 29,426 tractors in 2017, according to the CCJ Top 250. If the estimates of LTL jobs above are correct, then FedEx uses approximately 20,500 tractors in LTL service. The remaining 9,000 tractors may also perform linehaul for parcel service, but they might instead be used over relatively short distances to bring freight from truck terminals to airports. In this case, they might not be good candidates for automation.

In total, perhaps as many as 32,000 trucks could be automated among parcel carriers.[33] I cannot calculate revenue per jobs as I did above because I don't have "pure" parcel carriers to use as a baseline for revenue. In any case, the operations of UPS and FedEx are quite different from the jobs described above, so a single per driver revenue calculation doesn't make sense.

The Quality of At-Risk Jobs

The analysis above suggests that around 294,000 existing jobs might be at risk of automation. Even among these long-haul jobs, which are primarily composed of driving between large facilities for large firms, there are dramatic differences in job quality, pay, and driver characteristics. On one hand, for-hire truckload jobs are very tough jobs that have very high turnover, and the largest companies in this segment rely on a very inexperienced labor force. Within this workforce, however, it's likely that there will also be a significant number of long-term employees and contractors who are very experienced and earn good incomes. Some of these workers might be particularly hard hit by automation because they live in rural areas, where other well-paid jobs are difficult to find.

On the other hand, the labor market for LTL and parcel carriers is very different. These jobs still have a significant union presence, with the International Brotherhood of Teamsters representing workers at both the largest LTL firms and UPS. Overall, the jobs at risk in these segments are done by some of the most experienced and best compensated drivers in the industry. While these workers are also older and closer to retirement, these are very good jobs, and it is highly unlikely that the local and last-mile jobs that might replace them would be nearly as good, unless significant policy steps ensure that outcome.

FOR-HIRE TRUCKLOAD: HIGH TURNOVER AND USE OF INDEPENDENT CONTRACTORS

If the above analysis is correct, about 211,000 for-hire truckload jobs (both dry van and refrigerated) are at risk of being automated. Much of this segment is "perfectly competitive," meaning individual firms have very little pricing power. If they increase their rates, they will quickly lose customers. As a result, wages in this segment tend to stagnate until one or more larger firms, which can temporarily raise wages without pricing themselves out of the market, decide to grow their fleets by raising wages and then are followed by the rest of the segment.[34] As shown in Figure 4.1 (page 38), driver pay in for-hire truckload is thus significantly lower than in other long-haul segments.

These stagnant wages are compounded by tough working conditions. Drivers typically work the equivalent of more than two full-time jobs and are required to stay out on the road for weeks at a time.[35]

This combination of low pay and difficult conditions means that the segment struggles to retain drivers. As Figure 4.2 (page 38) shows, truckload carriers suffer from very high turnover rates, with the worst employers having more than 100-percent turnover—meaning they cycle through more than one worker per position every year. Conditions at many large truckload carriers (those most likely to automate) are so bad that they have likely caused several million workers to exit the segment soon after entering it in recent decades.

For-hire truckload companies thus rely heavily on training workers entirely new to the industry and retain those workers by indebting them for a year or more for that training. Some companies even use non-compete clauses to keep newly trained workers from moving to other firms.

SECTION FOUR: Estimating Job Losses and Likely Job Impacts

FIGURE 4.1

Average annual earning in different segments of the trucking industry

|	Segment	Average annual wage
LONG-HAUL	For-hire truckload *	$46,641 – $53,690
	Less-than-truckload *	$69,208
	Parcel **	$59,660
LOCAL	Ports ***	$28,783 (contractors) $35,000 (employees)
	Pickup and delivery ****	$35,610

* Costello, Bob. 2014. ATA Compensation Survey 2014. Arlington, VA: American Trucking Associations.

** BLS, Occupational Employment and Wages, May 2017, 53-3032 Heavy and Tractor-Trailer Truck Drivers, https://www.bls.gov/oes/current/oes533032.htm.

*** Smith, Rebecca, Paul Alexander Marvy and Jon Zerolnick. February 2014.The Big Rig Overhaul: Restoring Middle-class Jobs at America's Ports Through Labor Law Enforcement. National Employment Law Project, Change to Win Strategic Organizing Center and Los Angeles Alliance for a New Economy.

**** BLS, Occupational Employment and Wages, May 2017, 53-3033 Light Truck or Delivery Services Drivers, https://www.bls.gov/oes/current/oes533033.htm.

FIGURE 4.2

Annual driver turnover in different industry segments
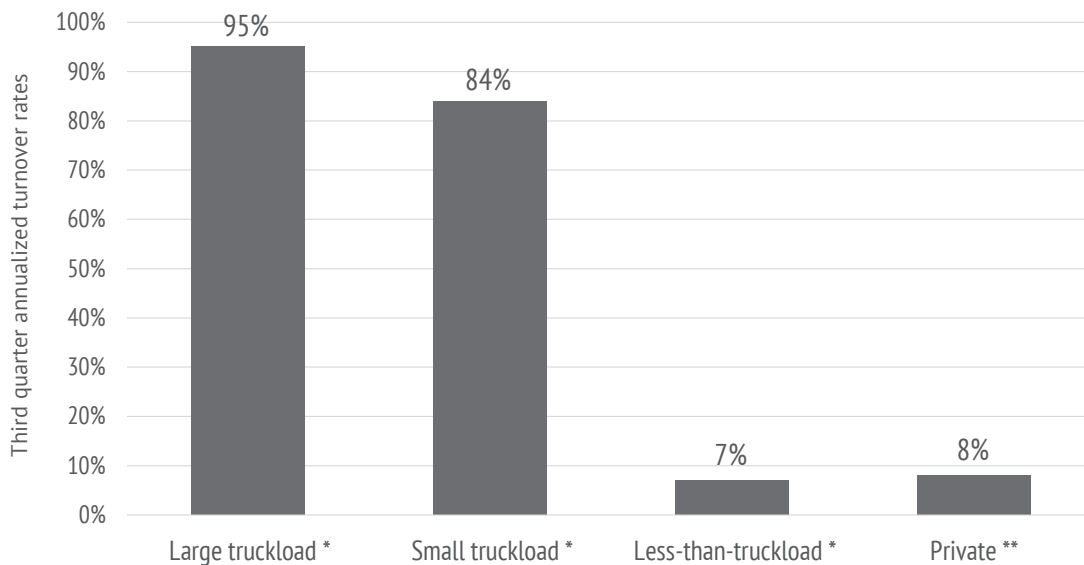
* Source: American Trucking Associations. December 7th, 2017. "Large Truckload Driver Turnover Rate Rose in Third Quarter." Arlington, VA: American Trucking Associations.
** Private Fleet Turnover rate is for the year 2014. Source: Costello, Bob. 2014. ATA Compensation Survey 2014. Arlington, VA: American Trucking Associations.

Table 4.3 represents the best data available on what new hires and their tenure look like at a large truckload firm—the type most likely to adopt driverless trucks. The researchers studied tenure for more than 5,000 workers hired by this firm and found that:

- 90 percent of the hires were inexperienced;

- 73 percent were trained by the company itself in one of its commercial driver's license schools;

- About half of all workers hired by the company had left within half a year. Many of those who stayed longer held out until just after a year, when the debt they owed the company for training was forgiven. In fact, the researchers suggest that without these training contracts, workers would leave faster and the company would no longer be profitable.[36]

These large firms generally have much less stringent hiring standards and are the easiest places for workers new to the industry to get their first job. After a year, opportunities open up at better employers, both in the segment and outside it. But the majority of would-be truckers likely never make it past the first year. Tens of thousands of workers annually, perhaps more than 100,000 in some years, train to become truckload drivers but don't stay in the profession for even a year.[37]

TABLE 4.3:
Estimated job tenure for drivers hired by large truckload firm

	Worker experience level	Percent of all drivers hired	Half of drivers are gone after	Three-quarters of drivers are gone after
All drivers (N>5000)		100	27.4 weeks	72.1 weeks
Experienced drivers	Rehires	4	284.7 weeks	— *
	Experienced	8	29.4 weeks	98.3 weeks
Inexperienced drivers	Company trained	73	30.1 weeks	73.1 weeks
	Prior training	14	18.1 weeks	49.1 weeks
	Limited experience	3	21.1 weeks	53.1 weeks

Source: Burks, S.V., J. Carpenter, L. Gotte, K. Monaco, K. Porter, and A. Rustichini. 2007. "Using Behavioral Economics Experiments at a Large Motor Carrier: The Context and Design of the Truckers and Turnover Project." IZA Discussion Paper No. 2789 (May). Bonn, Germany: IZA. The authors state, "76.4 percent are voluntary quits, while 23.6 percent are discharges for cause."

* Rehire retention was so long it could not be calculated with the data Burks et al. (2007) collected.

While there are about 3 million trucks on the road that require a commercial driver's license (CDL), there are more than 10 million CDL holders in the United States.[38] A significant number of them likely work in non-truck driving jobs that require a CDL, but it's also very likely that several million CDL holders are workers who have had the misfortune to pass through for-hire long-haul trucking's revolving door.

Instead of raising wages and retaining workers, it has been more profitable for large firms to lure workers into the industry with false promises of high wages and externalize training costs to the workers themselves and government training grants.

To keep attracting workers, the American Trucking Associations routinely publishes studies about the industry's "driver shortage," which are based employer estimates of the number of workers they say they would hire. The ATA has been forecasting a shortfall of tens of thousands of truck drivers almost continually since at least 2005. According to its analysis, the shortage "skyrocketed" to 50,000 drivers in 2017. These studies are dutifully taken up by major media, with headline hooks like CNN's "Truck drivers wanted. Pay: $73,000."[39] And more workers, unfortunately, swallow those headlines.

But once on the road, the troubles begin. As I documented in my 2016 book, *The Big Rig: Trucking and the Decline of the American Dream*, as inexperienced drivers become dissatisfied with the pay and long hours of the segment, carriers convince many of them to lease a tractor and become an independent contractor.[40] This situation typically leaves drivers far worse off, working more hours, yet often taking home less than minimum wage once all the costs of leasing a truck and paying for its operating expenses are deducted by the carrier.

Convincing drivers to lease a tractor enables carriers to retain workers for months longer. While these practices, including fraud and the misclassification of employees as independent contractors, are now being challenged by a number of lawsuits (with one headed to the Supreme Court this year) these abuses remain widespread.

Many of the jobs in for-hire truckload that might be replaced by autonomous trucks are not great jobs, yet in 2017, employees in dry van truckload earned an average of $46,641, which is better than what many could earn elsewhere with only a high school degree. And there are likely tens of thousands of drivers in this segment who earn above-average wages, have significant experience, and would like to make a career out of trucking. Some of these workers might transition into better segments of the industry as drivers in those segments retire.

Unfortunately, however, many of the drivers who have remained in truckload despite having more experience live in rural areas, and better employment options are far away. Others may work for small- and medium-size employers who will be less equipped to adopt driverless trucks. Just as carriers did in response to renewed competition after the trucking industry was deregulated, these smaller carriers will be forced to cut wages, and many of the abuses already widespread in the segment will intensify.

LTL AND PARCEL LINEHAUL: SOME OF THE BEST JOBS IN TRUCKING

Around 83,000 linehaul jobs are at risk of automation at LTL and parcel carriers. Some of these are among the best trucking jobs, with high wages and good working conditions. As the tenure data in Figure 4.3 suggest, these good jobs mean linehaul drivers are much more likely to have long-term careers in trucking.

FIGURE 4.3
Average driver tenure by segment
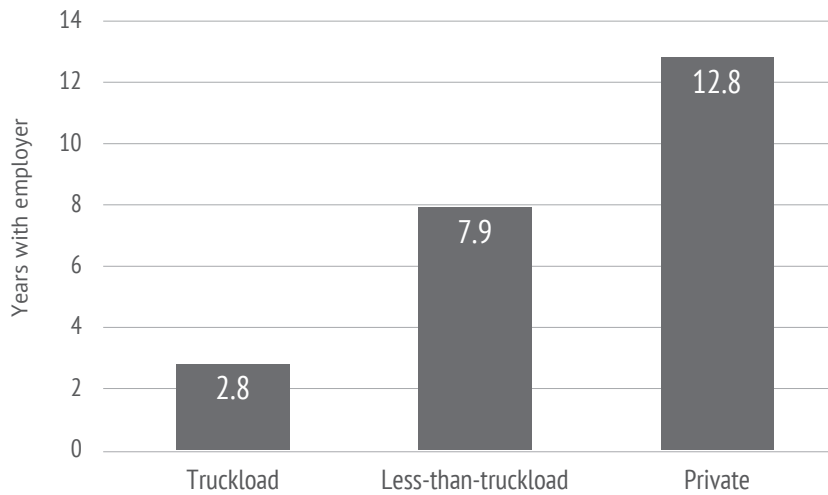
* Source: American Trucking Associations. 2012. Benchmarking Guide for Driver Recruitment & Retention. American Trucking Associations: Arlington, VA.

LTL drivers tend to be older than the average trucker and much older than the average U.S. worker, as Figure 4.4 (page 42) shows. Therefore, many existing drivers will be retired or retiring by the time autonomous trucks might be commonplace, especially since LTL drivers often retire several years earlier than drivers in other segments.

Some of the remaining linehaul drivers could perhaps transition over to local pickup and delivery (P&D) positions that are less likely to be automated, but a big pay cut would be likely. [41] As illustrated in Figure 4.5 (page 42), the average linehaul driver makes around $9,600 more than a comparable P&D driver. Moreover, Amazon and other large firms (most notably XPO Logistics) are increasingly using independent contractors for last-mile delivery. This shift could put significant downward pressure on local P&D driver wages.

It is important to note, however, that linehaul drivers at UPS and some of the largest LTL firms are unionized and will have a greater voice in how to make the transition to autonomous trucks.

FIGURE 4.4
Median worker age by industry segment
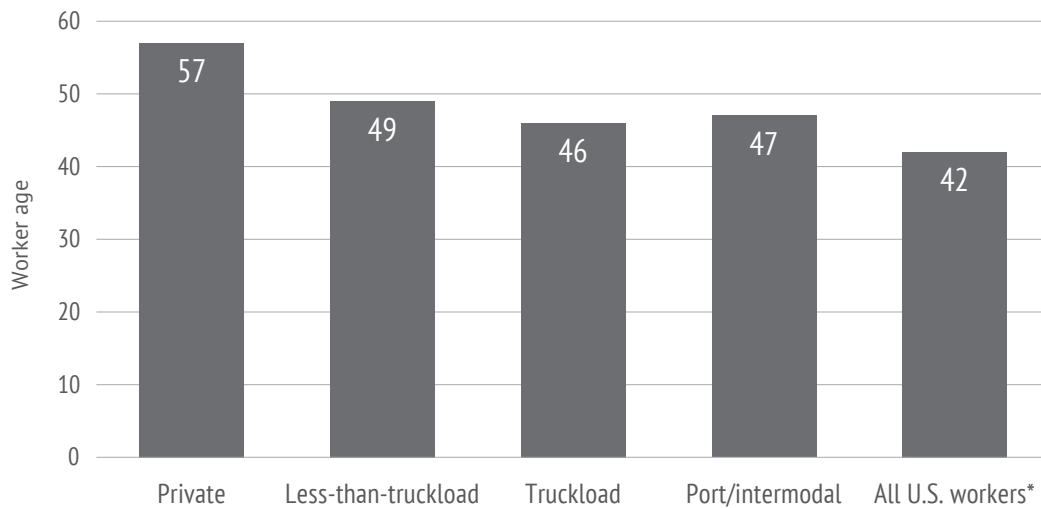
Source: Platner, Ryan, and Bob Costello. March 2018. ATA Driver Compensation Study: Operations Data 2017. Arlington, VA: American Trucking Associations.

* Estimated Age. Source: USDOL Bureau of Labor Statistics. January 19, 2018. Retrieved from https://www.bls.gov/cps/cpsaat18b.htm.

FIGURE 4.5
Linehaul vs pickup-and-delivery (P&D) driver earnings, by region
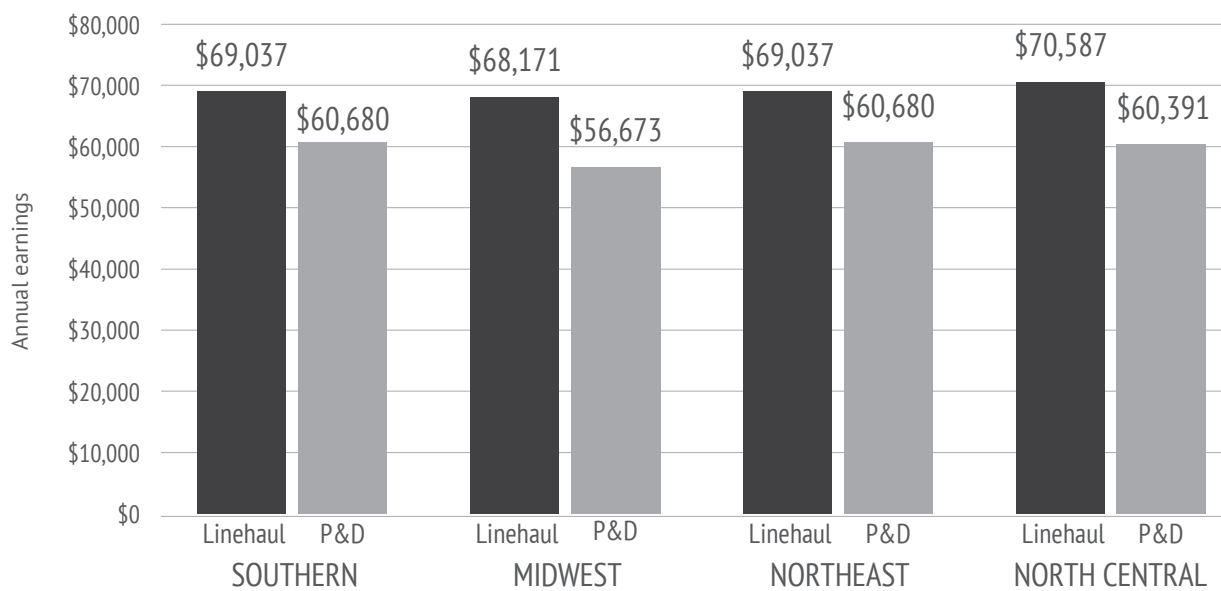
* Source: Costello, Bob. 2014. ATA Compensation Survey 2014. Arlington, VA: American Trucking Associations.

WHO ARE THE DRIVERS?

Unfortunately, government and other regularly collected data sources do not allow us to isolate the drivers who are most at risk by segment. The best source for a demographic portrait of these drivers comes from a nationally representative survey of 1,265 drivers collected at 32 truck stops in 2010.[42] The survey was limited to drivers who had driven a truck for a year or more and those who took at least one 10-hour rest period on the road (as required by federal regulations for long-haul drivers) on each delivery run. As a result, the drivers in the survey are those who drive long distances and aren't really new to the industry. This limitation is significant for thinking about the future of trucking jobs and the workers who will be affected; evidence suggests workers new to the industry are more likely to be people of color and immigrants, whereas white workers composed 74 percent of the sample in this survey.

However, if we want a sense of the *workers currently making a career* in the jobs that are at risk, the 2010 survey serves that purpose. Weighted national estimates based on the survey suggest this population has an average of more than 16 years of experience as long-haul truckers, that 35 percent are working as owner-operators, and that 90 percent work at for-hire carriers. These estimates suggest that 75 percent of these drivers are hauling truckload freight and just 4 percent are paid a salary or by the hour, meaning that the vast majority are pieceworkers paid by the mile or a percent of revenue per load. In addition, 94 percent of drivers in the weighted survey were male, and almost half were 50 or older.

The Quality of New Driving Jobs Created

While as many as 294,000 jobs could be lost to autonomous trucks, given the aging workforce, growing demand for trucking services as costs decline, and other factors, there will likely be enough jobs to accommodate the displaced drivers. In fact, with the growth of e-commerce and the need for local drivers to shuttle freight to and from ATPs, we could see many more local trucking and delivery jobs.

The critical question is: What will the quality of these jobs be? The discussion above illustrates that wages and working conditions for truck drivers will likely deteriorate as automation reduces the number of long-distance trucking jobs. Local and for-hire trucking jobs have always been the most competitive and least paid, unless they are unionized. We should be deeply concerned about labor conditions in these new jobs.

There is every reason to believe that the jobs created around autonomous truck ports will resemble port driving jobs. Just as port drivers move goods to and from ships, these drivers will move freight between customers and ATPs. The good news is that we know as much, arguably more, about port drivers and their working conditions than almost any other kind of truck driver, thanks to a number of high-quality research efforts.[43]

The bad, albeit unsurprising, news is that these are among the worst trucking jobs around. For-hire truckload suffers from destructive competition, and local-hauling has even lower barriers to entry

as trucks don't go as far and don't need to be as reliable. As a result, trucking carriers keep wages as low as possible and shift as much of the cost of inefficiency and risk of downtime and capital investment to workers as possible. To these ends, independent contractors are used—and to an even greater extent than in long-haul trucking.

It's estimated that there are some 75,000 port truckers in the United States. Surveys of more than 2,000 such drivers in seven major studies indicate that more than 80 percent of those drivers work as independent contractors, and the vast majority (perhaps 90 percent) of those workers are misclassified and should be employees. The surveyed drivers work very long hours, averaging 59 hours per week. Employees earned $35,000 and independent contractors just $28,783, before taxes. Not surprisingly, independent contractors were much less likely to have health insurance or retirement benefits.[44]

Moreover, most trucks used in port driving are old and polluting, with emissions exacerbated by the time drivers spend waiting and idling their engines (the prevalence of independent contractors means workers aren't paid hourly, so there's little incentive for firms to operate efficiently). This situation creates serious environmental justice issues in surrounding neighborhoods (typically lower-income communities of color), which suffer from high asthma rates and other health impacts.

If a similar industry model takes root for ATP driving, automation could thus replace some of the best trucking jobs with more of the worst. This forecast raises a host of serious concerns, from the health impacts described above to the degradation of some of the few good jobs remaining to workers without a college degree.

Policies for a 21st-Century Trucking Industry

In the coming decades, the way we move freight will change, in ways big and small. What that means for communities, workers, and an evolving trucking industry will be shaped not just by the latest technical innovations, but also by the response of governments, businesses, and workers across the sector. How technology changes truck driving is not an inevitability, and the action or inaction of policymakers will be key in determining which technologies make their way onto our public roadways, who benefits from this innovation, and who may be left behind.

Truck driving will be one of the first major occupations transformed by the coming wave of technological change, but policymakers have a chance to get ahead of these issues. Effective public policy can ensure that trucking evolves into a productive, high-road industry. Policymakers, collaborating with workers and industry leaders, have an opportunity to tackle some of our biggest challenges: creating good, family-supporting jobs; improving roadway safety; reducing traffic congestion; and reducing greenhouse gas emissions.

Below, I outline three key areas of policy solutions:

1.   Develop an industry-wide approach to worker advancement and stability;

2.   Ensure strong labor standards and worker protections; and

3.   Promote innovation that achieves social, economic, and environmental goals.

Working together with industry stakeholders, policymakers can help to ensure that the benefits of innovation in the trucking industry are shared broadly between technology companies, trucking companies, drivers, and communities.

1. Develop an Industry-Wide Approach to Worker Advancement and Stability

While cataclysmic loss of truck-driving jobs is not imminent, big changes in the industry will require many workers to adjust the course of their careers. Given the significant number of workers affected,

the diverse nature of firms, and the varied impact of automated trucks across industry segments, supporting workers during this adjustment process will require an industry-wide strategy that brings business, labor, and public-sector resources and perspectives to bear.

Create a Trucking Innovation and Jobs Council

Policymakers should create a Trucking Innovation and Jobs Council, bringing together diverse stakeholders across the sector—workers, employers, technologists, and policymakers—to create an action plan to develop a 21st-century trucking workforce and provide the necessary financial security to workers through this transition. The Council would develop and implement an action plan for how industry stakeholders would fund, design, and carry out policies and programs to accomplish two goals: 1) the development of good career pathways for trucking workers; and 2) the provision of direct financial safety net resources to support job transitions within and out of the industry. While such a Council may function best at the national level, in the absence of federal action, states should begin to create their own Innovation and Jobs Councils and action plans to start preparing for coming changes in the industry.

Build Strong Career Pathways

The most important work of Innovation and Job Councils would be to help workers advance in long-term, stable, rewarding careers. Specifically, the Councils should design a comprehensive suite of programs focused on dislocated, incumbent, and future workers that might include:

- Job-matching and career counseling services for dislocated and at-risk workers, potentially via regionally based hiring halls, working in partnership with employers, unions, and other local organizations.

- On-the-job training programs to transition workers into new roles, such as leading platoons and inspecting autonomous trucks. These programs could involve apprenticeships with paid, on-the-job training and industry-recognized credentials.

- Updated commercial driver training and credentialing, developed in partnership with industry stakeholders, including worker organizations.

- Rules for consultation and planning between drivers and employers before major layoffs. These rules should encourage plans to reconstitute jobs or to leverage work-sharing and retraining funds. Existing workers should be given first consideration for new jobs and/or retraining opportunities.

Create Safety Net Programs to Support Worker Transitions

Innovation and Jobs Councils would design financial safety net support programs for career development and job transitions. Councils would coordinate benefit requirements for workers receiving government support and administer financial support programs funded by revenues identified by the Council. Some key programs could include:

- Work-sharing programs to give workers time to train for new jobs or give companies time to reorganize their operations temporarily, without workers losing their income, health insurance, or retirement benefits. Such programs might allow workers to access a portion of the benefits they would have earned from unemployment insurance to make up for lost hours.

- Supplemental unemployment insurance benefits to extend financial support to workers who need additional time to retrain or find a new job.

- An emergency fund to assist workers facing dire financial hardships that result from reduced or lost income during a job transition (e.g., home foreclosure or medical emergencies).

- A retirement buyout package in lieu of job-training benefits for workers close to retirement.

Coordinate and Generate New Revenues for Industry-Wide Workforce Strategies

Innovation and Job Councils should leverage resources from employers, unions, and government, including existing public funding under the federal workforce investment system. Given the number of workers impacted, new revenue strategies will be needed to meet growing needs. One promising idea would be to adopt an Automated Vehicle Miles Traveled Tax. For every mile traveled by a driverless truck, a modest contribution from the truck's owner would go into an industry-wide fund to deal with the impact of this transition. Alternatively, the sector could consider other taxes, such as an excise tax on industry revenues or facilities fees at autonomous truck port operations.

2. Ensure Strong Labor Standards and Worker Protections

This report has documented how the coming wave of technological change could—without action from policymakers—result in deteriorating wages and working conditions for truck drivers. In fact, many of the job-quality problems we should be concerned about already plague significant portions of the industry. These problems are the result of existing policy failures that will leave even more workers vulnerable as autonomous trucks are adopted. The following are critical areas where policymakers can protect truckers now and into the future, putting into place a framework of strong labor standards that can shape the trajectory and impact of autonomous trucks.

Address Misclassification of Current and Future Drivers

The misclassification of employees as independent contractors is one of the most important labor issues in today's trucking industry. Automation and the potential digitization of freight matching will likely amplify it even further. Many of the new driving jobs that stand to be created by trucking automation will be ripe for misclassification as low-paying, low-quality jobs. Misclassification takes

away workers' rights, leaves them without basic protections such as the minimum wage, and strips them of many protections of our social safety net. This abuse of workers not only harms the workers themselves, it undermines good employers and costs us all through congestion, accidents, and air pollution.

Policymakers should clarify who is an employee and who is an independent contractor to prevent unscrupulous employers from gaining an advantage by skirting the law. Policymakers should follow the lead of the California Supreme Court, which recently ruled that a worker is an employee, unless the contracting employer can prove the worker 1) is free from control of the company; 2) performs work outside the company's normal business; and 3) is engaged in an independently established trade or occupation. Under such a standard, most of today's truck drivers would be employees and as such they would be protected under labor laws. Steps must be taken to ensure that this standard applies to new driving jobs which are created as a result of trucking automation.

Ensure Drivers Are Able to Earn a Living Wage

Truck drivers should be paid for all the time they work, including time at loading docks, ports, and shipper locations. Typically, truckers are paid only for the miles they drive, so much of their time is uncompensated. As long-haul miles are automated, the portion of work that is local—and thus unpaid—will grow for many of these drivers. Local policymakers should explore ideas such as state-level wage boards for truck drivers, which would bring together workers, trucking companies, and their clients to develop industry-specific agreements around wages. This policy could ensure stable and rising wages and good working conditions, even as local trucking jobs grow and well-paid long-haul jobs are lost.

Engage in Sector-Wide Consultation and Bargaining With Unions

As new automated technology takes hold in the trucking industry and as occupations in the industry begin to shift, it will be more important than ever for workers to join together to increase their ability to bargain with their employers. Policymakers should protect the ability of drivers and other workers to bargain collectively and join a union. In Europe, sector-wide bargaining models are the norm, as they were in the United States prior to industry deregulation. If policymakers are concerned about the future of livelihoods in trucking industry, building new models for bargaining over industry-wide labor standards could significantly improve drivers' livelihoods and ensure technology is implemented in a way that benefits employers, shippers, and workers.

Strengthen Job-Loss Early Warning Systems

As carriers involved in long-haul trucking adopt new technology and reorganize their workforce, drivers deserve an early warning of layoffs. Unfortunately, drivers working for long-haul carriers as dedicated independent contractors are not covered under the Worker Adjustment and Retraining Notification (WARN) Act, which requires employers of 100 employees or more to give a 60-day notice of any mass layoffs. The WARN Act should be amended to require that trucking companies

provide both employee and independent contractor drivers with a longer notice period, allowing drivers to start looking for a new job or to seek additional training and allowing government agencies to better plan to assist dislocated drivers.

Enforce Labor Rights Across Joint Employers and Delivery Clients

As e-commerce giants like Walmart and Amazon continue to grow, and as app-based platforms begin matching more drivers with their freight, these companies are becoming the de facto employer for truck drivers, even if a different company signs a driver's paycheck. When a shipper or platform shares or co-determines essential terms and conditions of drivers' employment, it should be considered a joint employer and jointly bear responsibility for wage theft or other labor law violations. In California, legislators recently proposed a law to create a public database of trucking companies with unpaid wage-theft judgements and to require trucking companies to disclose their history of labor law violations to corporate customers. If a company then continues to hire these trucking firms, they will be held jointly liable for future wage judgements. If autonomous trucking ports begin to develop the same issues with wage theft experienced by today's port drivers, this approach could be a useful tool for creating accountability and improving working conditions.

Invest in Labor Law Enforcement and Inspection Programs to Prevent Wage Theft

Port truck drivers have won back millions of dollars in wages from wage-theft cases in judgements that likely only touch the tip of the iceberg. Similarly, long-haul truckers lose hundreds of millions of dollars annually to wage theft. Aggressive enforcement could ensure these practices do not spread and that autonomous ports do not become a new source of wage theft.

Strengthen Protections Against Exploitative Leasing and Training Contract Practices

Federal policymakers should examine "lease-to-own" practices, in which poorly paid drivers, often new to the industry, are convinced to purchase commercial trucks through high-interest loans. This practice transfers the costs of operating trucks to workers rather than trucking companies and leaves these workers increasingly vulnerable, as trucks are becoming more expensive. Similar scrutiny should be given to training contracts, which typically lock a driver into working for one company until the debt of the driver's training has been paid off and often paint a deceptive picture of typical earnings in the industry. Some use non-compete clauses for workers they have trained. Policymakers should outlaw these abusive contracts and promote an apprenticeship model, as described above, which could help to more fairly spread the risks and costs of developing new drivers between workers and employers in the industry.

Prohibit Employment Contracts From Requiring Arbitration in Labor Law Disputes

Employers in the transportation sector are increasingly using arbitration clauses in employment contracts to stop workers from exercising their rights when faced with discrimination, harassment, stolen wages, or other exploitation. These agreements force workers to individually go through

arbitrators selected and paid by their employers to determine disputes, rather than being able to bring cases to public agencies or the court. In a recent Supreme Court ruling, *Epic Systems v Lewis*, the court affirmed that employees who sign such agreements must pursue claims through arbitration. Congress should act to clarify the Federal Arbitration Act in order to undo the harm from the *Epic Systems* decision. In the meantime, state policymakers should pass legislation (as has been proposed by California Assembly Member Lorena Gonzalez Fletcher [AB 3080]) to prohibit employers from retaliating against workers who refuse to sign mandatory arbitration agreements as a condition of employment.

3. Promote Innovation That Achieves Social, Economic, and Environmental Goals

To date, many policymakers have been hesitant to play an active role in shaping trucking technology development for fear of stifling innovation or "picking winners." In order to ensure the best social, economic, and environmental outcomes for drivers, local communities, and our transportation infrastructure, however, policymakers need to play an active role in regulating the industry and developing new technology.

For example, this report has identified technology adoption scenarios that can result in better outcomes for a range of stakeholders. These point to specific policy recommendations, such as:

Promote Public Safety and Good Jobs by Supporting Human-Led Platooning

Human–drone platoon technology is the one scenario in this report where new high-quality driving jobs are created. Moreover, it may be decades before automated systems can deal with the full range of circumstances occurring along the interstate. Drivers have the experience and knowledge to deal with poor weather and rapidly changing road conditions, like accidents, construction, traffic, and erratic drivers. In addition, separate local trucks and human–drone highway platoons provide many of the best environmental benefits of automation through increased fuel economy. Government agencies and regulators should therefore consider developing policies and contracting/procurement practices to promote platooning over other less adaptable, more economically harmful forms of trucking technology.

Promote Clean and Electric Trucks

Once private and for-hire carriers begin buying autonomous vehicles, many older, less fuel-efficient trucks once used for long-haul trips are likely to transition to local driving, converging at automated ports. Policymakers should create incentives to transition to cleaner fuels and eventually electric trucks to promote worker safety and public health.

Solutions like these will require strong public policy leadership to ensure that the benefits of innovation in the trucking industry are shared broadly between technology companies, trucking companies, drivers, and communities. Examples of specific strategies include:

Engage Stakeholders to Develop a Shared Innovation Agenda

In order to ensure that trucking technology accomplishes economic, social, and environmental goals, policymakers should bring together private and for-hire carriers, major shippers, worker representatives, and technology firms to examine the costs and benefits of various technologies and policy responses. State and federal leaders should consider creating a multi-stakeholder group to advise policymakers on innovation priorities and policy ideas to increase productivity, safety, and sustainability, while improving the skills, stability, and well-being of the workforce. This role could be served by federal or state-level Jobs and Innovation Councils, defined above, or through the creation of new advisory bodies specifically focused on developing effective research and development agendas, new approaches to regulation, and aligning existing federal programs.

Invest in Research and Development and Policy Expertise

Federal funding underlies many of the innovations that will make automated vehicles possible. The federal government should therefore ensure that public research funding related to automated vehicles prioritizes the development of new technology that provides a broad range of public benefits, particularly when it comes to ensuring good jobs for drivers. Policymakers also need to hire staff with the expertise to understand the state of the field and its trajectory and comfortably engage in substantive debates about economic and social impacts with trucking technologists, scientists, businesses, the workforce, and other stakeholders.

Allow State and Local Government to Test New Policy Responses

Given the many unknowns surrounding the introduction of autonomous trucks, federal policymakers should avoid actions that preempt the development of local solutions to protect the safety, health, and well-being of the public and the trucking workforce. For example, they should remove existing barriers to local policy and avoid additional policy to prevent local action. Already, Congress has considered legislation prohibiting local safety regulations surrounding automated trucks. Policymakers should not stifle local-level approaches and policy innovation.

Reinforce the Authority of Local Agencies to Promote Public Interest Around Autonomous Trucking Ports

For many of the scenarios profiled in this report, autonomous trucking ports were identified as a critical piece of our country's evolving logistics infrastructure. The growth of e-commerce and regional automated port infrastructure could lead to more underpaid and overworked drivers working in unsafe conditions, while adding to traffic congestion and poor air quality in communities across the nation. In order to allow local agencies to better protect their communities and local job quality, greater local control over port facilities should be codified to manage air quality and traffic congestion, ensure drivers are paid livable wages and have safe work environments, and ensure labor peace to protect the efficiency of our nation's logistics system.

Ensure Public Dollars and Public Policies Do Not Promote Displacement of Workers

Unless appropriate environmental, social, and economic protections are in place, policymakers should avoid investment in transportation and communication infrastructure that promotes automation of trucking jobs, purchasing services from carriers utilizing automated vehicles, or industry efforts to cut safety regulations for autonomous trucks. Instead, government agencies should be looking to adopt and promote technologies that achieve efficiency by augmenting the skills of the current workforce.

Improve Data Collection and Analysis

Current government or commercial data sources do not allow policymakers to understand who is driving which types of freight across various segment of trucking. We need to improve data collection to track the industry as it evolves and to identify shifts in demand and workforce needs. Government agencies should develop new plans for improved analysis of existing sources (including the Bureau of Labor Statistics, the Census Bureau, and the Federal Motor Carrier Safety Administration) and commission supplemental data collection to better monitor the impacts of the adoption of new trucking technology.

Endnotes

1   For example, see Veryard, Daniel. (2017, May 31). *Managing the Transition to Driverless Road Freight Transport*. International Transport Forum. Retrieved from www.itf-oecd.org; McKinsey Global Institute. (2017). *A Future That Works: Automation, Employment, and Productivity*. San Francisco, CA: McKinsey Global Institute; Center for Global Policy Solutions. (2017). *Stick Shift: Autonomous Vehicles, Driving Jobs, and the Future of Work*. Washington, DC: Center for Global Policy Solutions.

2   For example, see Ford, Martin. (2015). *Rise of the Robots: Technology and the Threat of a Jobless Future*. New York: Basic Books.

3   Motor Vehicle Operators (SOC) included: Heavy and Tractor-trailer Truck Drivers (1,678,280 million/44.2 percent), Light Truck or Delivery Services Drivers (826,510 workers), Bus Drivers, School or Special Client (505,230 workers), Driver Sales Workers (417,470 workers), Taxi and Chauffeurs (180,750 workers), Bus Drivers, Transit and Intercity (168,140 workers), Ambulance Drivers and Attendants, Except EMTs (19,730 workers). Beede, David N., Regina Powers & Cassandra Ingram. August 11, 2017. *The Employment Impact of Autonomous Vehicles*. Retrieved from http://www.esa.doc.gov/reports/employment-impact-autonomous-vehicles.

4   Industry data available from the American Trucking Associations website: http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx. Accessed May 19, 2018.

5   For even more detail, a glossary at the beginning of this report covers the terms used and others the reader may have encountered in discussions about autonomous trucks.

6   Sieber, W.K., C.F. Robinson, J. Birdsey, G.X. Chen, E.M. Hitchcock, J.E. Lincoln, A. Nakata, & M.H. Sweeney. (2014). Obesity and other risk factors: The national survey of U.S. long-haul truck driver health and injury. *Am. J. Ind. Med. 57* (6):615–626.

7   Bureau of Labor Statistics, U.S. Department of Labor. *Occupational Outlook Handbook, Heavy and Tractor-trailer Truck Drivers*. Available from https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm.

8   The major exception among dominant players in terms of the basic technology for self-driving is Telsa, which does not use lidar.

9   Dougherty, Conor. (2017, November 13). Self-Driving Trucks May Be Closer Than They Appear. *New York Times*.

10   Morgan Stanley Research Global. (2013, November 6). *Autonomous Cars: Self-Driving the New Auto Industry Paradigm*. New York: Morgan Stanley Research. p. 85.

11   Driver wages and benefits accounted for 43 percent of costs for carriers in 2017, according to the ATA's research arm. Hooper, Alan, & Dan Murray. (2017, October). *An Analysis of the Operational Costs of Trucking: 2017 Update*. American Transport Research Institute: Arlington, VA. Retrieved from http://atri-online.org/wp-content/uploads/2017/10/ATRI-Operational-Costs-of-Trucking-2017-10-2017.pdf.

12   Veryard (2017) drew a similar conclusion, suggesting that the technology might add less than 5 percent to the cost of a truck.

13   Cannon, Jason. (2017, January 19). Truck sales close 2016 just under 250,000 units. Commercial Carrier Journal. Retrieved from https://www.ccjdigital.com/class-8-north-american-truck-sales-2016-year-end/.

14   Strauss, William A., & Thomas Haasl. (2017). Economy to Cruise Near Speed Limit in 2017 and 2017 Even as Auto Sales Downshift. Chicago Fed Letter No. 381. Retrieved from https://www.chicagofed.org/publications/chicago-fed-letter/2017/381.

15   For example, see Center for Global Policy Solutions. (2017). p. 3.

16   Gittleman, Maury, & Kristen Monaco. (2018). *Truck Driving Jobs: Are They Headed for Rapid Elimination?* Working Paper.

17   JB Hunt Transportation Inc. (2015). 660 Minutes: How Improving Driver Efficiency Increases Capacity. White Paper. Retrieved from http://blog.jbhunt.com/wp-content/themes/files/pdf/660_Minutes.pdf.

18   I have worked as a consultant for Uber ATG and others involved in the development of autonomous trucks in the past. None of those organizations provided funding for this research.

19   I've previously proposed "urban truck ports" that would deliberately segment truck trips into local and long-distance parts so that drivers could get home more often and the most efficient trucks possible could be used. This kind of segmentation dovetails perfectly with the capability of autonomous trucks. For more information on my concept for these facilities, see: Viscelli, Steve. (2017, February 17). *Stalled: Make Big Trucks More Fuel Efficient With Smarter Infrastructure Investments*. Kleinman Center for Energy Policy: University of Pennsylvania. Philadelphia, Pennsylvania. Retrieved from https://kleinmanenergy.upenn.edu/policy-digests/stalled-make-big-trucks-more-fuel-efficient.

20   This idea was first explained to me by Jonny Morris, the Head of Public Policy at Embark, one of the prominent firms working on exit-to-exit autonomous trucks. As best I can tell, the term "Jetson Fallacy" may have originated with Professor Michael Bess, who used it to critique how science fiction imagined lots of new technology and gadgets but failed to imagine how biotech would alter human bodies. See Smith, Bryant Walker. (2017). How Governments Can Promote Automated Driving. 47 N.M.L. Rev. 99. Retrieved from http://digitalrepository.unm.edu/cgi/viewcontent.cgi?article=1411&context=nmlr. The term was also used by Liza Mundy in a 2013 *Slate* article, "The Jetson Fallacy," *Slate*. (2013, October 21). Retrieved from http://www.slate.com/articles/technology/future_tense/2013/10/jetson_fallacy_if_we_live_to_150_the_nuclear_family_will_explode.html.

21   During fieldwork for a book I recently published, I actually did this kind of driving for Walmart for a short period, so I am somewhat familiar with it. See Viscelli, Steve. (2016). *The Big Rig: Trucking and the Decline of the American Dream*. Berkeley: University of California Press.

22   Distribution centers existed before Walmart. They were famously employed by Sears and Roebuck. Sears had seven massive distribution centers in the United States that used everything from mail to rail to send the goods customers ordered via its catalogue. Sam Walton, on the other hand, bet on the obvious solution to supply his stores: trucks.

23   Lammert, M., A. Duran, J. Diez, K. Burton et al. (2014). Effect of Platooning on Fuel Consumption of Class 8 Vehicles Over a Range of Speeds, Following Distances, and Mass, SAE Int. J. Commer. Veh. 7(2), doi:10.4271/2014-01-2438; Roberts, Jack, Rick Mihelic, & Mike Roeth. (2016). Confidence Report: Two-truck Platooning. North American Council for Freight Efficiency; Bevly, D., C. Murray, A. Lim, R. Turochy, R. Sesek, S. Smith, G. Apperson, J. Woodruff, S. Gao, M. Gordon, N. Smith, A. Watts, J. Batterson, R. Bishop, D. Murray, F. Torrey, A. Korn, J. Switkes, & S. Boyd. (2015). Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment: Phase One Final Report. Washington DC: FHWA, U.S. Department of Transportation. Retrieved from http://eng.auburn.edu/~dmbevly/FHWA_AU_TRUCK_EAR/FHWA_AuburnDATP_Phase1FinalReport.

24   For more information on how platooning might work, see the website of the leading U.S. developer of the technology, Peloton: https://peloton-tech.com/how-it-works/.

25   See Roberts, Mihelic, & Roeth (2016).

26   The difference between the way some truck manufacturers and Silicon Valley have approached self-driving is often described as incremental (i.e., adding one automated feature at a time until a vehicle can do everything required to drive itself) versus disruptive (i.e., going straight to Level 4 all at once).

27   See Roberts, Mihelic, & Roeth (2016).

28   See Morgan Stanley (2013), p. 85.

29   See Veryard (2017), p. 25.

30   Five carriers in the group hauled 99-100-percent refrigerated freight, generated $3,395,060,863 in revenue, controlled 12,563 tractors, and utilized 16,231 drivers or approximately 1.3 drivers per tractor (likely reflecting a greater use of team driving). These figures suggests average revenue per driver of $209,000.

31   A relatively small number of drivers at private fleets hauling freight over long-distances may also be at some risk, but since most private drivers move freight from distribution centers to stores, their work is likely to involve significant urban driving and other tasks (like unloading) and thus will be safe from automation. It is possible, however, that private firms will move to for-hire transportation using autonomous trucks operating from autonomous truck ports for long-distance shipments before autonomous trucks can go from facility to facility. LTL fleets might do so as well for their linehaul as prices drop and long-distance transport from autonomous truck port to autonomous truck port becomes consistent.

32   LTL drivers and carrier insiders with whom I spoke suggested that the highest percentage of linehaul drivers a large firm might have would be somewhere in the 40s.

33   Additional support for using this ballpark estimate for parcel linehaul is BLS data that suggests around 29,880 heavy and tractor-trailer truck drivers work in courier and express delivery services, which does not include some self-employed truckers.

34   Burks, Stephen V., Kristen Monaco, & Arne Kildegaard (2018, March 20). Is the Labor Market for Truck Drivers Broken, and Will Autonomous Trucks Fix It? Working Paper. Retrieved from https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=TRF18&paper_id=29.

35   *The ATA Driver Compensation Study* report based on 2014 annual compensation, pay rates from the first half of 2014, surveyed 130 different fleets, covering around 115,000 employee drivers and 17,000 contractors. The for-hire truckload carriers in the study are an appropriate comparison with 66 percent of the sample identifying as national fleets and 31 percent identifying as regional fleets. They had a mean length of haul of 413 miles and median length of haul of 375. These fleets employed 66,509 drivers and operated 52,214 tractors. They also had 13,281 independent contractors (13,281/65,495 total power units, about 20 percent of their capacity). Costello, Bob. (2014). *ATA Compensation Study 2014*. Arlington, VA: American Trucking Associations.

36   Hoffman, Mitchell, & Stephen V. Burks. (2017). *Training Contracts, Employee Turnover, and the Returns from Firm-Sponsored General Training*. IZA Discussion Paper No. 10835. Bonn, Germany: IZA. Retrieved from SSRN: https://ssrn.com/abstract=2988182.

37   Ibid.

38   Costello, Bob, & Ron Suarez (2015, October). Truck Driver Shortage Analysis. Arlington, VA: American Trucking Associations. Retrieved from http://www.trucking.org/ATA%20Docs/News%20and%20Information/ Reports%20Trends%20and%20Statistics/10%206%2015%20ATAs%20Driver%20Shortage%20Report%202015. pdf.

39   Gillespie, Patrick (2015, October 9). Truck Drivers Wanted. Pay: $73,000. CNN Money. Retrieved from http://money.cnn.com/2015/10/09/news/economy/truck-driver-shortage/index.html.

40   See Viscelli (2016). Chapter 3.

41   More research is needed on the truck driver population to answer questions like this. For instance, it is clear that for-hire truckload drivers suffer from health problems at much greater rates than the general population. The job undoubtedly contributes to these rates. But it may also be that workers choose long-haul trucking because of their physical inability to do other jobs. In my own research, drivers have often told me that they moved to trucking because they could no longer do more physically strenuous manual jobs, including very good jobs in the construction trades. Similarly, it may be that linehaul drivers are less physically able to do the more demanding tasks of local pick-up and delivery.

42   For a full description of the survey methodology see Sieber et al. (2014).

43   Studies of port drivers are generally of higher quality and less expensive than studies of other truckers because port drivers are easy to access, given the fact that they all come to same place to work.

44   Smith, Rebecca, Paul Alexander Marvy, & Jon Zerolnick. (2014, February). The Big Rig Overhaul: Restoring Middle-class Jobs at America's Ports Through Labor Law Enforcement. National Employment Law Project, Change to Win Strategic Organizing Center, & Los Angeles Alliance for a New Economy. Retrieved from http://www.justice4ladrivers.net/BigRigOverhaul2014Finalsm.pdf.

Data Appendix

All data were compiled from firm-reported data to *Transport Topics* and *Commercial Carriers' Journal* as reported in the "2017 Transport Topics Top 100 For-hire" and "2017 CCJ Top 250" rankings. Contact author at steveviscelli1@gmail.com for more information.

Data used for per-driver revenue calculation (refrigerated)

Company	2016 revenue	% revenue from refrigerated	Tractors	Total drivers
CR England, Inc.	$1,304,898,000	100	4,165	6,283
KLLM Transport Services, LLC	$937,000,000	100	4,000	3,126
Hirschbach Motor Lines, Inc.	$251,697,000	100	1,107	1,070
John Christner Trucking LLC	$239,015,863	99	841	802
Stevens Transport, Inc.	$662,450,000	100	2,450	4,950
TOTAL	$3,395,060,863		12,563	16,231
Revenue per driver (2016 revenue/total drivers)	**$209,171**			

Data used for per-driver revenue calculation (dry van)

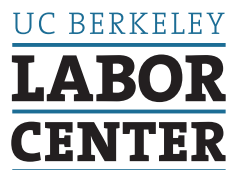| Company	2016 revenue	% revenue from dry TL	Tractors	Total drivers
Paschall Truck Lines, Inc.	$ 237,000,000	98	1,239	1,427
Challenger Motor Freight Inc.	$ 258,496,000	100	1,350	1,550
Black Horse Carriers, Inc.	$ 337,500,000	100	1,424	1,664
Martin Transportation Systems, Inc.	$ 237,500,000	100	980	1,390
P.A.M. Transportation Services, Inc.	$ 432,852,000	100	1,729	2,588
TOTAL	$ 1,503,348,000		6,722	8,619
Revenue per driver (2016 revenue/total drivers)	**$174,423**			

Heartland Express, Inc. is a similar carrier to those used for this calculation, however, their reported numbers of drivers and revenue do not seem to be accurate and so were not included. Heartland reported $612,937,000 for 2016, 5,430 trucks and 5,234 drivers. That results in a per driver revenue of $117,107. Not only is this far below the average of similar companies, the fact that Heartland reported fewer drivers than trucks suggests that either something dramatically reduced their asset utilization (there is no other evidence this is the case) or that the number was reported incorrectly. If Heartland is included than the per driver revenue for the segment is $152,754.

Data Appendix

Data used for per-driver revenue calculation (LTL)

Company	2016 revenue	% revenue from LTL	Tractors	Total drivers
YRC Worldwide Inc.	$4,697,500,000	102	15,135	19,522
Old Dominion Freight Line, Inc.	$2,991,517,000	100	7,994	9,683
Estes Express Lines	$2,403,615,000	100	6,516	7,755
R+L Carriers	$1,429,000,000	100	5,959	5,336
Saia Inc.	$1,200,000,000	100	4,000	4,800
Central Transport International, Inc.	$703,000,000	98	3,180	3,152
Dayton Freight Lines, Inc.	$493,700,000	98	1,642	2,075
TOTAL	$13,918,332,000		44,426	52,323

Revenue per driver (2016 revenue/total drivers)	$266,008

Institute for Research on Labor and Employment
University of California, Berkeley
2521 Channing Way
Berkeley, CA 94720-5555
(510) 642-0323
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