

Effect of Automated Trucks on the **Truck Driver Workforce**

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Workshop Report

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Effect of Automated Trucks on the Truck Driver Workforce

An NSF Workshop Report: Effect of Automated Trucks on the Truck Driver Workforce – June 29–30, 2018

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EXECUTIVE SUMMARY

The issue of workforce disruption from automated trucks has been on the U.S. government's radar. On April 26, 2017, Senators Susan Collins and Jack Reed sent a letter to the U.S. Government Accountability Office asking it to look into how autonomous trucks will affect truck drivers and the communities where they live. Various efforts to evaluate how to solve these challenges have been proposed. The Virginia Tech Transportation Institute (VTTI), with funding from the National Science Foundation's (NSF) Human-Technology Frontier, conducted a workshop that brought together representatives from different domains with unique perspectives on the trucking industry.

The day-and-a-half NSF workshop was held June 29–30, 2018, at NSF headquarters in Arlington, Virginia. The goal of the workshop was to identify the most critical unanswered questions related to the effects automated trucks will have on the U.S. economy and, more specifically, how automated trucks will affect the current and future truck workforce. The discussions and findings of the workshop are presented here as research needs for future NSF program solicitations.

Types of Jobs Needed Under These Different Implementation Scenarios

More research is need to understand how jobs that still require a human will be completed—for example, when the automated truck is driving terminal-to-terminal with no safety driver. Relevant questions include how vehicle inspections will be performed; what happens when an automated truck is involved in a crash or experiences a software or mechanical malfunction; what occur when law enforcement personnel stop an automated truck, etc.?

Certification Processes Needed to Ensure a Formal Safety Framework

How safe do automated trucks need to be? There was consensus that automated trucks need to be far safer than human drivers, but how much safer? Data are needed to answer these questions; the question is what type of data?

Regulatory, Insurance, and/or Legal Perspectives Needed as Automated Truck Technology Matures

The government should be involved in the regulation of desired safety outcomes (rather than specific technologies). Research is needed to understand what these outcomes should be and how these data are shared with the government.

Types of Trucking Operations Likely to be First Adopters of Automated Trucks

Automated trucks will, at least initially, be purchased by well-capitalized fleets. Thus, one area of research would be to evaluate how this technology could be distributed across the spectrum of different sized fleets.

Changes in Organization of Carriers Due to the Introduction of Automated Trucks

An assumption was made that driver demand will largely be focused on local delivery, which could be similar to local drayage markets that exist at ports. Thus, research is needed on how to make these positions more attractive, including mandating a living wage.

The Potential Impacts to Drivers and Other Workers in the Delivery Process During the First Decades of Automated Truck Implementation

Skill demands for drivers under Level 4 automation will be different, and potentially more mentally taxing. During this time, when drivers are not actively involved in the driving process, what can be done to keep them engaged and ready to take over if needed?

The Location Choices of Warehouses, Distribution Centers, Manufacturing Factories, and Truck Stops in an Automated Truck Future

There are important questions regarding how uncertainty will impact investment, something that will affect many stakeholders. Research that includes land-use and highway planners, etc. should certainly be part of this conversation. Optimization

analysis needs to work on identifying the types of freight, the types of lanes/customers, and the types of motor carriers serving them, that justify automated truck investments.

How the Current Truck Driving Workforce Can Be Integrated with Automated Trucks

Do we train human drivers to adjust their driving style to that of automated vehicles or should we program automated vehicles to drive like human drivers, only safer?

The Barriers to Effective Integration with Automated Trucks

With more pickup and delivery operations, how can we help older, less physically fit drivers do this work? Research is needed to understand whether the new generation of workers will be more or less interested in trucking as an occupation and whether they will have the additional technical skills and inclinations that might be needed.

System Design to Enhance the Driver-Automated Truck Interaction and Interface

Some attendees questioned whether truck drivers were being engaged in this discussion as anything more than an after-thought. Research is needed to understand how these technologies can be co-created with truck driver input.

The Skills Truck Drivers Have That Could Transfer to New Jobs Created by Automated Trucks

Research is needed to understand the existing skills that truck drivers have beyond the skills associated with driving a truck. Thus, there needs to be research with a representative sample of truck drivers to identify the range of potential skills that translate to other areas, especially STEM areas.

The Cross-Disciplinary Research Challenges in Designing New Curricula for Reskilling

Research is needed to understand and identify the new specific jobs (and skills) that will be required with the deployment of automated trucks. The primary challenge in

designing new curricula for reskilling truck drivers is this uncertainty of what jobs/skills will be required.

Opportunities for Public-Private Partnerships in Reskilling Truck Drivers

Research is needed to understand how to best engage in this type of partnership with regard to reskilling truck drivers.

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INTRODUCTION

BACKGROUND

Surface transportation has become the primary means of transporting goods, which relies heavily on large trucks. Trucks affect every U.S. citizen regardless of personal mode of transportation, as 100% of all consumer goods are delivered by trucks at some point in the delivery cycle.ⁱ There are approximately 3.5 million commercial truck driving licenses in active use today,ⁱⁱ and approximately 1.8 million of these licenses are used by drivers operating heavy and tractor-trailer trucks.ⁱⁱⁱ Trucks hauled 11.4 billion tons of freight in 2015, valued at more than 13 billion in 2012 dollars.ⁱⁱⁱ Since the 2008 recession, demand for freight services has steadily increased as the economy has grown, and truck drivers have needed to move more goods throughout the U.S. As of 2015, there were 551,150 interstate motor carriers actively operating in the U.S.^{iv} The trucking industry contributes significantly to the nation's economic portfolio, hauling 61% of the total freight transported in the U.S. by value in 2016,ⁱⁱⁱ and contributing an estimated 3.5% of the U.S.'s Gross Domestic Product.^v

Contrary to the transportation system's gradual evolution, vehicle technology is undergoing rapid changes that could affect all types of road transportation, and its effects on trucking could have a particularly important effect on society. Trucks affect every U.S. citizen regardless of personal mode of transportation as 100% of all consumer goods are delivered by trucks at some point in the delivery cycle.^{vi} Approximately 3.5 million professional truck drivers haul more than 10 billion tons of freight annually in the U.S., grossing more than \$700 billion in freight revenues.^{vii} Since 2010, demand for freight services has increased, and truck drivers have needed to move more goods throughout the U.S. As of 2015, 551,150 interstate motor carriers were actively operating in the U.S.^{viii} The trucking industry contributes significantly to the nation's economic portfolio, employing approximately 8.7 million people and hauling more than two-thirds of the total freight transported in the U.S.

Increasing demand for consumer goods and just-in-time inventory strategies (i.e., receiving goods only as they are needed) place a significant demand on truck drivers as

well as the U.S. highway system, as more and more goods are delivered by trucks. According to the Bureau of Labor Statistics, while the heavy and tractor-trailer truck driver workforce will only grow by slightly over 100,000 individuals from 2016 to 2026, with the level of expected retirements there will be openings for over 210,000 drivers per year over this period.^{ix} This may amount to over 100% turnover in some segments of the industry. In addition, the trucking industry has been aware of a truck driver shortage for some time,^x and industry surveys of member firms show that turnover rates in an important industry segment (long distance truckload) have been persistently high for decades.^{xi}

Traffic congestion is one of the most critical challenges compromising the efficiency of the transportation system. The annual cost to the U.S. economy of travel delays caused by traffic congestion amounts to \$160 billion or \$960 per commuter; each year, delays keep travelers stuck in their vehicles for seven billion extra hours, corresponding to 42 hours per commuter, and wastes three billion gallons of fuel.^{xii} In addition, traffic congestion leads to higher crash rates and negative environmental impacts resulting from increased CO₂ emissions and noise. These effects degrade the public's quality of life.

Beyond the costs associated with reduced efficiency and pollution, trucks represent a safety concern. Large truck and bus crashes place an estimated \$112 billion burden on the U.S. economy, including costs related to lost productivity, property damage, medical treatment and rehabilitation, travel delays, legal services, emergency services, insurance, and costs to employers.^{xiii} Although large trucks have lower rates of involvement in property damage-only crashes and injury crashes compared to passenger cars, due to their size and weight, large truck crashes are more likely to result in death and are more costly. In fact, over two-thirds of fatal truck crashes, which usually involve a passenger vehicle, result in the death of other vehicle's driver. In 2014, there were 326,000 property damage-only crashes, 3,424 fatal crashes, and 82,000 injury crashes involving large trucks.ⁱⁱ Compared to the general U.S. working population, heavy truck drivers are 12 times more likely to die on the job^{xiv} and three times more likely to suffer an injury involving time off work.^{xv}

It is for all of these reasons (demand for goods, safety, congestion, environment, and lower driver cost) that OEMs and technology firms are pouring funds into the development of automated vehicles (AV). The transportation system is expected to undergo a major change with the introduction of AVs. By 2050, 80% of vehicles sold and contributing to miles traveled will likely be AVs.^{xvi} This is expected to result in an estimated 21,700 lives saved and 4.2 million fewer crashes each year as well as reduced traffic congestion, increased fuel efficiency, and increased productivity.^{xvii} As a disruptive yet beneficial technology, AVs will also profoundly affect the U.S. economy. Significant social issues may arise, as the proliferation of AVs have the potential to eliminate truck drivers' jobs and make support staff unnecessary. The introduction of AVs may also create new job opportunities for science, technology, engineering, and mathematics (STEM)-tech employees. Within the trucking industry, this transformation of the transportation system will have far-reaching effects across a variety of domains, including engineering challenges in developing automated trucks and associated infrastructure; licensure and regulations; liability, privacy, and cyber security; education and training; and economics.

Objective

The issue of workforce disruption from automated trucks has been on the U.S. government's radar. On April 26, 2017, Senators Susan Collins and Jack Reed sent a letter to the U.S. Government Accountability Office asking it to look into how autonomous trucks will affect truck drivers and the communities where they live. The Virginia Tech Transportation Institute (VTTI), with funding from the National Science Foundation's (NSF) Human-Technology Frontier (HTF), conducted a workshop that brought together representatives from different domains with unique perspectives on the trucking industry. These representatives included engineers, computer scientists, regulators, truck drivers, trucking management, economists, educators, lawyers, insurers, psychologists, and sociologists. The solutions to the problems created by AVs will require going beyond collaborative efforts to integrate the above domains and arrive at novel solutions. The goal of the workshop was to identify the most critical unanswered questions related to the effects automated trucks will have on the U.S. economy and, more specifically, how automated trucks will affect the current and future

truck workforce. The discussions and findings of the workshop are presented here as inputs for future NSF program solicitations. Thus, the workshop's major outcome was the research agenda presented here outlining research needs related to how automated trucks will impact the truck driver workforce.

Workshop Overview

The day-and-a-half NSF workshop was held June 29–20, 2018, at NSF headquarters in Arlington, Virginia. The first day of the workshop had two objectives: (1) provide general knowledge on the different automated truck deployment scenarios; and (2) begin the process of identifying research gaps that would likely impact drivers with the deployment of automated trucks. The first day included sessions on automated truck implementation scenarios, regulatory and insurance perspectives, industry views on the use of automated trucks, and the impact of automated trucks on the U.S. economy/driver demand. The second day of the workshop focused on convergence issues of automated trucks and truck drivers, including two sessions on enhancing the driver-truck interface and understanding skill requirements and job skills training/reskilling challenges and strategies.

The workshop had 53 participants, including organizers, panel members, stakeholders, and small group moderators. Appendix A includes the full list of attendees and Appendix B includes the full agenda. Panel presentations are available on the workshop website (<https://www.vtti.vt.edu/atw>). The workshop was funded through NSF's Growing Convergent Research HTF research portfolio (Division of Information and Intelligent Systems) to address grand challenges in the context of NSF's "10 Big Ideas for Future NSF Investment."

Research Agenda

The format of the workshop included brief presentations (~7 minutes) from invited panel members followed by group discussion. After the group discussion, participants broke into small groups (~10 participants) where they discussed two thought questions with the guidance of a lead moderator. The report summarizes the main research needs and

gaps identified in these large and small group discussions as noted from the moderators as well as transcription from audio recordings of the workshop.

RESEARCH AREAS

SESSION 1: AUTOMATED TRUCK IMPLEMENTATION SCENARIOS AND THE ROLE OF THE DRIVER

The mission of this panel was to discuss the unanswered questions and research opportunities regarding the time horizon for the full deployment of automated trucks as well as how and where drivers will be needed from first deployment to full deployment as drivers remain in the loop.

Types of Automated Truck Implementation Scenarios That Are Likely to Occur in the Future

Different automated truck implementation scenarios will have varying effects on truck drivers. Thus, understanding each scenario will inform the needed job tasks, potential for displacement, and identification of yet-to-be-created jobs. Most attendees agreed that Level 5 automated trucks were many decades in the future, and thus, should not be discussed in greater detail. One view was that Level 5 trucks will require significant investment in infrastructure, which could be analogous to competition to build cell tower networks. This smart infrastructure will likely be privately owned and several firms will likely charge the public and motor carriers for its use. An alternative view was that most of the automation for vehicles operating on the public highways will be developed at the vehicle level, leading to vehicle-to-vehicle communication standards, as automation advances will substitute for the functions of smart infrastructure. In this view, smart infrastructure will be developed in more limited applications.

Attendees were also in agreement that Level 3 automated trucks are too risky given the dangers of “handing off” the driving duties to a human driver; most companies in this space are focusing their efforts on Level 4 automated trucks. Level 5 assumes the truck can operate in any operational environment without a driver, whereas Level 4 trucks can only operate in specific operational environments without a driver. Thus, Level 4 automated trucks require a safety driver or a driver to pilot the truck in operational environments that exceed its performance capabilities. Automated trucks will rely on

machine vision, LIDAR, mapping, or some combination of these sensors. Regardless of which type(s) of sensor is used, there was widespread agreement that, at least initially, automated trucks would operate on highways in a “terminal to terminal” fashion with potential for platooning. Human drivers would take the cargo the “last mile” to its intended delivery point. One potential model for automated truck failures and/or the last mile delivery is remote driving by human drivers. This model is currently being tested and would be similar to drone aircraft operations. Terminal to terminal deliveries with a safety driver would likely begin in the next 5–7 years.

As automated truck implementation scenarios were not the focus of the workshop, we will not elaborate on the potential research challenges in this area. These issues (e.g., public acceptance, cybersecurity, reliability, technical feasibility, etc.) have been explored in other workshops and conferences.

Types of Jobs Needed Under These Different Implementation Scenarios

Most attendees were in agreement that drivers would be needed until regulatory guidance indicated otherwise; however, one of the significant cost savings of automated trucks would be the removal of the driver. Attendees also identified a number of new jobs that the introduction of automated trucks would require, including computer engineers, robotics engineers, tele-operators, and human factors analysts. Jobs would also be created for maintenance technicians and, in some models of trucking, central monitors/dispatchers. Beyond that, the group assumed that large numbers of drayage drivers, associated mechanics, etc. would keep their jobs since automated technology would only affect over-the-road driving in a terminal-to-terminal model. In fact, mechanics and other support personnel would likely see increases in value, as these positions would likely require more specialized training.

The attendees agreed that all types of jobs associated with trucking would start to change if drivers are not always actively in control of the truck; however, they were unclear on what changes would actually occur and how. More research is need to understand how jobs that still require a human will be completed. For example, what will the workflow be when the automated truck is driving terminal-to-terminal with no safety

driver; how will vehicle inspections be performed; what happens when an automated truck is involved in a crash or experiences a software or mechanical malfunction; what takes place when law enforcement personnel stop the automated truck?

SESSION 2: REGULATORY/INSURANCE PERSPECTIVES ON AUTOMATED TRUCKS

The mission of this panel was to discuss the unanswered questions and research opportunities regarding the regulatory, insurance, and legal perspectives in the deployment of automated trucks

Certification Processes Needed to Ensure a Formal Safety Framework

The primary unanswered question in this session was, “How safe do automated trucks need to be?” There was consensus that automated trucks need to be far safer than human-piloted trucks, but how much safer? Most agreed that crashes, though likely to be significantly reduced, will still occur, but there is still a question as to what the public is willing to accept to deem these vehicles safe.

While it is clear that data is needed to answer these questions, it is still unclear what the most useful type of data will be. Further, some type of safety certification process is needed prior to allowing automated trucks on the road, but more research is needed to determine what those tests should look like. Given that access to edge scenarios will benefit the driving public, the consensus among attendees was that no matter the type of data or means of collecting it, there should be sharing of these data through a government clearing house or other entity.

In effect, companies would share data and videos on their vehicles’ performance in a series of mutually agreed upon (or regulatory specified) “edge scenarios.” Companies would not be expected to produce details of their technology, but would be required to report miles driven and all accidents. This model attempts to address intellectual property concerns while producing data that is useful to regulators and organizations charged with certifying safety. Mileage and accident data by themselves are vulnerable to gaming (e.g., miles on low throughput roads), which is why supplemental data on an

agreed set of edge cases is needed. Trial lawyers will be a vital part of this process as litigation in this area moves to a product-liability perspective.

Regulatory, Insurance, and/or Legal Perspectives Needed as Automated Truck Technology Matures

Most attendees agreed that regulation was necessary; however, there was concern that over-regulation may stifle technological innovation. The government should not regulate specific technologies, but instead regulate the safety outcomes desired (see certification process above). The certification process could be similar to the National Highway Traffic Safety Administration's 5-Star rating or the Insurance Institute for Highway Safety's crash certification process. Regulation could inform which specific traffic scenarios the automated truck would be tested under and could be supplemented with a certain amount of on-road testing with a safety driver. In order for the business case for automated trucks to be achieved, the existing hours-of-service regulations would need to be revised for safety drivers (e.g., 11 hours of driving in a 14-hour working window). Some attendees were concerned about the Federal Motor Carrier Safety Administration's minimum liability insurance requirement for motor carriers, which was set at \$750,000 per crash in 1985 and has never changed. This low policy value increases the incentive for a small firm in a civil liability case to declare bankruptcy rather than focus on safety-increasing strategies.

SESSION 3: INDUSTRY VIEWS ON USE OF AUTOMATED TRUCKS

The mission of this panel was to discuss industry perspectives on the unanswered questions and research opportunities regarding the role of automated trucks in the delivery of goods and how the industry will adopt this technology.

Types of Trucking Operations Likely to be First Adopters of Automated Trucks

The introduction of automated truck technology will not be uniform, but will likely start in niche operations, such as port operations, and will expand to broader applications in 10 to 15 years (e.g., exit-to-exit on interstates and other limited access highways, with low risk cargo; no hazardous materials in early implementations). Early adopters are also likely to be in geographic regions with good weather, such as Phoenix and Los Angeles.

The majority of attendees believed automated truck adoption would be driven by a desire to save money by getting the driver out of the cab and/or by being able to keep the truck on the road a greater portion of the day. However, this economic perspective should be evaluated through the lens of the supply chain rather than the carrier. For example, from the shipper's perspective, more driving in a day will permit the use of fewer distribution points, potentially reducing inventory and distribution center operations costs and transforming supply chains in ways that are difficult to foresee.

A significant concern among attendees was that when automated trucks first enter the industry, it will initially be through purchases by well-capitalized fleets. As with any new technology, adoption will only occur at more than the pilot stage when the revenue benefits are sufficiently greater than the costs. A large fraction of long-distance trucking operations are held by owner-operators or small firms that operate on small margins and have very little capital. Automated trucks will likely enter the industry as new equipment and will likely be relatively expensive compared to the costs of current capital equipment until the technology becomes better developed. Most owner operators may be unable to afford these trucks and might face being squeezed out of the market, as automated trucks would be able to drive longer and would likely have better safety records. Thus, one area of research would be to evaluate how this technology could be distributed across the spectrum of different size fleets. Also, the introduction of cheaper, safer tech would, at least for some time, increase competition and put downward pressure on wages and working conditions.

Changes in Organization of Carriers Due to the Introduction of Automated Trucks

Attendees agreed there would be significant experimentation with different business models. Many of these were predicated on what business models OEMs would follow. For example, carriers could purchase the automated trucks and be responsible for their maintenance, or OEMs could own and maintain the automated trucks and carriers would be responsible for contracting for their services (i.e., trucking as a service). Many argued that internet technology, cyber security, and liability issues would drive the ownership/contracting pattern. However, attendees were unclear on which of these

issues was most important in shaping the potential for a new model of trucking as a service.

One likely possibility is that new freight transfer stations may evolve outside of large cities. These might take the form of locations at which trailers would be switched between over-the-road automated trucks and local delivery tractors, which are anticipated to be automated later in the automated truck development cycle. They might also take the form of warehouses or distribution centers, which would permit the consolidation of many existing distribution centers into fewer centers. This would potentially result in large savings, as the amount of inventory required to be held near the point of sale would be reduced.

Large carriers are likely to create special operating units to handle automated trucks, partly because the mechanic and IT specialist support work is likely to be distinctive. Some trucking jobs that involve significant work for the driver beyond driving tasks will not be as affected, especially early in the process. This includes livestock haulers (care of cargo), flatbed haulers (cargo securement and protection from weather), tanker drivers (specialized loading and unloading skills, washing out tanks between loads of different types), and oversize freight drivers (cargo securement, coordination with escort vehicles, specialized routings). Driving work in these settings may become higher value in contrast with work done by automated trucks.

However, if future driver demand is largely focused on local delivery, with automated trucks driving terminal to terminal, attendees predicted similarities to local drayage markets that exist at ports. Port drayage owner-operator jobs are not especially good jobs by the usual standards due to poor pay and long working hours, though they do keep drivers in a given local area. Another possibility discussed by attendees was a similarity to tele-operators that handle local distribution remotely in cube farms. Evidence from Air Force drone operators suggests cube farms and call center-type jobs are generally high-turnover/low-pay positions. Thus, research is needed on how to make these positions more attractive, including mandating a living wage.

SESSION 4: TRUCKING IMPACT ON THE U.S. ECONOMY AND DRIVER DEMAND

The mission of this panel was to discuss the unanswered questions and research opportunities regarding how automated trucks will impact the U.S. economy and driver demand. This panel also discussed the interaction between automated trucks and infrastructure needs.

Potential Impacts to Drivers and Other Workers in the Delivery Process During the First Decades of Automated Truck Implementation

As indicated in several other sessions, attendees agreed that the main implication is fewer over-the-road drivers and more drayage drivers, who typically earn lower wages. Initially, it may be that ownership of over-the-road carriers will shift sharply to larger fleets that can afford the new equipment. This has several implications, including (1) the loss of over-the-road driver jobs partially offset by the jobs required to manage and operate the terminal, including safety and cargo inspection, etc., technicians required to maintain the trucks' technology, etc.; (2) the possibility that terminals' drive for efficient operation will cause an upgrade of drayage drivers' jobs and wages in order to guarantee on-time pick-ups, etc.; and (3) the extent to which automated trucks might displace railroad shipments, particularly current truck/rail intermodal movements, which would increase the number of truck movements and have possible job implications.

Initially, safety drivers will be required until Level 4 automated trucks are deemed safe to travel without them. Research has shown that a driver who is monitoring, but not actively controlling, a vehicle will lose situational awareness after some time on the job, and that it takes the individual between 5 and 12 seconds to reacquire accurate situational awareness. During this time, when drivers are not actively involved, what can be done to keep them engaged and ready to take over if needed? Skill demands for drivers under Level 4 will be different, and the work will likely be more mentally challenging.

Location Choices of Warehouses, Distribution Centers, Manufacturing Factories, and Truck Stops in an Automated Truck Future

Most attendees assumed automated trucks would operate on highways only in a terminal-to-terminal model, with drayage drivers distributing products from terminals into urban areas. There already is a potential foundation for these terminals in the network of existing truck stops near exit ramps of major interstate highways. It is likely that market forces will result in some of these truck stops becoming large terminal yards where loads from automated trucks would be transferred to drayage trucks for local delivery. As automated trucks end up spending a greater fraction of each day on the road, due to relaxation or elimination of hours-of-service regulations, these terminals might be more widely spaced than current major truck stops. Initially, this will be a time of significant variation and experimentation, which will raise many operational questions. For example, will an individual carrier have sufficient shipping volume to justify its own terminal or will most terminals be open to all carriers? Similarly, when do automated carriers have wholly owned drayage carriers and when do they contract with independent drayage? The evolution of this model involves a timing risk since today's distribution centers are built assuming a 25-year life span and automated technology can change dramatically in 25 years. This raises the important question of how uncertainty will affect investment, something that will impact many stakeholders in terms of warehousing and logistics facilities and jobs. Land-use and highway planners, among others, should certainly be part of this conversation.

Currently, a significant amount of high-value perishables (e.g., produce, seafood, meats, flowers, etc.) is sent by airfreight, with truck drayage at origin and destination. If automated trucks are fast enough and cheap enough, some fraction of the airfreight work could be captured by automated trucks. Automated trucks are also a significant threat to railroad intermodal service. There may be a significant shift in rail intermodal to automated truck line-haul at origin and destination if travel speeds and cost can be lowered. Optimization analysis needs to work on identifying the types of freight, the types of lanes/customers, and the types of motor carriers serving them, which justify automated truck investments.

SESSION 5, PART 1: CONVERGENCE OF AUTOMATED TRUCKS AND HUMAN LABOR – ENHANCING THE DRIVER-TRUCK INTERFACE AND UNDERSTANDING SKILL REQUIREMENTS

The mission of this panel was to discuss the unanswered questions and research opportunities regarding how automated trucks will converge with human truck drivers, including the role of the truck driver, how driver-truck interfaces can be better designed, and the skills needed for this integration.

How the Current Truck Driving Workforce Can Be Integrated with Automated Trucks

Most of the integration issues were discussed in earlier panels. Panel members agreed that safety drivers would be required during the initial deployment of automated trucks on open roadways. In addition, these drivers will be required to provide feedback on how the automated trucks operate and perform. There will likely need to be reskilling, as automated vehicles will presumably drive differently than today's human-driven trucks. This will require new learning on how to interact with other automated vehicles that do not necessarily behave as those operated by human drivers. This issue applies to truck drivers operating in an environment with automated cars, and car drivers operating in an environment with automated trucks. In the early stages, this could lead to safety issues, as "expectation" errors are made by human drivers. How do we train human drivers to adjust their driving style to that of automated vehicles, or should we program automated vehicles to drive like human drivers, only safer? A question raised about the tens of thousands of miles of driving experience being accumulated in automated vehicle tests was how this experience is being used for deep machine learning and for explicit human coding of behavior—are we teaching machines to drive like humans, and if so, is this the correct course?

Barriers to Effective Integration with Automated Trucks

Vehicle technology is likely to change many aspects of the driver's job and so careful job design is needed to make sure the technology leaves human truck drivers with a

coherent role. Attendees noted a number of potential barriers in the transition process, including (1) the absence of a mechanism for over-the-road drivers to participate in decisions that involve the number and quality of jobs; (2) absence of capital among smaller players to buy current equipment; and (3) the configuration, administrative structure of and access to terminals will be controlled by agreements between over-the-road carriers, terminal developers and drayage drivers. Some agreements could attempt to limit competition, thus creating various barriers to the transition. One of the primary issues was in regard to the potential for more non-driving tasks. With more pickup and delivery, it may not be possible for older, less physically fit drivers to do this work. There are also generational effects to consider. The existing over-the-road workforce is older than the average U.S. worker. It is unknown whether new workers will be more or less interested in trucking as an occupation or if they will have the additional technical skills and inclinations that might be needed.

System Design to Enhance the Driver-Automated Truck Interaction and Interface

Many attendees were concerned about driver involvement, or lack thereof, in the design process. Some questioned if truck drivers were being engaged in this discussion as anything more than an after-thought. One example was Tesla's demo electric truck tractor. Tesla has put a narrow cab in the center of the tractor, thus multiplying the angles that make blind spots for the driver to the sides and rear. A number of attendees pointed to the transition role for over-the-road drivers to give feedback to algorithm designers about performance. System design, beyond giving feedback, will depend on careful task analysis of everything truck drivers currently do, including behavior in emergency situations, record keeping, etc. Mistakes by users come from unmet expectations about how an interface will respond. The correct design principle for intelligent vehicle interfaces is the "principle of least surprise." Engineers, whether electrical, information technology, mechanical, etc., do not always consider user design. A cross-disciplinary user design approach that includes design-for-user principles at the beginning, along with the involvement of safety and health professionals, is desirable.

The transition also offers the potential for proper terminal design. A high proportion of over-the-road drivers are paid primarily by the mile, and record their work time and duty

status under the hours-of-service regulations. Most firms do not pay drivers in this group for much of the time they spend waiting at shippers, receivers, distribution centers, or load switching points, so their primary form of pay is received when moving. As terminals develop, it is important to construct incentives that reduce waiting time and congestion. These might elements include (1) reduction of waiting time for assignments, (2) a premium on drayage drivers following precise schedules, which might lead to an upgrading of those jobs, and (3) adequate pay for loading and unloading activities, as the emphasis on same day delivery means more loading and unloading, activities that are often unpaid under current pay arrangements.

SESSION 6, PART 2: CONVERGENCE OF AUTOMATED TRUCKS AND HUMAN LABOR – JOB SKILLS TRAINING/RESKILLING CHALLENGES AND STRATEGIES

The mission of this panel was to discuss the unanswered questions and research opportunities regarding how automated trucks will converge with human truck drivers, including the challenges and strategies in training/reskilling skills, how to overcome these challenges, and the strategies needed to enable drivers to contribute to the trucking system.

Skills Truck Drivers Have That Could Transfer to New Jobs Created by Automated Trucks

Most attendees were unsure what skills drivers had beyond the skills associated with being a truck driver. Thus, research needs to be conducted with a representative sample of trucks drivers to identify the range of potential skills that translate to other areas. Some attendees indicated that a portion of truck drivers switch between construction and driving a truck based on demand and pay. Table 1 shows the job tasks for truck drivers (53-3032.00) using the O*NET Code Connector (<https://www.onetcodeconnector.org/ccreport/53-3032.00>). Of these 27 work activities, 13 activities are what one would typically think of as driving a truck (e.g., maintain vehicle in good working order and read maps to determine routes). However, less typical activities include reviewing documents or materials for compliance with policies

and regulations and recording operational or production data. Thus, as indicated above, there still appears to be a need for truck drivers; however, there is a question as to whether the remaining driver skill set, absent of actually driving, will result in a living wage. There may be important segments within the population affected, with some workers physically able and having other skills, and some workers finding themselves in very different conditions and with few options. This needs to be better understood before making any recommendations.

In a number of scenarios presented by panel members, drivers would be responsible for safety in a more global sense, overseeing the operation of the automated truck's systems. At least initially, there would be a great desire to understand the "edge scenarios" and the capabilities of the system while operating under those conditions. This suggests the driver overseeing this system would benefit from extensive experience in trucking and with the system itself. However, the case of an autopilot system where the goal is to have a less experienced and less expensive driver, as is increasingly common, seems fundamentally at odds with the case where there is a need for a more skilled worker to ensure safety.

Table 1. Heavy and Tractor-Trailer Truck Driver Work Tasks from O*NET (53-3032.00).

Acquire supplies or equipment.	Monitor cargo area conditions.
Adjust routes or speeds as necessary.	Notify others of emergencies, problems, or hazards.
Choose optimal transportation routes or speeds.	Operate communications equipment or systems.
Collect fares or payment from customers.	Operate vehicles or material-moving equipment.
Connect cables or electrical lines.	Package materials or products.
Direct material handling or moving activities.	Read maps to determine routes.
Follow safety procedures for vehicle operation.	Record operational or production data.
Inspect cargo areas for cleanliness or condition.	Record service or repair activities.
Inspect cargo to ensure it is properly loaded or secured.	Remove debris or damaged materials.
Inspect motor vehicles.	Report vehicle or equipment malfunctions.

Install parts, assemblies, or attachments in transportation or material handling equipment.	Review documents or materials for compliance with policies or regulations.
Load shipments, belongings, or materials.	Review work orders or schedules to determine operations or procedures.
Maintain vehicles in good working condition.	Secure cargo.
	Verify information or specifications.

Cross-Disciplinary Research Challenges in Designing New Curricula for Reskilling

The primary challenge in designing new curricula for reskilling truck drivers is the uncertainty in identifying the specific jobs and skills that will be required with the deployment of automated trucks. There will likely be new inspection tasks that include sensors and/or computing gear, which may require new training content. One positive to the current truck hiring model is that it consists of slow fleet turnover combined with fast driver turnover and the incremental rollout of vehicle technology. This means that self-sorting rather than reskilling might be the most likely mechanism for developing a new driver workforce.

Many attendees agreed the existing commercial driver license (CDL) training model that many drivers entering the occupation experience, wherein the skills necessary to pass the CDL test are quickly obtained (i.e., a CDL mill), should be replaced with a model more like an apprenticeship. This would allow fleets to conduct more job-specific and ongoing training to adapt to new technologies. Many larger truck fleets already have extensive in-house training, so this may not be a significant change in larger fleets; the primary issue is how this training can be included in smaller fleets or third-party training with less resources.

One challenge noted by many attendees was the lack of participation by truck drivers in the workshop. Many had questions about the occupation and the inclinations of the people who choose it, which would allow a more specific assessment of what types of curricula would be needed, and, more importantly, desired by truck drivers. Attendees did not feel like they knew enough about the drivers that might be displaced. It was understood that most drivers were older, less educated, from more rural areas, and

exhibited more health problems than the average worker, which raised the issue of whether reskilling was even a reasonable solution. Taken together, these factors seem to indicate that this might be a difficult population to retrain for higher skilled jobs. Attendees were unsure what other jobs the given existing driver workforce could be trained for. Given these uncertainties, curricula should explore short-term stackable modular curricula within an apprenticeship model.

Opportunities for Public-Private Partnerships in Reskilling Truck Drivers

Attendees struggled with this discussion topic, as many believed that most technology companies did not want to engage in this type of partnership. Technology firms want to avoid entanglement with the government whenever possible, as it is perceived to be a recipe for slowing time-to-market, which is a key dimension of competitive success. A first logical step in creating these partnerships, as discussed above, is to form a consortia of businesses within specific sectors, the goal being to share information on safety-related issues. Another option is to follow the model of the Manufacturing Extension Partnership, where federal government funds half and the balance is paid by state/local governments and private entities in each center. For each dollar of investment, the Manufacturing Extension Partnership generates \$17.9 in new sales growth for manufacturers and \$27.0 in new client investment, which translates into \$2.3 billion in new sales annually. For every \$1,501 of federal investment, one manufacturing job is created or retained.

Strategies and Techniques to Allow Truck Drivers to Be Involved in the Development and Implementation of Automated Trucks

Attendees agreed there was a lack of a mechanisms by which drivers could voice their opinions on such issues as integration and training. The lack of voice reflects, in part, the high degree of fragmentation of the over-the-road trucking industry, with many trucks currently owned by owner-operators or small firms. When asked whether the technology could and should be co-created with truck driver input, attendees agreed that technology developers should talk and drive with truck drivers to deeply understand the variety of work and the challenges of driving a truck. At present, the discussions have not included drivers, but rather the larger players, such a fleets, shippers and

receivers, and distribution warehouses. An effort should be made to include drivers in this process through questionnaires, surveys, focus groups, and listening sessions.

CONCLUSIONS

The purpose of the “Effect of Automated Trucks on the Truck Driver Workforce” workshop was to provide a diverse audience with general information about the deployment scenarios for automated trucks and start to identify knowledge and data gaps in addressing how automated trucks will affect the current and future truck workforce. The workshop report outlines a variety of discussion questions regarding this topic, including deployment scenarios, regulatory/insurance perspectives, industry views, impact on U.S. economy, and driver skills and training issues

It is clear that notions of displacement of the entire workforce are unfounded. In fact, the consensus was that new jobs would be created with a shift of existing over-the-road jobs moving to more local delivery. Thus, the issue does not appear to be displacement per se, but a move to potentially lower paying jobs. Attendees were unclear if the existing workforce had the necessary skill set to move to these new, as yet unknown, STEM jobs. Large fleets seem to be well positioned to handle this change given their existing in-house training apparatuses, with smaller fleets and owner-operators possibly being pushed out of the market or taking on niche or specialty roles. However, given the age of the existing workforce combined with high driver turnover and the incremental roll out of new technology, self-sorting rather than reskilling might be the most likely mechanism for developing a new driver workforce.

One other issue that attendees grappled with was the issue of convergence between automated trucks and truck drivers (i.e., ways automated trucks could enhance truck drivers’ capabilities). The business case for automated trucks in a terminal-to-terminal model assumes a driver is not present; however, driving is not the only job that truck drivers perform. Thus, driving duties will be largely replaced by the automated truck, but there will be other roles for truck drivers. In other words, the technology will not eliminate all truck drivers, but will more likely change their role. The industry has a high turnover rate, where many workers do not stay in their positions long, suffer adverse health consequences, and live for weeks or sometimes months in the machine they operate. Given these conditions, truck driving would seem to be a good case for a job

that should be automated. On the other hand, these jobs, despite how hard they are on drivers, provide much better incomes than workers can earn elsewhere. Thus, attendees were more concerned about equity of pay and quality of work issues than convergence issues.

The workshop brought together a cross-disciplinary audience (mostly researchers) in psychology, sociology, law, engineering, education, economics, and technology to discuss a range of issue regarding how automated trucks will impact the truck driver workforce. However, more work is needed, though some is already underway. The Partnership for Transportation Innovation and Opportunity (<https://ouravfuture.org/>) is addressing many of the issues discussed in this workshop. These issues were also discussed at the most recent Automated Vehicles Symposium in San Francisco, CA (<http://www.automatedvehiclessymposium.org/avs2018/home>). The workshop website has been expanded to include the panel presentations as well as new information and will be updated as work continues.

It was also clear that skilled drivers would be needed to understand edge scenarios as well as automated truck performance. This would provide OEMs and technology vendors with much needed data to improve their technologies. Additionally, researchers and policy makers should understand the evolution of automated trucks as they operate on our nation's roads. This will come from data sharing from OEMs and technology vendors, and also from government census data. One data source that could be used to understand this evolution is the shuttered (in 2007) Vehicle Inventory and Use Survey (VIUS). The VIUS provided data on the physical and operational characteristics of the U.S. truck population. This census could be un-shuttered and add questions regarding automated truck technologies and features.

The authors hope the issue and ideas presented in this workshop report will inform new research and lead to improvements in our understanding of how automated trucks will impact truck drivers. Please contact the first author (jhickman@vti.vt.edu) if you have any comments or concerns regarding this report or if you would like to contribute to work in this area.

APPENDIX A: ATTENDEES

Name	Organization
Alex Epstein	National Safety Council
Annie Lien	Consultant
Bill Kahn	Paccar
Bob Costello	American Trucking Associations
Casey Pierce	University of Michigan
Chris Caplice	Massachusetts Institute of Technology
Chris Hayes	Travelers
Dale Lewis	Massachusetts Institute of Technology
Dion Tims	Bosch
Ellen Partridge	Environmental Law & Policy Center
Eric Teoh	Insurance Institute for Highway Safety
Erin Mabry	Virginia Tech Transportation Institute
Frank Levy	Massachusetts Institute of Technology
Guang Chen	Centers for Disease Control/National Institute for Occupational Safety and Health
Jay Lim	American Trucking Associations
Jeff Loftus	Federal Motor Carrier Safety Administration
Jeffrey Hickman	Virginia Tech Transportation Institute
Jennica Bellanca	Centers for Disease Control/National Institute for Occupational Safety and Health
Jim Yan	Navistar
Johan Engstrom	Virginia Tech Transportation Institute
John Lee	University of Wisconsin
Julian Brinkley	Clemson University
Karen Levy	Cornell University
Kathy Zhang	Columbia University
Ken Boyer	Michigan State University
LaTasha Swanson	Centers for Disease Control/National Institute for Occupational Safety and Health
Mahmudur Rahman	Centers for Disease Control/National Institute for Occupational Safety and Health
Michael Cammisa	American Trucking Associations
Mike Belzer	Wayne State University
Mike Lukuc	Texas Transportation Institute
Mike Rayo	Ohio State University
Mina Sartipi	University of Tennessee-Chattanooga
Mohammad Tayarani	University of New Mexico
Naomi Dunn	Virginia Tech Transportation Institute
Quanyan Zhu	New York University

Rahul Mangharam	University of Pennsylvania
Randy Eberts	Upjohn Institute
Ray Mundy	University of Missouri-St. Louis
Reinhold Mann	University of Tennessee-Chattanooga
Richard Bishop	Bishop Consulting
Ryan Olson	Oregon Health and Safety University
Sanjit Seshia	University of California at Berkeley
Steve Boyd	Peloton
Steve Burks	University of Minnesota
Steve Viscelli	University of Pennsylvania
Thomas Weakley	Owner–Operator Independent Drivers Association
Victoria Lee	Massachusetts Institute of Technology
Wenwen Zhang	Virginia Polytechnic Institute and State University
Yuche Chen	Vanderbilt University

APPENDIX B: AGENDA

Thursday (June 28)

- **8:00a-8:30a: NSF Introduction, purpose of workshop, and workshop ground rules.**
- **8:30-10:05: Session 1: Autonomous truck implementation scenarios and the role of the driver.** The mission of this panel will be to discuss the unanswered questions and research opportunities regarding the time horizon for the full deployment of autonomous trucks as well as how and where drivers will be needed over this time horizon (from first deployment to full deployment) as drivers remain in the loop. This sets the envelope for the rest of the workshop.
 - Thought Questions
 - Which types of autonomous truck implementation scenarios are likely to occur in the future (e.g., fully autonomous truck, limited use, etc.).
 - What types of yet to be created jobs are needed under these scenarios? Think creatively, e.g., engineering studying human-computer interactions?
 - 8:30-9:00: Panel Presentations (~7 minutes each)
 - Bill Kahn from Paccar
 - Steve Boyd from Peloton
 - Jim Yan from Navistar
 - Sanjit Seshia from University of California at Berkeley
 - 9:00-10:05: Discussion
 - 9:00-9:20: Group discussion with Panel
 - 9:20-10:10: Small group discussion
- **10:05-10:25: Break**
- **10:25-12:00: Session 2: Regulatory/insurance perspectives on autonomous trucks.** The mission of this panel will be to discuss the unanswered questions and research opportunities regarding the regulatory, insurance, and legal perspectives in the deployment of autonomous trucks (i.e., discuss how the role of each of these entities might change with the deployment of autonomous trucks).
 - Thought Questions
 - What certification processes are needed to ensure a formal safety framework or scalable verification tools to quantify safety (how safe should automated trucks be?
 - Governmental policies play a critical role in the transition to autonomous trucks without deterring technological progress. What regulatory, insurance, and/or legal perspectives will be needed as the technology matures?
 - What are the research challenges in achieving and assuring safety and verification in autonomous trucking?
 - 10:25-10:55: Panel Presentations (~7 minutes each)

- Rahul Mangharam from University of Pennsylvania
 - Jeff Loftus from Federal Motor Carrier Safety Administration
 - Chris Hayes from Travelers
 - Ellen Partridge from Environmental Law and Policy Center
- Discussion: 10:55-12:00
 - 10:55-11:15: Group discussion with Panel
 - 11:15-12:00: Small group discussion
- **12:00-1:15: Lunch at NSF Cafeteria**
- **1:15-2:50: Session 3: Industry views on use of autonomous truck. Industry views on use of autonomous trucks in the end-to-end delivery system.** The mission of this panel will be to discuss industry perspectives on the unanswered questions and research opportunities regarding the role of autonomous trucks in the delivery of goods and how the industry will adopt this technology. How does the industry view uses within what is technically and legally possible, what do they need to know better prior to deployment, etc.?
 - Thought Questions
 - Given the different implementation scenarios, which types of trucking operations are likely to adopt autonomous trucks?
 - How will the organization of carrier fleets adjust to the introduction of autonomous trucks?
 - 1:15-1:45: Panel Presentations (10 minutes each)
 - Michael Cammisa from American Trucking Associations
 - Thomas Weakly from Owner-Operator Independent Drivers Association
 - Ray Mundy from University of Missouri-St. Louis
 - 1:55-2:50 Discussion
 - 1:55-2:15: Group discussion with Panel
 - 2:15-2:50: Small group discussion
- **2:50-3:05 Break**
- **3:05-4:40: Session 4: Trucking impact on US economy/driver demand.** The mission of this panel will be to discuss the unanswered questions and research opportunities regarding how autonomous trucks will impact the US economy and driver demand. This panel will also discuss the interaction between autonomous trucks and infrastructure needs and what data are needed to test their theories.
 - Thought Questions
 - Given the different implementation scenarios, what are potential impacts to drivers and other workers in the delivery process during the first decades of autonomous truck implementation?
 - How will autonomous trucks influence the location choices of warehouses, distribution centers, manufacturing factories, truck stops in the future?
- What are the optimization research challenges that can enhance this shift?

- 3:05-3:35: Panel Presentations (~7 minutes each)
 - Bob Costello from American Trucking Associations
 - Chris Caplice from Massachusetts Institute of Technology
 - Mike Belzer from Wayne State University
 - Steve Burks from University of Minnesota at Morris
- 3:35-4:40: Discussion
 - 3:35-3:55: Group discussion with Panel
 - 3:55-4:40: Small group discussion
- **4:40-5:00: Day 1 Wrap**

Friday (June 29)

- **8:00-8:20 Day 1 Review**
- **8:20-9:55: Session 5, Part 1 Convergence of autonomous trucks and human labor – enhancing the driver-truck interface and understanding skill requirements:** the mission of this panel will be to discuss the unanswered questions and research opportunities regarding how autonomous trucks will converge with human truck drivers, including the role of the truck driver, how driver-truck interfaces can be better designed, and the skills needed for this integration.
 - Thought Questions
 - How can the current truck driving workforce be integrated with autonomous trucks?
 - What are the barriers to effective integration (e.g., social, technical, cultural, cognitive)?
 - How can systems be designed and engineered to enhance the driver-autonomous trucks interaction and interface?
 - What are the skills needed to build these interfaces and effectively operate within these interfaces?
 - 8:20-8:50: Panel Presentations (10 minutes each)
 - John Lee from University of Wisconsin
 - Richard Bishop from Bishop Consulting
 - Johan Engstrom from the Virginia Tech Transportation Institute
 - 8:50-9:55 Discussion
 - 8:50-9:10: Group discussion with Panel
 - 9:10-9:55: Small group discussion
- **9:55-10:10: Break**
- **10:10-11:45: Session 6, Part 2: Convergence of autonomous trucks and human labor – job skills training/re-training challenges and strategies:** the mission of this panel will be to discuss the unanswered questions and research opportunities regarding how autonomous trucks will converge with human truck drivers, including, challenges and strategies in training/re-training skills, how to overcome these

- challenges, and what strategies will enable drivers to actively contribute to the trucking system.
- Thought Questions
 - What skills do truck drivers have that could transfer to the new jobs identified in Session #1 and the previous session?
 - What are the cross-disciplinary research challenges in designing new curricula for reskilling? Who can contribute to developing such modules?
 - How can various groups (regulators, carriers, labor organizations, etc.) help truck drivers to reskill? Are there opportunities for public-private partnerships?
 - What strategies and techniques will allow drivers to continue to be an active and involved in the development and implementation of autonomous trucks?
 - 10:10-10:40: Panel Presentations (10 minutes each)
 - Steve Viscelli from University of Pennsylvania
 - Annie Lien, Industry Consulting and Advisor
 - Randy Eberts from Upjohn Institute
 - 10:40-11:45: Discussion
 - 10:40-11:00: Group discussion with Panel
 - 11:00-11:45: Small group discussion
 - **11:45-12:15: Final Wrap and Thank You**

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