AUTOMATION IN THE TRUCKING INDUSTRY: A CLASSIFICATION FRAMEWORK FOR TECHNOLOGY-BASED SOLUTIONS

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ABSTRACT

The transportation industry has been transformed from stone roads with carriages and paved roads with motor vehicles to roads and new emerging industries such as trucking. The trucking industry has a unique position in US history. Trucking has been a hero and a bridging link to the supply of goods, moving around 71% of the country's freight. Since the introduction of the highway system, the trucking industry's benefits for customers have been generally recognized, although there have also been specific challenges in this field. The trucking sector has been forced to turn to technological solutions to solve the problems due to a combination of labor shortages, increased competition, changes in deregulation, fuel prices, and the continuous search to reduce costs and improve efficiency.

The cost, organization, and effectiveness of the road system are expected to change due to innovations in automated transportation technologies and artificial intelligence. The combination of artificial intelligence and human capabilities can overcome current challenges by offering technology options that could benefit supply chain and logistics industry operations. Companies in this industry will be forced to choose the technological option that best suits their needs and objectives in adopting automation. Currently, there are different options in terms of automation in motorized vehicles; however, a classification is needed to choose the most appropriate one according to the type of need. This paper investigates the trucking industry with automation in mind to better understand the emerging sector. In addition, this paper presents a model of technology-based trucking options. It ends with managerial implications and future avenues of research.

INTRODUCTION

The combination of technological innovations and economic development has led to remarkable changes over time, boosting industries such as manufacturing, communications, and transportation. The arrival of technologies such as AI, the Internet of Things (IoT), and Cloud Computing within industries have transformed productivity, employment, and other facets of the human economy (Laiton-Bonadiez et al., 2022). The combination of new technologies, the labor shortage, the COVID-19 isolation situation, and the constant search for cost reduction and efficiency improvement have changed business in the 21st century (Güler et al., 2021). The transportation industry, especially the trucking service field, has been forced to make fundamental adjustments to keep pace with rapidly changing events (Belman et al., 2018). High speed was given priority with the development of land transportation to incorporate mass storage in trucks and rails, with trucks being essential to bringing about the mechanization of transportation. From the late 19th to the early 20th century, there was a transition from stone roads with carriages to paved roads with motor vehicles to roads and the emergence of numerous trucking firms (Daggett, 1941).

The trucking industry peaked in popularity between 1992 and 1999. According to the Bureau of Labor Statistics, employment within the industry grew 31.1% faster than total US employment growth during those years due to the implementation of roads (Hokey and Lambert, 2002). The road system grew almost 1% in terms of its length in miles for this same period and 6.1% from 1992 to 2016, thus favoring the trucking industry's growth(US Department of Transportation, 2022b). Trucking has a unique position in the history of the United States. Thomas J (2021 considers the trucking industry to be a popular hero and a bridge link for the supply of goods to the citizens of the nation. The US trucking industry, moving about 71% of the country's cargo, reached a worth of $740 billion in 2018(Kim et al., 2022; Viscelli, 2018). In the logistics industry, for instance, trucking is the primary mode of transportation. Almost all the tangible goods we use are transported by truck at some point in the supply chain. (Roy, 2001; Viscelli, 2018). Making it a relevant industry above other transportation modes such as trains, rails, ferries, or planes.

Since the road system's introduction, the trucking industry's benefits to customers have been generally acknowledged, yet there have also been particular challenges in this field. Some of the challenges the trucking business is currently facing were created by the sector on its own, such as labor shortages or increased competition. In contrast, others just appear due to the economic environment, such as deregulation or fuel prices (Engel, 1998). The growing demand for its popularity and the deterioration of truck driver wages propelled this industry into a crisis of labor shortages due to aging, affecting its probability and incrementing operative costs (Kim et al., 2022). Despite the efforts made by this industry to control the expenses, Min and Lambert (2002) suggested the enforcement of the workforce as the primary strategy for productivity gains. At the same time, Kim et al. (2022) argue that relying solely on increasing the workforce is problematic given the decline in the working-age population and social output (Koricanac, 2020a).

Meanwhile, technology-based solutions have begun to gain ground in the trucking industry to address workforce problems. Automated transportation seems to be an innovation in the transportation industry that seeks to combat labor shortages, thus preventing the increase in operating costs. The adoption of autonomous vehicle (AV) technology will likely transform the cost, organization, and efficiency of the road transport system (Kim et al., 2022; Standage, 2021). Companies like Tesla, TuSimple, Locomation, and Daimler are at the forefront of adopting autonomous driving technology (ADT). These automakers see the benefits of fully autonomous trucks, so they want to bring today's personal vehicle technology and its ability to adapt to self-driving to large companies with thousands of trucks in their fleets. For example, TuSimple Holdings Inc. completed more than 550 miles (885 km) of driving on public roads in Arizona without a human behind the wheel and only with self-driving trucks (ATBS, 2021; US News, 2022). Locomation has also contracted with major trucking companies to automate their fleets (Locomotion, 2022).

AV technology is a new and innovative technology based on AI that is offered in different transportation industries, such as logistics or supply chains. According to the SAE, there are currently six stages of driving automation proposed in the living document J3016, which establishes a standardization of autonomous driving capabilities within the automotive industry. The six stages described in the document are based on functionality, where the first three stages (S0, S1, and S2) include the basic functionality of driver support and are defined as "Driver Support Systems," while the last three levels (S3, S4, and S5) includes a complete driving autonomy and is defined as "Automated Driving Systems" (Harrington et al., 2018; Koricanac, 2020a). The premise of driverless vehicles has been around for a while, but the available technology and the high prices have prevented mass manufacturing (Bagloee et al., 2016; Krasniqi and Hajrizi, 2016). Any form of automation involves an investment; thus, businesses adopting these technologies may examine whether their goals and objectives and any potential benefits are compatible before adopting. Bagloee et al. (2016) predict, based on the deployment and adoption of previous smart vehicle technologies such as automatic transmission and electric hybrid driving, that by 2040, the demand for autonomous vehicles is expected to increase due to the reliability of technology, and constitute about 50% of vehicle sales.

High-tech companies, primarily in the US and China, have been attempting to create highly sophisticated software that will enable trucks to deliver freight throughout the nation without the aid of a human driver. The race to provide the safest and most effective automation technology for trucks is fierce. It is anticipated that advancements in automation and AV will enable companies to save up to $10 billion each year, contributing to one of the main objectives of this adoption: cost reduction (Koricanac, 2020a). While offering solutions to several issues the trucking industry has faced for a long time, both in the social sphere and within organizations. Solutions include reducing emissions, mitigating accidents by compensating for driver inattention, reducing stress, and driving for monotonous periods while optimizing rest times for drivers of towed vehicles. It also compensates for driver shortages, reduced traffic congestion, improved highway safety, and mileage costs with better aerodynamics (Bagloee et al., 2016; Berger, 2016).

The combination of AI and human capabilities can overcome the current difficulties in the trucking industry operations and planning. With the implementation and evolution of automation in the trucking industry, more technology options seem to benefit the operations of logistics and supply chain companies. With the substitution of the human driver for an automated controller, it is expected to obtain benefits such as the optimization of the drivers' rest times, greater efficiency in the use of fuel by making better use of the vehicle, and therefore the elimination of human errors (Berger, 2016; Kim et al., 2022). Companies will be forced to choose the technological option that best suits their needs and objectives in adopting automation. Currently, there are different options regarding automation in motorized vehicles, as presented by the SAE in the J3016 document. Thus, the present study proposes a classification model for technology-based road transport options for trucks based on three guidelines, driver, AI, and automation, as well as the possible combinations among them.

LITERATURE REVIEW

Modern transportation methods do not result from a revolution based on a few mechanical inventions. They are the result of a long and slow evolution, such as the development of industry and the invention of the printing press, which allowed the dissemination of knowledge and aroused the interest of landowners in trade and industry, promoting the movement of passengers and goods through different transport methods (Daggett, 1941). However, Daimler and Levassor state that the beginning of road (truck) transport is primarily associated with the invention of the gasoline-powered internal combustion engine rather than other factors. Initially, the most common mode of transportation was the movement of people, which gradually changed to the movement of products as society developed (Daggett, 1941; National Geographic Society, 2022). Before 1800, moving products across regions was a slow, challenging, expensive, and frequently dangerous process. People relied on natural force, whether human or animal, such as carts, sleds, or even boats without artificial power and well-conditioned roads (Bowersox et al., 1981). With the advent of technological advances of the time, such as artificial power and the steam engine, the US first developed its railway system at the beginning of the early 1920s, helping to connect the growing nation and create a set of distinct local and regional economies (Allonso, 2015; Mohl, 2008; Wootton et al., 1995).

Traditional Trucking

The first rail or tramroads developed in the United States were brief stretches intended for industrial uses to transport granite or other heavy loads. Most railroad transportation was over short distances; thus, many American railroads were organized to render local service. Despite the expectations regarding the arrival of this invention, both in England and in the United States, the introduction of the railways provoked the opposition of some groups that resisted the change due to the high costs, the low efficiency in time, and personal preferences in other methods, such as waterways or even cars. The social pressure and minor disadvantages of the railways enhanced the preference for highways. Highways were built primarily to meet the needs of local traffic, where they were initially used as smooth roads for the commercial and industrial development of the time, leaving the railways to handle long-distance movements due to their higher profitability (Bowersox et al., 1981).

Since the transportation revolution in the United States in the early 1800s, the trucking industry has become a dominant mode of cargo transportation. In 2021, the US Department of Transportation reported that approximately 72.2% of freight total domestic tonnage shipped in the US was transported by truck. Only in primary shipments 10.93 billion tons of cargo were moved, which generated revenue in gross freight of $875.5 billion, around 80.8% of the nation’s freight bill for that year. Freight tonnage is forecast to rise faster from 16.4 billion tons in 2019 to 20.6 billion tons in 2030 (Costello, 2021). The total revenue derived from primary freight shipments in the US will increase from an estimated $1,083 billion in 2021 to $1,627 in 2032, making the trucking industry an integral part of the country’s economy (McNally, 2022; US Department of Transportation, 2022). Trucks play a crucial role in intermodal transportation systems, including pipelines, ships, planes, and trains, and their influence is felt throughout the entire transportation industry (US Department of Transportation, 2016). Consequently, the freight transportation system relies on various modes to support national and international supply chains. Freight transportation is now considered a crucial component of doing business, with 24.1% of the 38.9 million registered trucks used for commercial purposes in 2020 alone, not including government and agricultural purposes, and 1.95 million heavy and tractor-trailer truck drivers (Costello, 2021; Woods, 2022).

Companies within the trucking industry evaluate performance in terms of reliability, time efficiency, and quality of service for competitiveness, where drivers are a crucial element (Min and Lambert, 2002). Due to long drives and accident risk, traditional trucking operates under two systems: solo driver or as a team operation. The solo or team drivers could be owner-operator, lease-operator, or company driver. Solo or solo drivers operate alone, and their sleeping hours are spent in a sleeper berth inside the truck while the vehicle is parked. The team's drivers, meanwhile, operate with a partner, sleeping in a moving vehicle at their respective sleeping hours, guaranteeing the constant movement of the truck (Dingus et al., 2001; Klauer et al., 2005a).

Most long-haul truck drivers are allowed to work an 11-hour limit after 10 consecutive hours off duty by taking a 30-minute break after 8 hours of driving. Despite the regulations put in place to keep drivers from being overworked and the potential risks, they often work much longer to meet their deadlines, making it a demanding and risky job (FMCSA, 2022; Turnbull, 2017). According to the American Trucking Association, the truck driver shortage was first documented in 2005 with a need of approximately 20,000 drivers; by 2015, this shortage reached 45,000; by 2021, 87,000, and by 2030, it is projected to reach 160,000 (Costello, 2017; Placek, 2022). While all industry sectors struggle to find enough drivers, the ATA emphasized that the real shortage is in "long-haul trucking," which refers to truck drivers traveling long distances across state lines. Truckers all over the world are getting older. According to the Bureau of Labor Statistics, the average age of a commercial truck driver in the US is 55 years old, which means that these drivers will retire within the next 10 to 20 years and will no longer be eligible to fulfill this job.

Faced with the lack of truck drivers, logistics and trucking companies have struggled hard to solve this problem, which does not seem to improve. In order to recruit more drivers, especially young truckers, most carriers have been offering benefits such as high pay wages or 401K and tuition reimbursement options. In April 2022, Walmart announced that it would pay its long-haul private fleet truck drivers as much as $110,000 a year when the average for a long-haul driver is $56,491 a year in 2022 (Cortes and Sprague, 2022; Redwood, 2021; Woods, 2022). The industry has also chosen to reduce time on the road based on government regulations imposed where truckers will work a maximum of 11 hours driving within a 14-hour duty period (FMCSA, 2022; Lardieri, 2019). Yet, such efforts have led to an increase in the cost of transportation and commodity prices that affect both logistics companies and customers. The growth of expenses and the absence of a workforce have led companies to create strategies to survive in the supply chain industry, delivering products to customers quickly at low cost but creating an environment of risk of accidents.

The demand for the trucking industry's services is extremely high compared to other transportation modes and is projected to remain strong for decades. The need for trucks is expected to grow by 1.4 percent annually through 2045, according to the United States Department of Transportation (Rubocki, 2018). Thus, in order to meet the increased demand for services and address current issues, such as driver shortages, high risk of accidents due to human error, truck exhaust pollution, and road traffic congestion, the trucking industry should consider technology-based options to address the issues (Bagloee et al., 2016; Berger, 2016). Automated transport is an option with great progress in the transport sector, and its objective is to combat labor shortages and current problems while avoiding increased operating expenses (Kim et al., 2022; Standage, 2021). The deployment of autonomous vehicle (AV) technology is projected to disrupt the economics, structure, and efficiency of the road transportation system.

Automated Vehicles

AV technology is a new and innovative technology stimulated by AI offering efficient solutions to logistics companies and supply chains regarding trucking transportation (Koricanac, 2020a; Ma et al., 2020). The idea of cars that drive themselves has been around for decades. In 1918, vehicle automation was initially envisioned, but only until 1939 did General Motors first exhibit the concept at the “Futurama” exhibition (Faisal et al., 2019; Standage, 2021). The basic concept of automation of road vehicles refers to the total or partial substitution of the human work of driving by electronic and/or mechanical devices. Early advances in vehicle technology focused on features such as autonomous speed, automated emergency braking, lane centering, and other basics of cruise control, which are represented for the three first stages of the taxonomy of driving automation systems for on-road motor vehicles in its living document J3016 (SAE, 2022).

AV technology has experienced drastic growth in the past few years. Self-driving vehicles represent a fast-paced field of modern technology as companies compete for dominance in this important field of emerging transportation capacity. Hi-tech companies, mainly from the US, have been working on developing highly sophisticated software that will allow vehicles to reach the highest stages of automation at S3, S4, and S5 stages, according to SAE (Faisal et al., 2019; SAE, 2022). Recent advances in AI have opened up nearly unprecedented opportunities to improve performance across various industries, including the automotive and transportation sectors, where the trucking industry has seen encouraging results in productivity, sustainability, reliability, and safety. For instance, by being able to adapt to each shipment to boost efficiency by suiting well to the type of truck’s engine, the weight of the truckload, and the terrain, AI could significantly lower firms’ costs in various areas, such as fuel wear and tear. Authors such as Agrawal, Gans, and Goldfarb (2018) predict that AV can save up to $10 billion in a year for companies after its implementation (Faisal et al., 2019; Koricanac, 2020).

Current advances in driving automation have mainly focused on passenger transport based on driver assistance technologies. Car manufacturers such as Honda, Tesla, Cadillac, and Ford have developed car models with semi-autonomous driving features such as adaptive cruise control, lane centering assist, and automatic parking (Mijatovíc, 2022; Patel, 2022). Cars are able to detect and classify their local environment, determine different types of objects on the road, and even interpret sensory information to identify appropriate navigation routes under traffic rules (CBS News, 2022; Slowik and Sharpe, 2018). There will likely be about 8 million driverless or semi-autonomous vehicles on the road by 2025 (ABI Research, 2018). Self-driving cars might need to develop through six stages of driver assistance technology breakthroughs in order to be considered fully autonomous. Today, human drivers still play an important role in autonomous driving systems; even the highest level of driving automation available to consumers requires the engagement and undivided attention of drivers. There are several levels of driving automation technology, classified according to their level of autonomy and support to the human driver, where each level specifies how much control a vehicle can exert over the dynamic driving job (Dimitrakopoulos and Panagiotopoulos, 2021).

The levels for driving automation have been standardized and developed by SAE International (2022). The taxonomy of degrees of automation in vehicles is explained in the living document J3016, which represents the most recent and complete common lexicon, where six different stages of automation of highway passenger vehicles are classified (Darlintong, 2020; Shahandashti et al., 2019). SAE J3016 defines driving automation on a scale of zero to five; Stage 0 means that no functions of the vehicle are automated, while Stage 5 means the vehicle can operate without human intervention or even presence (Synopsys, 2022). S0, S1, and S2 are classified as driver support features where the driver's intervention is required at specific points. S0, named "No Driving Automation," represents most vehicles on today's roads. The driver provides the dynamic driving task with the support of features limited to provided warnings and momentary assistance. S1, named "Driver Assistance," represents vehicle features as a single automated system for driver assistance, such as steering or brake/acceleration under driver's supervision. S2, named "Partial Driving Automation" or "Advanced Driver Assistance System," represents automated features combined where the vehicle can control both steering and braking/accelerating supervised by the driver (SAE, 2022).

S3, S4, and S5 are considered automated driving functions in which the driving automation system at the board executes the main part or all the driving tasks, including vehicle control and monitoring of the driving environment. In such cases, the driver must be able to resume the driving task at any time (Dimitrakopoulos and Panagiotopoulos, 2021; SAE, 2022). S3 is called "Conditional Automation," where the driver is not required when the automated driving features are engaged. Thus, the driver must be ready to take control when needed. S4, named "High Automation," represents features that drive the car under limited conditions as long as they are met. While S5, called "Full Automation," can perform all elements of the dynamic driving task under all conditions while the driver is not involved in any driving task (Dimitrakopoulos & Panagiotopoulos, 2021; Harrington et al., 2018; SAE, 2022).

Investment in autonomous cars has been highly significant. According to Forbes (2022), total global investment in AV technology exceeds $200 billion and is expected to increase once AVs are adopted for different purposes. Just as society was transformed when Henry Ford introduced the first assembly line, AV will have a transformative impact on both human lifestyles and the economy. The impact that each level of automation in passenger transport has created in society is generating a domino effect in the logistics industry, which will change road freight transport and retail trade. For AV to fit into the trucking industry, some specific features may need to be implemented due to the different designs, weights, dynamics, and purposes of trucks, such as Driver-Assisted Truck Platoon (DAPT), Highway Assistant, and Predictive Powertrain Control, platoons, real-time vehicle-to-vehicle communication, Highway Pilot and Truck Pilot Berger, (2016).

Following the same six levels of automation proposed by SAE, Berger (2016) has stated six levels of automation in trucks from L0 to L5 that include the features needed to transfer more control from the driver to the truck. L0 and L1 are currently developed, L2 is pending, and L3, L4, and L5 represent the trucking industry's future. An interplay of human capabilities and technology areas enables autonomous trucks. Based on three criteria—driver, AI, and automation—and potential combinations. The current study suggests a classification model for technology-based trucking options (Figure 1). Just as Berger (2016) pointed out the necessary additions for adopting truck automation technology from the classification of existing automation levels, this article presents a useful classification model to understand the possible combinations, interactions, and the whole potential of automation technology in the trucking industry.

The proposed model (Figure 1), "A model of technology-based trucking options," consists of three overlapping circles illustrating the logical relationships between Driver, AI, and Automation. The intersection of the circles creates sections that represent further categories. Each section is shaded based on the development timeline. The light gray section comprises the current traditional truck options, such as (1) Traditional Trucking and (1/3) Traditional Platooning with Two Drivers. The dotted section comprises truck options pending development, such as (3) Traditional Platooning and (1/2) Assisted Automated Trucking. At the same time, the dark gray section covers the industry's expected future fully automated truck options, such as (2) Fully Automated Trucking, (2/3) Fully Automated Platooning, and (1/2/3) High Automated Platooning with Service Employees.

As shown (1) in Figure 1, traditional truckers perform tasks determined by the Occupational Requirements Survey (ORS). The tasks of traditional truckers include driving long distances following traffic laws, reporting incidents on the road or serious mechanical problems affecting the operation, ensuring proper transportation of cargo, and keeping track of work hours and driven mileages, following all federal and state regulations (Gittleman and Monaco, 2020; US BLS, 2022). Long-haul truck drivers, as defined by the ORS, drive large trucks and tractor-trailers with a gross vehicle weight rating of at least 26,000 pounds, mostly moving cargo along intercity routes that occasionally cross multiple states (CDC Centers for Disease Control and Prevention, 2022; US BLS, 2022). The physical demands of truck driving may be high. Driving for many consecutive hours tends to be exhausting, and some drivers are even required to load and unload their trucks in addition to their regular tasks.

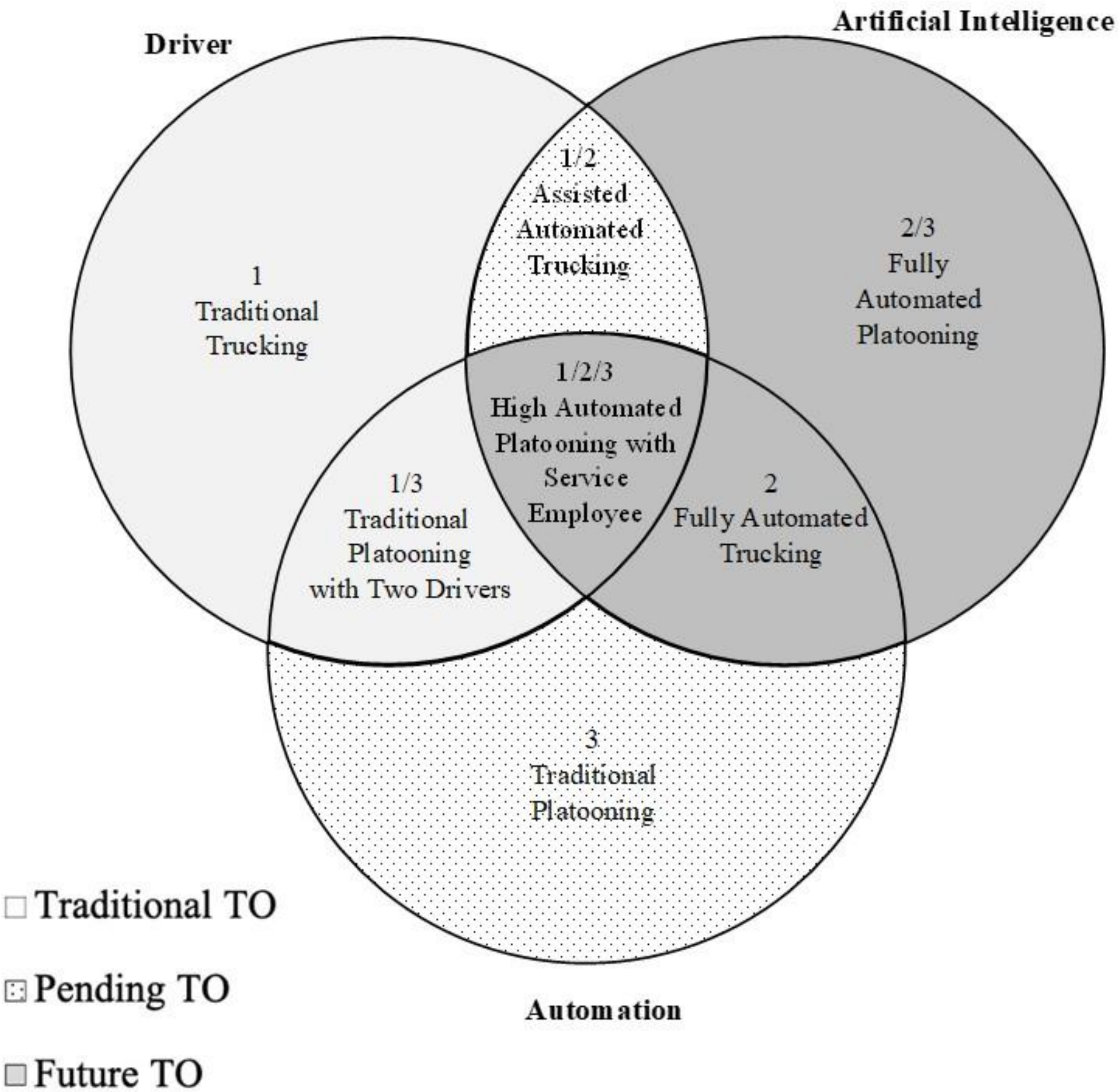
The present laws for truck drivers prohibit them from driving after 15 hours of labor (driving and non-driving chores) and limit their driving time to 10 hours, followed by an 8-hour rest period, due to the physical and mental tiredness of their operations (Braver et al., 1999). Due to limitations on hours of service, trucking companies have considered putting a two-driver crew on a truck. The trucks are equipped with bunk units that allow the co-driver to sleep during their rest time while the truck continues its journey to provide an effective way to rest and increase the productivity of the vehicles, which is determined according to the distance traveled. (Hanowski et al., 2005; Klauer et al., 2005b). The inclusion of AI has accelerated in the transportation industry as a possible solution to strict regulations on emissions, fuel consumption and working hours, the

lack of truck drivers, the increase in traffic congestion, and concerns about safety and accident proneness (Katreddi et al., 2022a).

AI increasingly drives the industry's technological development, allowing the processing of large volumes of data, improved machine learning, and the development of powerful computers (Rubocki, 2018). Assisted Automated Trucking (1/2) describes the ability of trucks to reach certain levels of autonomy with technological and AI interaction with areas that include hardware, software, and embedded controls. Advanced driver assistance systems (ADAS) based on AI are becoming more widespread in trucks with the promise to reduce the cognitive load on drivers and increase driving safety in general. AI options for trucks seek to assist the driver (who holds the primary responsibility of the truck) with driving features such as blind spot detection, collision warning system, traffic sign recognition, or adaptative cruise control (Rudigier et al., 2021a).

Most ADAS currently use a wide range of sensors, including video cameras, traditional radars, and lidars that mimic a human driver's perception process, reducing human error. While certain truck activities may be automated, the truck is not fully autonomous if the driver must still present (Rudigier et al., 2021b). Fully Automated Trucking (2) Figure 1 represents the performance of AI without any human intervention and is denoted as Fully Automated Trucking. (2) category represents a truck that can operate without a driver in the vehicle at all. The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip (Crandall and Formby, 2016). The fully autonomous technology comprises software with an adaptive cruise control system that adapts to any environment.

Fully autonomous trucks are still under testing, yet they are expected to comprise intersection management systems and collision avoidance systems with other heavy trucks, cars, motorcycles, and pedestrians at the same time (Müller, 2020). The intelligent autonomous truck will have to use sensors to sense its surroundings, evaluate and process the data, and then use that information to define further its environment and status information (Rudigier et al., 2021b; TuSimple's Editorial Team, 2022). The information is estimated by self-learning to predict future environmental changes and thus make autonomous decisions without driver responsibility (Fisher, 2022; Wang and Zhang, 2022).



According to current AI developments, platooning is considered one of the most significant developments in road transport so far. Section (3) shows Traditional Platooning as a technology-based option that is only partially autonomous (Katreddi et al., 2022b). Traditional Platooning allows two or more trucks to follow each other closely through a combination of production safety systems and connected vehicle technology (Waldman, 2020). Trucking platooning uses features such as radars and vehicle-to-vehicle (V2V) communication where multiple trucks, guided by the lead vehicle driver, can safely follow each other in proximity, like train cars (Katreddi et al., 2022b; US Department of Transportation, 2021). The lead driver drives normally, supported by best-in-class active safety systems. The connected fleet can accelerate, brake, and turn in unison, while the semi-autonomous functions of the main truck reduce the possibility of human error (Waldman, 2020). The remaining fleet has drivers steering, monitoring the road, and responding as needed to other traffic with feet off the pedals until they break the chain to finish their planned deliveries (Perry, 2022).

In 2020, for instance, Locomation, an automation technology company, teamed up with Wilson Logistics, a trucking and logistics company, to launch an automated platooning program. Locomation has developed a platooning system named Autonomous Relay Convoy (ARC) as a pilot program that enables the driver to be off duty while in the cab, extending the hours the trucks can be on the road, not restricted by the 11 hours of service. Under the terms of the agreement, at least 1,120 Wilson Logistics tractors were equipped with Locomation's (ARC) technology, with the first units delivered in early 2022 (Baker, 2020; Kingstone, 2020). Section (1/3) represents the Traditional Platooning with Two Drivers, based on technology that works in the same dynamic as traditional platooning, with the difference of team drivers instead of solo drivers in each truck. Based on truckdrivers' regulations, even in Traditional Platooning (3), driving hours restrictions represent constraints. The team drivers allow the platoon to keep a non-resting trip during its operation. While drivers take turns resting, they maintain safety and efficiency according to current regulations.

As in Fully Automated Trucking (2), the need to improve and optimize the truck's operation drives the platooning strategy to achieve absolute automation, eliminating any responsibility from the driver. Section (2/3) in Figure 1 represents Fully Automated Platooning, where the platoon operates completely autonomously without needing a driver in any of the trucks. For example, the trucks can vary the speed with a constant following distance, join or split the platoon simultaneously, and detect any type of failure (Lu and Shladover, 2014). Currently, only semi-automated platooning has been tested, as the current infrastructure cannot safely support fully automated platooning. The semi-automated platooning is somewhere between a support role and a fully automated truck.

The current autonomy approach keeps a human firmly seated in the cab of the truck squad's lead vehicle. In this case, the V2V connectivity between the trucks acts as an enabler that allows the automation of the following vehicles (Mascalchi and Willemsen, 2022). The main driver of the truck has the support of ADAS systems, understood as Assisted Automated Trucks (1/2), in which the driver is still responsible for the driving task (Bishop, 2020). By fully automating driving tasks to achieve the platoon's total autonomy, the driver's presence is no longer essential (Hjälmdahl et al., 2017). The human driver in the lead truck will begin to handle a wide range of complex non-driving operational scenarios, such as refueling vehicles, communicating with the central station, or communicating with customers to coordinate the delivery. Thus, the role of the human goes from being a driver to being an assistant employee, as described in section (1/2/3) from Figure 1, High Automated Platooning with Service Employee.

MANAGERIAL IMPLICATIONS

Today's society is beginning to feel the effects of AI technology. The use of autonomous vehicles is growing in the transportation sector. Over the past decade, autonomous vehicle technology has been the most adaptive trend in the automotive industry, and it promises to increase road safety and driver comfort (Koh, 2022). Substantial advancement in the field of autonomous vehicle technology is attracting increasingly more attention from vehicle manufacturers, technology companies, and the general public. Trucking companies need to take advantage of the growing popularity of automation. Working with manufacturers so that beneficial vehicles are designed with high technologies that impact the market. The phenomenon of autonomous driving is not new, yet it is probably one of the most stunning inventions ever made. In lieu of being merely a theoretical concept, autonomous trucks have been built and are already in use worldwide. Volkswagen subsidiary Scania is creating the world's first fully autonomous truck platooning system(Moon, 2017). Singapore intends to platoon four trucks on public highways to move containers between ports. While on the roadway, Korea has successfully shown platooning of heavy-duty trucks (Kim et al., 2022).

AV supporters claim this technology provides environmental stability and social benefits. The global autonomous vehicle market is expected to reach USD 325.9 billion in revenue by 2030, with the US dominating the autonomous vehicle market (Renub Research, 2022). Factors such as strong and established automotive company clusters and the establishment of the world's largest technology companies, such as Google, Microsoft, and Apple, have led the US to occupy this position. Technology developer companies, in alliance with logistics companies, seek to have a vision of the future so as not to be left behind in the development of AV. Thus, alliances between these industries will be essential for the trucking industry. In 2020, for example, Daimler Truck, with its independent subsidiary Torc Robotics, started its proposal to develop L4 autonomous trucks in the US. The companies have the most extended association for autonomous truck driving technology in the industry and have been safely and reliably testing a fleet of autonomous trucks on public roads in the US daily (Daimler Truck, 2022; Ribeiro, 2021).

Even though AV has been claimed to represent advanced technology that does not require human functions, the technology cannot be implemented on autonomous trucks (AT) as impeccably as in theory. Geistfeld (2017) and Koh (2022) consider that once the act of driving in humans is eliminated and control is given to a computer or an automated system, the driver's moral responsibility disappears since he does not have control of the vehicle. Thus, the road tests of AT performed worldwide have included drivers inside the trucks as service employees in case of emergency (Paulsen, 2018). As in the rest of the world, safety concerns and unknown effects are significant reasons that legislation allowing AV testing on public roads is challenging to implement. American transportation regulation has allowed states like California, North Dakota, Tennessee, Virginia, and Michigan to test and use AV under restricted mobility to specific test areas and driving conditions; thus, companies adopting AT must be aware of the regulations established (NCSL, 2020). According to Harrington et al. (2018), AV is expected to eventually operate in unstructured environments and close the gap with humans regarding adaptability, as current infrastructure is designed and built based on human capabilities. Road signs, for instance, are scaled and placed according to human perception capabilities concerning speed restrictions and local traffic patterns. Hence, managers should be aware of the need for the road infrastructure to change to keep up with advancements in AV technology.

Safety in the trucking industry is a huge concern. According to *the National Highway Traffic Safety Administration (NHTSA, 2021),* an estimated 439,206 large trucks were involved in police-reported traffic crashes nationwide only during 2020. Trucks are difficult to control, maneuver, and stop quickly because of their design, size, and weight. The risk of truck accidents is more than double that of car accidents, so automation is expected to reduce the accident rate due to driver error. While Ats can handle tasks like merging into traffic from an on-ramp or changing lanes, companies are still working to ensure they can respond to less common situations, like a sudden car collision or an unexpected pedestrian on the road (Metz, 2022). The prospect of sharing the road with autonomous vehicles while companies test and demonstrate their capabilities raises concerns for most American drivers. According to a survey carried out by CDL Life in 2021, 53% of drivers would feel less safe sharing the road with autonomous trucks, generating a rejection of these technological advances. Rei (2021) considers that Ats will have to share the road with human-powered vehicles for a certain period based on the evolutionary behavior of the roads and transportation. Eventually, Ats will occupy their own roads in the long run.

An Update on the State of the Development after 2022

In recent years, the autonomous trucking industry has seen multiple significant changes. The category entered the growth phase, and as expected, it is experiencing shake-outs among some inventors and changes in the directions for others. For example, Alphabet’s Waymo entered self-driving taxi development, exited trucks, and planned to test their driverless taxis in 10 new cities, starting with Las Vegas and San Diego in 2025, building on their success in San Francisco (Hawkins, 2025). Tesla is getting ready to launch its robotaxi service (Reuters, 2025). They obtained California’s first set of permits to run the Cybercab, their robotaxi without a steering wheel and control pedals. Another important player, BAE Systems of Australia, together with Trusted Autonomous Systems, is developing AI systems to be used in unmanned ground vehicles for the army (Military Leak, 2024).

Meanwhile, the development of autonomous trucks (ATs) proceeded on multiple fronts. Kodiak Robotics and Aurora were leading the others in aiming for fully automated driverless trucks (Taube, 2024; Clevenger, 2024). Both companies use teams of two specialists to ride in the trucks to monitor the systems. So far, the tests with teams of safety drivers and technology monitoring service employees have been satisfactory and plans to take the ATs to public roads without drivers are underway.

We expect the commercial adoption of ATs will be fast as the collaboration among technology developers, established truck makers, component suppliers, shippers, trucking and logistics companies. Multiple stakeholders also encourage discussions on safety and labor relations. For example, Aurora, which was planning to have about 20 fully autonomous trucks by the end of 2024 on the Dallas-Houston route, collaborates with truck manufacturers, Paccar and

Volvo, suppliers, and fleet partners, including Continental, FedEx, Schneider, Werner, Uber. Similarly, Kodiak Robotics, which plans to operate ATs on public roads again, works with Loadsmith, Maersk, Werner, C.R. England, Ryder Systems, and Pilot Company, among others. Kodiak also partners with the US Department of Defense to use its system on military vehicles. The Dallas-Houston route was picked as the first driverless operation in Kodiak (Taube, 2024) (Clevenger, 2024).

As major expansions are planned for the ATs, the discussions about how ready the US highways and citizens are flaring up. The majority of discussions seem to focus on three main topics: safety and related regulations, the impact on labor and union relations, and overall costs.

1. <u>Safety: improved or compromised</u>

   During the early development of ATs, a robotaxi hit a jaywalking pedestrian and dragged her about 20 feet in 2023 (Thadani, 2024). This event caused a fear of potential catastrophes that a heavier AT may cause. The majority of issues with autonomous vehicles seem to come from the erratic behavior of other drivers and pedestrians. Both Kodiak and Aurora put safety first as they designed their systems to slow down and let other drivers merge. Aurora truck systems are designed to operate in fog and light rain. They do not intend to operate in ice or snow conditions. An Aurora technology specialist reported an incident when the system recognized traffic in a foggy drive before the human controllers in an interview (Taube, 2024). However, the risk is still noteworthy as large long-distance trucks at speeds above 65 miles per hour on rural roads and brings in the debate of whether the US road structure can handle that type of technology.

   The lack of federal regulations and confusing and contradictory state laws seem to slow down development, especially road tests. ATs can run on all roads of the US unless a state explicitly forbids it. Texas, Florida, Arizona, and Nevada allow road tests and completely driverless trucks. California, Massachusetts, and New York forbid it.

2. <u>Labor: New jobs or lost jobs</u>

   The potential for job loss among drivers creates concerns and forces unions to act, claiming that the notion of lack of human interaction in 18-wheelers on chaotic highways and crowded cities terrifies people. The role of the drivers seems to change and enhance as they need to know more about technology to be able to run and maintain the systems. Moreover, trucking companies claimed that they have difficulty finding drivers for long haul and boring routes like the Dallas-Houston highway. (Thadani, 2024) A bill in California that required a trained human driver behind the ATs was introduced but later vetoed by the governor (Reuters, 2024). Still, the loss of immediate jobs is a valid concern, that requires all players to reinvent their logistics networks and retrain labor for the emerging jobs.

3. <u>Benefits or costs for logistics companies:</u>

   A major apparent benefit of ATs is reducing time by eliminating the physical limitations of human labor. Right now, truck drivers are allowed to drive 11 hours and stay 10 hours off duty in consecutive hours by law. ATs help the transfer of goods around the globe faster. Aurora estimates that ATs could cut fuel costs by 13 to 32 percent as they don’t have to return home at the end of the shift, detour for bathroom breaks, or idle during rest times (Skibell, 2024). However, maintenance costs may increase different and special service requirements for these ATs. For example, Pilot opened the first AT Port by collaborating with Kodiak Robotics in Villa Rica, GA. They provide a hub for drivers to pick up and drop off first and last-mile deliveries, refueling, maintenance, and inspections. This indicates that technology can create new job opportunities for maintenance technicians, dispatchers, and fuelers while providing alternative routes to long-haul drivers.

The Trucking Options Model may help the industry to organize interactions among humans, robotics and trucking requirements to provide optimum logistics and transportation service alternatives that match the needs of customers and logistic companies the best. When the dust settles, standards, the necessary support services, and job definitions will emerge. AT development also caused side inventions such as robotaxis, unmanned military ground vehicles, etc. Eventually, the technology developed for ATs will diffuse into all other vehicles like personal cars, planes, and trains and will change the future of transportation vastly. Maybe, instead of rushing to connecting flights, passengers will be transferred to their main flights via human-size drone bubbles from their homes directly in the future.

FUTURE RESEARCH AVENUES

The current study proposes technology-based trucking options based on AI, driver capabilities, and their combinations. The levels of automation range from traditional trucking, where AI tools assist the driver, to the highest level of automation, where AI takes complete control of the truck. As the amount of automation increases, so does the transfer of responsibility from the driver to the truck, with the driver leaving his ability to intervene only in an emergency and becoming a support employee inside the truck. Future research should consider the comfort of transitions from a fully automated system to human driver intervention during emergencies. Zhang et al. (2019) emphasized the significance of assessing the driver's reaction ratio after becoming a support employee and monitoring the system for long periods. It is critical for regulators to establish a limit regarding the number of working hours for a support employee inside the truck, just as authorities established it for drivers in traditional trucking. Driver exhaustion and reaction time tests and transition simulators to retake control of the truck will be necessary.

Further research should also be conducted to examine the environment in which AT will perform in the current infrastructure. Multiple surveys on the perception of AVs versus traditional vehicles have analyzed that at least 45% of Americans have expressed discomfort sharing the road with driverless vehicles (Rainie et al., 2022). The design nature of trucks themselves and their weight when carrying goods makes them more prone to fatal road accidents. AT must ensure that the AI technology is adaptive and safe for both the support employee inside the cabin and the traditional vehicles with which it must share the road. ATs may need to process large amounts of data in real time. Sari et al. (2022)highlight the importance of AT connection with road infrastructures and networks to offer better connectivity and safety. Thus, more research would help determine if the current highways could be (adapted or if there is a need to invest in alternated technological infrastructure only for ATs, especially for platooning operations.

In truck platooning, a platoon can consist of many trucks moving together over short distances, just like a road train. There is no universal cap on the number of trucks that can link in platooning. Janssen et al. (2015) assert that when truck drivers must merge into highway traffic from on- and off-ramps, a platoon of more than two trucks would be a problem. However, more research should be conducted regarding the dynamics of traffic immersion with platoons of different dimensions. This would help to identify the types of trucks that will be able to platoon and the regulations necessary for ensuring safety on the road. Regulations in the state of Minnesota, for instance, have limited platoons to three trucks in order to keep safety due to possible intimidation of fellow road users and troublesome to leave or enter the highway in coordination with car drivers (Minnesota Department of Transportation, 2019). These current laws point out the limitations regarding traditional platooning and semi-autonomous platooning in some other states, but will they be the same regulations for fully autonomous platooning?

In the US, both railroad and trucking have promised an innovative future for the transportation industry. There is certainly a similarity between truck platooning and rail systems. The technology required to automate trucks is not cheap. The technology is estimated to cost between $30,000 and $100,000 (United World Transportation, 2023). Experts fear the high cost of autonomous trucks will drive small and midsize fleets out of the trucking industry. Thus, big companies and regulators will need to take measures to prevent the disappearance of small businesses and a possible impact on the country's economy. Research should be necessary to determine the transition methodologies from the traditional system to the fully automated one and to identify what possible use will be given to traditional trucks once the transition is completed.

Rail transport is one of the most environmentally friendly modes of transport, which is why many national and international authorities have set ambitious goals to increase the market share of rail transport (Lawson, 2007). In the mid-1820s, the US invested significant money in a rail system that promised to change freight transportation. Today, this system presents an almost total abandonment, where 1,755 rails are considered abandoned (Association of American Railroads, 2022). Currently, the deployment of automated vehicle technology is on the rise, and the US is targeting the implementation of AT for freight transportation. Meanwhile, Europe plans to shift 50% of long- and medium-stance haulage from road to train (Schwerdfeger et al., 2021). Future research should incorporate the railroad experience to learn from the lessons and produce more appropriate results for AT investment, taking into account cost, safety, and efficiency. A detailed comparison of the two systems would aid in determining how automation in the trucking industry would outperform the railroads and benefit the economy from across the supply chain.

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