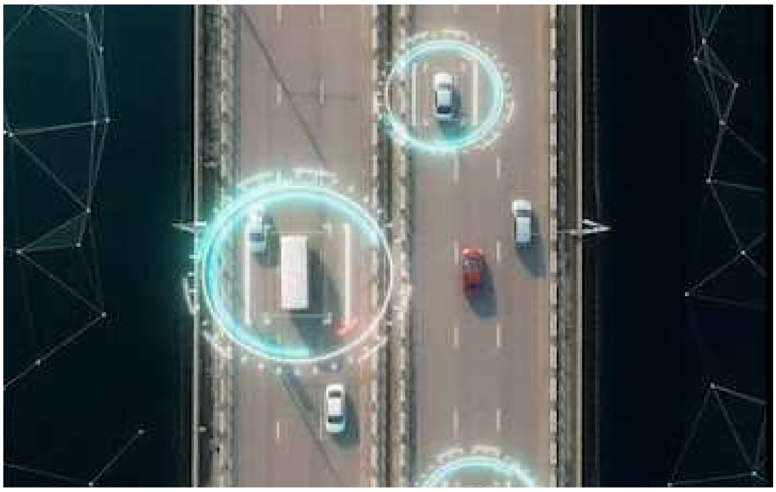

Automation in the trucking sector

Understanding the transformative effects on jobs and businesses

Ewa Ptaszynska, Berkeley, June 2020

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Disclaimer

Contents

If you bought it, a truck brought it. This is true now about a majority of products and it will become literally true when driverless trucks replace human-driven big rigs carrying goods within and across national borders. The crucial question is what will happen with truckers. Will automation technologies wipe out trucking jobs (around 2 million in the US and more than 3 million in Europe)? Will carriers (90% of which are small, owner-operator companies) be able to absorb the costs of a transition triggered by automation technologies and benefit from the innovation? Will the automation help to solve the current problems in the trucking sector such as difficult working conditions, shortage of drivers and throat-cut competition?

The technology in itself is neither a threat nor a solution. The scope and magnitude of positive and negative effects of the emerging automation technology depend greatly on policy and employers' responses.

The stakes are high as the automation of the trucking operations holds a promise of significant productivity gains, reducing fuel consumption and CO_2 emissions, reducing road congestion, cutting down road accidents caused by human error. It also has a potential to improve working conditions in the trucking sector and address the problem of the shortage of professional drivers. However, these benefits of innovation may be overshadowed by the negative effects of job and business losses which, if not properly handled, may result in market polarization with fewer well-paid, high-skill jobs and more low-paid, low-skill and less secure short-contract jobs.

Public policy will play a fundamental role in ensuring fair and safe deployment of automated and connected vehicle technologies and in preparing the trucking businesses and the workforce for the transition.

The purpose and scope of the study

This study aims to contribute to the discussion on how to cope with likely negative direct effects of the automation on trucking jobs and businesses and how to ensure that the innovation brings progress to the workers and to the society. Based on analysis of various technology deployment scenarios this study provides policy recommendations for mitigating negative impacts and ensuring smooth transition of the affected workforce and carriers. The focus of the study is on the American and European trucking industries.

Methodology

The study identifies key segments of the trucking industry which will be early adopters of the automated driving technologies, and it forecasts possible scenarios for commercial launch of automated trucks. The scenarios are established based on criteria of feasibility (i.e. technological maturity, demand for automation technology, legal preparedness) and desirability (i.e. potential productivity gains, improvements in road safety and in working conditions). These scenarios serve as a basis for estimating potential impacts on the trucking sector in terms of (i) quantity and quality of lost/displaced jobs, (ii) future jobs and new skillsets that may be required, and (iii) evolution of the businesses and main competition factors.

The findings presented below are based on industry research, participation in the platooning test runs, and consultations with a range of stakeholders: researchers, Silicon Valley automated vehicle (AV) technology developers, trucking organisations, representatives of administrations, and other experts in the field of automated driving technologies. The findings have to be considered within the caveats of evolving technological, regulatory and economic uncertainties.

Findings

The deployment of automated driving technologies in the trucking sector will be gradual. Assuming there is a favourable regulatory framework for testing and adoption of AV technologies, the highly automated (driverless) trucks could operate on the highways within the next fifteen years. On the one hand, COVID-19 crisis could delay the development of highly automated driving technologies as manufacturers and investors scale back innovation funding to concentrate on short-term cash management. On the other hand, the pandemic should strengthen reasons for pursuing the adoption of driverless, safer and more efficient truck deliveries.

Trucking industry is highly heterogeneous. Not all of its segments are equally suited for automation. The long haul trucking segment is a prime target for automation as it is easier to automate operations on highways than in complex urban traffic, and driverless long-haul operations promise significant returns on investment. However, the growth of e-commerce and a recent rapid increase in demand for local deliveries during COVID-19 outbreak will most probably speed up the automation of the local deliveries segment as well.

The first generation platooning technology (human-driven trucks travelling in convoy), which has been tested for the last two decades, is the most mature for commercial launch. However, the industry and developers are most interested in the second generation platooning (with human-led truck and following driverless trucks) and stand-alone driverless trucks in highway operations. This is because, in addition to fuel savings and road safety advances produced by first generation platooning (due to a decreased drag between trucks and more fluent driving) highly automated driving system (driverless trucks) will bring substantial labor cost savings, improved efficiency of the use of fleet and other productivity gains.

The numerous on-road tests confirm that platooning can reduce fuel consumption by 7-10 % on the average. The driverless technology could increase utilization of trucks from the current 50% of the fleet use up to 80% (e.g. by not having to comply with driving time limits) and reduce carriers operating costs by about 40% (by eliminating drivers' compensation costs).

The assessment of impacts on the workforce are based on the analysis of five most feasible and desirable potential scenarios for how the automated driving technology could be used.

- **First generation platooning on highways** – human-driven trucks travelling in convoy, connected electronically (by wireless communication) and following each other at short distances. The human driver in the lead truck drives normally and drivers in following trucks keep control over steering, but they have feet off the pedals as the system tries to follow the movements of the leader as regards accelerating and braking. Trucks can form and dismantle platoon on the road.
- **Second generation platooning on highways** – so called 'automated following' platooning system, where the lead truck is driven normally by the human driver and the following trucks are highly automated (without a human driver on board. The lead truck is equipped with Advanced Driver Assistance System (ADAS) including Forward Collision Avoidance and Mitigation, and following trucks try to follow the movements of the leader as regards steering, accelerating, braking. Drivers bring the load from a factory or a warehouse to the staging yard near the highway where they swap trailers between conventional and highly automated tractors and from where the driverless trucks drive long distance on highways in the human-led platoon. At the end of the highway journey, at another staging yard, local drivers would take over the transport operation by swapping again the highly automated tractors with conventional ones and carrying the load to its final destination.
- **Exit-to-exit highly automated trucks –** driverless trucks operate stand-alone on highways starting and ending in the areas adjacent to highway. Local drivers swap the trailers between highly automated and conventional trucks at staging yards and carry load for the first and last mile delivery.
- **Hub-to-hub highly automated trucks –** highly automated trucks operate between freight transit hubs or distribution centres including driving on roadways adapted for heavy-duty trucks, between the hub and the highway. In this case, there is no need for special staging yards near highways (as in exit-to-exit scenario) to swap trailers between conventional and highly automated tractors.
- **Highly automated local deliveries –** small custom-built driverless vehicles, which navigate in urban traffic at low speeds delivering parcels, food and other small cargo. Human handling linked to the vehicle is limited mainly to loading and vehicle maintenance.

A few technology developers focus on other technology applications, such as highly automated trucks remotely controlled by operators in the control centres or human-machine operated trucks requiring swapping dynamic driving tasks between the automated system and the human driver during the journey. However, the majority of experts interviewed consider these use cases unviable and dangerous, therefore no detailed consideration is given to these cases in the study.

Table 1. Forecasted AV deployment scenarios and effects on jobs and skills (assuming favourable regulatory framework addressing the risks of job losses/displacements, job-skills mismatches, and illicit employment practices)

Phase of deployment	Dominating use cases	Direct effects on jobs	New jobs / new skills
Slow uptake 2020-2030	1st generation platooning in commercial operations, 2nd generation platooning tests on dedicated highways Test operations of highly automated trucks in exit-to-exit on dedicated highways	No significant job losses Improved skills and working conditions in platoon operations and in test runs of driverless trucks (team work, less tiring driving, possibly better wages for upskilled drivers) More local delivery jobs	Fleet consolidators Platooning coordinators Safety/test drivers Skills to monitor software and hardware of automated driving systems
Rapid adoption 2030-2035	Commercial operations by highly automated trucks in 2nd generation platooning and in exit-to-exit, on dedicated highways Pilot operations by highly automated trucks in hub-to-hub Small driverless delivery vehicles in local operations	Loss of many long-haul driving jobs Some displaced drivers absorbed by the labor market thanks to a rapid growth in the demand for local driving and first/last mile delivery jobs Revenue and wage losses by truckers shifting from long-haul to local deliveries or non-driving jobs in the sector	New AV-related jobs and services in the trucking sector (e.g. emergency on-road repairs of highly automated trucks) and in AV-industry New skills required to operate, maintain, oversee self-driving system
Market penetration 2035-2045	Highly automated trucks in commercial operations on all highways Driverless small delivery vehicles in many urban areas	Lost and displaced jobs are gradually absorbed by new jobs and business opportunities in the short-haul and AV industries and in new services	New jobs in the trucking related sectors and new services that may emerge

The short-term direct effects on jobs and small carriers may be primarily negative. The indirect effects are likely to be positive as cost of AV technology falls, productivity rises, demand for freight transport increases and new job opportunities emerge, but it may take longer until the displaced workers find alternative jobs and new business models emerge. New jobs and business opportunities will be created most likely in three broad categories: new transportation jobs, new AV-related jobs and new jobs providing other goods and services linked with transportation.

It is estimated that, separately in the US and in Europe, between 200,000 and 900,000 of (mainly) long-haul trucking jobs could be lost and displaced over 10 to 20 years or more. Most of the affected workers will find new jobs or retire. The redeployment process may lead to wage and revenues increases for some and decreases for others. Those who will have possibilities to upgrade their skills will have well-paid jobs (such as automated driving system operators, fleet consolidators, specialized technicians, AV technology installation and maintenance workers) in the trucking sector or in the AV-related industry. Others either will perform usual and/or new non-driving tasks (loading/unloading, vehicle maintenance, cargo securing, fueling, vehicle and system inspection, etc.) or will shift to local driving and first/last mile delivery segment, which will upsurge significantly following the increased demand for long-haul driverless operations. However, these local driving jobs are usually less paid and there is a risk that current problems of misclassifying drivers as independent contractors (false self-employed) will exacerbate in this segment. Without robust policy measures many of those local driving and first/last mile delivery jobs may be shifted to on-demand jobs ("uberization") with uncertain income and no social protection.

Deployment of automated trucking technologies will also affect the organisation of the road haulage market leading most likely to its consolidation. Big fleets will most probably be early adopters of technologies and will be first to enjoy productivity gains. Many small carriers in the long-haul segment may not be able to absorb the initial high costs of technology and thus not survive until the technology becomes affordable. Some of them may join big operators, others will shift to local and first/last mile deliveries segment. In both cases they will lose a big part of their revenues. Some other carriers may re-orientate their business to trucking-related services, such as operating truck-staging areas at the highways or emergency on-the-road services or freight-truck matching platforms.

The introduction of automated driving technologies will gradually replace, transform and create work in the trucking industry and all other linked sectors. The history of technological revolutions shows that automation brings net growth in employment and skills in the long run and that it is usually accompanied by certain regulatory changes (including deregulation) enabling net positive effects of a an initial disruption.

Recommendations

Public policy should facilitate the automation of the trucking sector and in the same time mitigate the direct negative effects of the automation on jobs and businesses as well as ensure that economies and citizens reap the promised benefits of the innovation. To be effective, this requires coordinated engagement of all stakeholders: policymakers, researchers, technology developers, trucking businesses and workers. The efforts of preparing the trucking workforce and businesses for a transition should focus on four main pillars:

Research and collaboration

The stakeholders need to exchange data and cooperate closely to better anticipate and manage the transformative effects of the trucking automation. An independent Trucking Jobs Automation Council could be established to coordinate this collaboration, advise governments(s), and come up with an action plan(s) for addressing transition costs of those affected by the automation. Stakeholders' information sharing platform and a comprehensive database about employment in the trucking sector would help to collect necessary data for analysis of trade-offs between automation benefits and costs of forecasted jobs and business losses. Close collaboration between governments would be necessary to address the problem of patchwork of rules and initiatives that may hamper effective transition to automated cross-border trucking.

Workers protection

To deal with layoffs, job displacements and business bankruptcies the social protection net should be extended to cover also the most vulnerable workers, such as independent contractors (bogus self-employed), owner-operators, part-time workers. An early layoffs warning system should be in place to warn all workers, regardless of their employment status (including independent contractors) about company plans to invest in driverless technologies. Early retirement pensions would help older workers who have lesser possibilities for retraining and reemployment. Trade unions should extend their membership and activities to contract workers and other non-standard types of employment.

Jobs and skills creation

Policy makers in collaboration with industry stakeholders should create the list of forecasted skillsets which should serve as basis for establishing training programs for displaced and laid-off drivers and feed into the school-age educational programs, e.g. to develop STEM (Science, Technology, Engineering, Maths) competencies of future workforce. The free or subsidized vocational training programs should be offered to drivers who want to change their career pathways and work in other sectors.

To finance the workforce transition programs an "automated driving revenue tax" could be introduced. The carriers who enjoy major productivity gains due to replacing their drivers with highly automated trucks would pay part of their automated driving related revenues to contribute to the transition program for displaced drivers. This should be applied prudently to not discourage carriers to invest in innovative technologies, as this would hamper a progress.

Other measures could include automated trucking funds for small carriers to help them bear automation costs and seed funds for start-ups creating AV and /or trucking-related jobs and services.

The policymakers should ensure the effective enforcement of labor standards to prevent illicit employment practices and deterioration of working conditions, in particular in non-driving jobs and local, first/last mile deliveries segment.

Regulatory framework

Several laws and rules applicable currently to professional drivers and carriers in the trucking sector should be modernized. In particular, the rules on driving time limits and rest periods should be adapted to the automated driving situations. The definition of driver, working time and on-duty/availability periods must be revised to enable appropriate recording of active and inactive periods of a driver/truck operator. This entails a necessary revision of the rules on enforcement and enforcement tools such as tachographs (in the EU) or Electronic Logging Devices (in the US). Another policy option (instead of adapting the existing rules) could be to create a specific standalone set of rules applying exclusively to automated driving operations.

Wrap-up

The following major points can be ascertained from the report:

1. The automation of trucking operations has a potential of creating significant economic, social and environmental benefits for the sector and the society, but it also entails the risks of direct negative impacts on jobs and businesses.
2. The short-term job losses and displacements, concentrated in the long-haul trucking segment and in the geographical areas where the trucking industry is a major employer will likely be offset in medium to long-term, by increased demand for first/last mile delivery jobs and emerging AV-related jobs.
3. The automated trucking technology will be deployed gradually over the next 25 years, which leaves room for labor market adjustments and adequate policy development to help the sector absorb the transition costs.
4. Much work remains to scale the impacts, manage risks and retrain the workforce. The policymakers and the industry stakeholders should coordinate efforts to establish robust mitigation strategies and a favourable (technology and business-neutral) regulatory framework to facilitate the transformation of the trucking industry into safer, cleaner and more efficient sector with good quality jobs.

I. Introduction

Imagine a world where roads are occupied with highly automated trucks moving in full synchronization with each other, with road infrastructure, with other vehicles and road users. Imagine a road haulage transportation system where road accidents do not happen, traffic flow is fluent, goods are delivered on time, carriers optimize the use of their fleets and increase economic productivity, and citizens enjoy the benefits of non-congested roads and reduced greenhouse gas (GHG) pollution. This vision of a future is a main driving force behind the efforts of innovators, researchers and regulators across the world, to develop and adopt connected and automated driving systems in a trucking sector.

The inevitable question is: what about truck drivers? How do they fit, if at all, in this vision of a future? Will their jobs evaporate with the deployment of automation technologies or will they strive and thrive in a future transportation ecosystem?

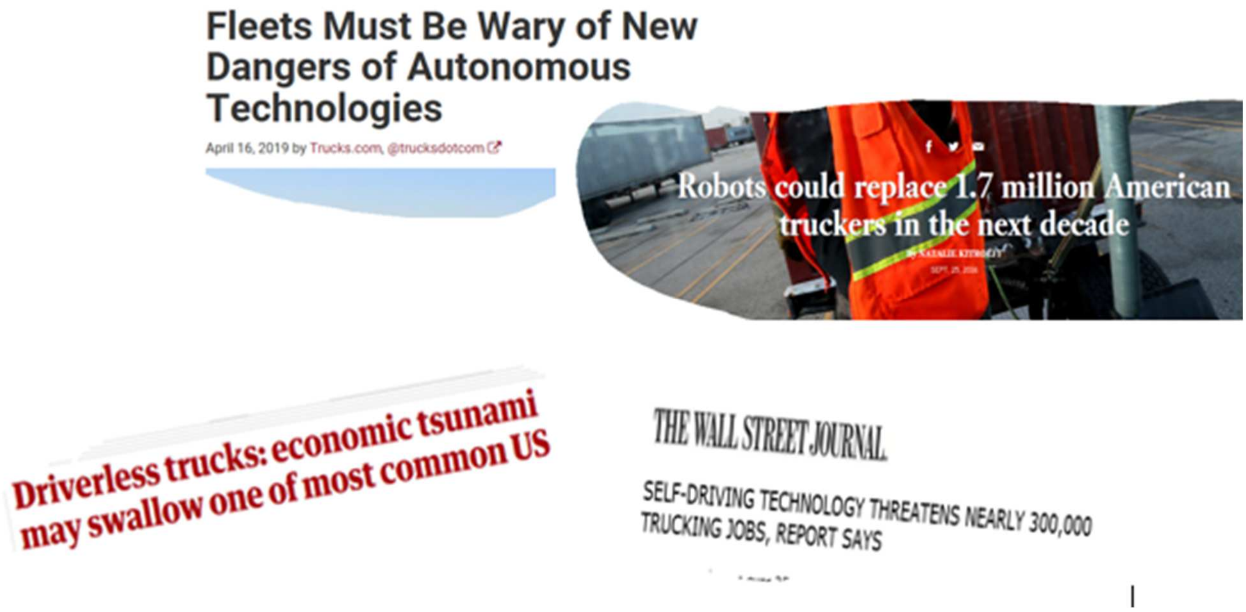
In 2004, Professor Frank Levy from the Massachusetts Institute of Technology (MIT) and Professor Richard Murnane from Harvard University published their comprehensive research in *The New Division of Labor. How Computers Are Creating the Next Job Market*[1]. They provided a list of professions which will most probably be fully automated. As an example of a profession which will not be replaced by the automated technologies in the near future, they pointed to the job of a truck driver. They claimed that it was inconceivable that algorithms could safely drive a truck, without human intervention, on the crowded roads.

Merely one decade later Google and Tesla not only could imagine automated driving technologies, but they started testing and using prototypes of self-driving trucks. In October 2016 the first commercial delivery by a self-driving truck took place. The self-driving truck developed by the start-up OTTO carried 2,000 cases of Budweiser beer 200 kilometres down Interstate 25 in Colorado from Fort Collins to Colorado Springs. While the operation was carried out entirely by the automated driving system on the highway, the human driver piloted the truck manually to and from the highway.

> *"Today transportation has become synonym with innovation" – Elaine L. Chao, US Secretary of Transportation; TRB, January 2020*

What once was considered science fiction – vehicles communicating with one another and replacing partially or fully human intervention in driving activity – is becoming a reality worldwide. With the availability of digital technologies (big data, internet of things (IoT), cloud computing, artificial intelligence (AI)) connected and automated vehicle (CAV) technologies are developing at a rapid pace. Automated trucks are being tested on public roads around the world. It seems that high level automation technologies are on the verge of commercialization. The stakes are high, as CAV technologies hold a promise of significant productivity gains, reducing fuel consumption and accompanying greenhouse gas emissions, reducing road congestion and road accidents but also a promise of enhancing working conditions.

The horses are out of the stable – there is no question about whether but rather when the technology will be ready for widespread commercialization and how to ensure fair and safe digital transformation of the road haulage sector. The inevitability of automation in the trucking sector brings hopes, but also uncertainty and many questions. It sparks fascination and fears. Whilst enthusiasts of automated driving systems consider them a life-saving technology, the sceptics regard automated trucks an unguarded missile on wheels. The innovators race to develop what they see as the next high-tech "pot of gold", and the experts warn about challenges, including how to train a machine to be better than a human at making life-and-death decisions[2]. Some experts and press propagate predictions that automation will result in millions of truck drivers losing their jobs.



Others see in the automation technologies a key enabler of better working conditions and a creator of new jobs within and outside the sector.

We need to separate the facts from the hype. Undoubtedly, as the history of previous industrial revolutions shows, the emerging automation technologies will have significant transformative effects on businesses and on jobs, both positive and negative, in the trucking industry and in all other sectors linked with trucking.

It is important to understand that a technology itself does not threaten anyone. It is people and culture, policy choices and employers' choices, which drive digital transformation more than technology does. Automation is not a goal in itself, but a tool for solving concrete transportation problems. Therefore, it is necessary to rethink the purpose for which technologies are currently developed and to reflect on how we can shape the future of the trucking sector to reap the best benefits from those technologies and to mitigate the accompanying unavoidable downsides.

> *"Technology and innovation can only make sense when they bring progress to people and the society" –Mireille Helon, CEO of Orange Silicon Valley.*

This report is my humble contribution to the debate about the impacts of the connected and automated vehicle technologies on the trucking sector, and in particular on carriers and truckers. The report is a result of my research carried out during my fellowship at the University of California in Berkeley in the academic year 2019-2020. It builds on a comprehensive literature review, interviews with researchers and self-driving technology developers based in Silicon Valley, representatives of the state and federal administrations, carriers associations, small owner operators' organisation, truckers' organisation and participation in demonstrations of the automated and connected technologies.

I have selected California for my research as it has the largest number of automated truck technology developers in the U.S. and it offers good weather conditions as well as favourable regulatory framework for technology testing on public roads. Numerous similarities between US and EU trucking industries and parallel directions of research and innovation in transport let me believe that some of my findings may be relevant in the EU context.

This report endeavours to reply to three key research questions: (1) when and in what technological configurations will the CAV technologies be deployed in the trucking sector; (2) what changes will these technologies bring to the workforce and businesses; (3) what steps should regulators take to assist drivers and businesses affected by automated trucking technologies.

To assess how the adoption of CAV technologies could affect the current and future trucking workforce and businesses, it is crucial to understand how the trucking sector functions, what the key technological developments are, what the challenges are and what opportunities the automation technologies may yield.

The report is structured in six sections. The first section sets the context for a discussion about automation in the trucking industry. The second section gives a brief overview of the trucking sector and the problems that it currently encounters. The third section focuses on explaining the technological developments and main challenges. In section four, possible scenarios are suggested for the uptake of automation technologies by the trucking sector. The fifth section presents potential implications of deployment of the technologies in different scenarios. The final section proposes policy considerations aimed to shape and facilitate the digital transformation of the trucking sector.

At the time of drafting this report, the world keeps struggling with COVID-19 pandemic that affects citizens and all sectors of economy. The coronavirus outbreak creates new uncertainties about the dynamics of AV technology developments and deployment and adds a new dimension to the debate on the automated driving technologies. The findings of this research should be considered in the context of the evolving technological, regulatory and economic uncertainties.

II. Trucking industry automation – why it matters

A. Trucking industry in a nutshell

"If you bought it, a truck brought it" – this is a common saying in the sector. "The only thing not delivered by a truck is a baby" is another saying about trucks. Indeed, the vast majority of products are delivered to their final destinations by trucks both in the US and in the EU. Experts estimate that most grocery stores in the U.S. would start running out of food products in just 3 days if truckers stopped working. My guess is that, in the era of on-time delivery, many production lines would stop working sooner than in 3 days if trucks stopped bringing production supplies.

In the US as well as in Europe, the fear of total lockdown aiming to flatten the COVID-19 infection curve, leads people to hoard food and hygienic products from the stores and pharmacies. To restock empty shelves and to cope with increased demand for e-commerce deliveries the US and EU governments took measures to ensure that trucks keep rolling, delivering food and hygienic products to the shops and individual clients as well as medicines and medical supplies to hospitals and other health care institutions. This exceptional situation highlights the importance of trucking to the daily lives of all citizens.

Regulators and economists on both continents call the trucking industry the lifeblood of the economy. The key statistics presented in the following paragraphs demonstrate that this statement is not exaggerated.

Trucking industry in figures

In the U.S. trucks move 71% of all freight by weight[i]. In 2018, the industry was worth almost $786.7 billion in gross freight revenues[3]. According to data from the Bureau of Labour Statistics (BLS) in 2017 there were nearly 1.9 million[ii] truck drivers classified as "heavy and tractor-trailer truck drivers" (operating trucks over 26,000 pounds), and about 900,000 "light truck and delivery services" drivers (operating trucks weighing less than 26,000 pounds)[4]. According to the Women in Trucking Association, in 2019, 10% of all over-the-road (long-haul) truck drivers are women.

In the EU, the road haulage sector[iii] makes up 51% of the overall freight transportation industry (air, water, rail, pipeline, and road) and 74% of all inland freight transport. In 2016, the road haulage industry was worth nearly € 340 billion (ca. $ 370 billion) in turnover[iv]. The sector employs around 3.2 million heavy truck drivers, out of which only 2% are women[5].

In the U.S. in 2019, there were about 892,000 for-hire carriers (those that transport goods for others, like J.B. Hunt) and about 772,000 private carriers (those that transport their own goods using their in-house fleets, like Walmart)[v].

[i] The freight transportation industry consists of the following transport modes: air, water, rail, pipeline, roads.
[ii] This figure includes about 150,000 self-employed truck drivers, called also owner-operators.
[iii] "Road haulage sector" is the term used in the EU while in the US the common term is "trucking industry". Both terms describe the sector involved in transporting goods by trucks.
[iv] The term "turnover" used in the European statistics means the same as the term "revenue" used in the US.
[v] According to the U.S. Department of Transportation

In the EU, in 2016, there were around 590,000 for-hire transport undertakings[6], and this figure does not include the so-called "own-account" operators (or "private carriers" in American vocabulary).

Both in the U.S and in the EU, the trucking industry is extremely fragmented. Carriers' fleet sizes range from one truck (owner-operator) to tens of thousands of trucks. Around 90% of all carriers have less than six trucks in the U.S. and less than 10 employees in the EU.

> *If the US trucking industry was a nation and its annual revenue of nearly $800 bln was their GDP (more than GDP of Colombia, United Arab Emirates and other 198 countries in the world) it would have ranked 31st (in GDP terms) according to CIA Factbook.*

The trucking sector is a huge segment of the American and the European economies. Does the size matter? Yes, because an industry this large and so closely tied to all other industries, touches everyone. Therefore, the digital transformation of the trucking industry will have widespread effects on other sectors of the economy and on the society.

Types of trucking operations

The trucking industry is not homogeneous. Carriers differ greatly depending on the type and size of freight carried, type of vehicles used, distances for deliveries, business models chosen. Specialization of drivers is common, with the majority of truck drivers taking on long-haul operations. Automation technologies will not be deployed in a single defining moment and neither in the entire trucking industry in the same way. The likeliness of automation and the impacts on quantity and quality of jobs will be different for each of the trucking segments. Therefore, it is useful to understand how the trucking industry is organized.

In the U.S. the following main segments of the trucking industry can be distinguished[7]:

- **Long-haul and local haul.** Long-haul operations require drivers to drive hundreds of miles for a single route, usually being on the road for several days or weeks at a time. These operations may be full truckload shipments, with freight from a single customer or less-than-truckload, with combination of shipments from different customers. Local haul routes are often called first-mile and/or last-mile operations, as they typically involve delivering packages and shipments between a customer and carrier's drop-off point where the shipments are combined and then shipped over longer distances and/or from the drop-off point where shipments are divided and delivered to final destinations. Local haul operations may also be a part of multimodal operations, like moving shipping containers at ports or moving freight a short distance from a train that has transported it long-distance[8]. Viscelli[9] uses in his analyses a distance of beyond 150 miles as a lower edge for long-haul and as an upper edge for defining short-haul operations.
- **Full truckload and less-than-truckload**. Full truckload is the movement of large amounts of homogenous cargo, which fills the trailer (either in terms of space or permitted weight). Truckload may be carried by for-hire carriers or by private carriers. Less-than-truckload operations involve partial truckload deliveries and try to optimize movement based on combining freight shipments from different customers (e.g. YRC Freight, XPO Logisics)
- **For-hire and private carriers.** For-hire carriers transport freight for client companies and usually from customer location to customer location (e.g. J.B. Hunt, Knights Transportation). Private carriers (in EU called on-own-account operators) operate their in-house fleets to move their own goods from the distribution centres to the stores (e.g. Walmart, PepsiCo)

- **Specialized operations.** These are operations requiring specialized trailers to carry freight such as cars, gases, trash, life animals, frozen food. These also include the so-called flatbeds, which transport oversized loads like windmill turbines and bridge trusses.
- **Pickup-and-delivery**. This involves the movement of small items, for instance courier service and parcel delivery (e.g. USPS, Fedex and UPS). This concerns also first/last mile deliveries (as described above).
- **Intermodal hauling.** Intermodal hauling usually refers to short distance transport of freight, which is moved over long distance by another mode of transport (sea, rail, air, and inland waterways). This includes port haul operations to transport containers between shipyards and warehouses, distribution centres, stores, and other destinations. For freight that is moved most of the way by rail, trucks are used to transport the freight for the remaining distance to the final destination.

The quality of jobs in these different segments varies greatly. While long-haul truckers usually earn more than drivers in local operations (the more you drive, the more money you make) and drive newer more comfortable trucks, they are exposed to higher expenses of living on-the-road for long periods, away from their families. Local truckers are typically home every day, but they deal with more loads each day and have to drive in demanding urban areas, with more traffic and tighter lanes than long haul truckers who mostly operate on highways.

Carriers focusing their activity on long-haul carriage usually have higher revenues than local carriers, but they have higher operating costs (e.g. newer trucks, more expensive drivers) and typically face very tight cost-based competition.

It is important to remember that not all driving jobs are the same, not all the work performed by truck drivers involves driving, and not all segments of the trucking industry are equally well suited to automation.

Challenges for carriers and truckers

Innovative technology is neither a problem nor a solution in itself. It may be, however, the tool to solve current and forecasted problems in the road freight transportation. Therefore, before moving to a presentation of emerging automation technologies, it is important to outline the main challenges that the trucking sector faces. This understanding will help to better assess business cases and potential benefits and risks of applying Automated Driving Systems (ADS) technologies. It is important to note that these key challenges may affect differently (or not at all) various segments of trucking industry described in the preceding section.

Cost-based competition. Carriers operate on very low profit margins and they have to handle fierce cost-based competition with others. Driver compensation cost (wages, benefits and bonuses) represents the largest cost component for carriers, accounting for 43% of total average marginal operating costs[10]. The second biggest cost element is fuel (22%) followed by a cost of purchase or lease of a truck (16%). In Europe labour costs account for 35 to 45% of the costs[11]. As carriers have no influence on fuel or insurance prices, and limited influence on the cost of purchasing or leasing trucks, they tend, unsurprisingly, to look for savings in labor costs. This takes different forms, from lack of pay raises, through paying only for a loaded mile driven[vi] to encouraging drivers to become independent contractors (self-employed). Using drivers as independent contractors enables carriers to avoid high employment costs such as social security contributions, paid annual leaves and others. Drivers registered as independent contractors and working solely for their ex-employer, frequently using a truck 'leased' from that employer, are not really

[vi] In the EU, drivers are paid for their working time, though they may get remuneration based on the number of kilometres driven or amount of freight carried if this performance-based remuneration does not endanger road safety, which is almost impossible to verify. In the U.S. drivers are usually paid per loaded mile driven, so they do not get paid for other periods when they are obliged to stay in or around their trucks doing other tasks such as loading/unloading, paper work, waiting at the load/unload points, etc.

independent. They are, in fact, misclassified employees deprived of their social protection rights (or false self-employed in the EU vocabulary).

Empty runs. In the U.S., the share of total miles that truckers drive empty (and frequently do not receive remuneration for this driving time) has been consistently stuck around 35% since at least the 1990s. While some carriers are close to zero, others run even 55% of their miles empty. In the EU, on average, empty vehicles performed one-fifth of road freight journeys in 2016. The empty runs levels range from 12% (of total journeys) for intra-EU cross-border journeys to between 15 % and 30 % for national journeys within a Member State. Empty runs are in general problematic from the perspective of environmental footprint (unnecessary additional CO_2 emissions), efficiency of transport operations (unproductive use of fuel, truck and driver's time) and road capacity (unproductive road infrastructure occupancy). In addition, in the U.S. this is also a problem of unpaid time at work, as drivers frequently do not get remuneration for driving empty trucks.

Difficult working conditions. In the 1950-70s, the trucking sector was the best-paid and most powerful segment of the US middle-class jobs. The situation of truckers started worsening in the 80s due to deregulation of the industry and decline of trucking unions[12]. These two processes led to increased cost competition between carriers and decrease in job quality (declining wages and precarious employment conditions). In Europe, the trucking sector is highly regulated. Nevertheless, market opening, huge divergences in labor and social protection standards between Member States and increasing cost-based competition have led to deteriorating working conditions. Employers developed a model of truckers as independent contractors, shifting risks and costs to drivers (as described above). On the other hand, truckers' work environment has become more comfortable and truck driving has become less physically demanding thanks to design and other technical improvements in newer trucks such as more comfortable seats, better ventilation, ergonomically designed cabs. Nevertheless, driving for many hours at a stretch, sometimes in difficult weather conditions and heavy traffic, loading or unloading cargo, and making many on-time deliveries contribute to fatigue and stress. In addition, long-haul truckers spend many weeks and even months on the road, away from home.

Driver shortage. Both in the U.S. and in the EU, truck drivers are mostly men aged between 40 and 60. The average truck driver is about 49 years old. Due to difficult working and pay conditions the trucking industry struggles to attract women and young people. Shortage of truck drivers, in particular for long-distance haul, is already a global issue.

According to the American Trucking Association (ATA) the industry was short of 60,000 truck drivers in 2018. Further ATA estimates that, with almost half of the truckers population retiring within the next few years and with projected increase in demand for freight transport, shortage of drivers will balloon reaching 175,000 vacant positions of on-the-road truck drivers by 2026.

Owner-Operator Independent Driver Association (OOIDA) does not entirely agree with these estimates. It considers that there is no shortage of drivers, but shortage of pay. With around 400,000 Commercial Driver Licences (CDL)[vii] issued every year, there should be a sufficient number of drivers. However, according to OOIDA, precarious employment conditions, inadequate pay and long periods away from home result in high turnover of drivers (over 90% in some cases[viii]) and in difficulties recruiting qualified long-haul truck drivers with high safety records.

[vii] CDL is a state-issued licence that a driver must have in order to operate certain commercial vehicles, including trucks and tractor-trailers.

[viii] In 2018 turnover at large truckload carriers was 94% and in small, truckload carriers it was 73%. Less-than-truckload carriers reported lower turnover of 10%.

Desiree Ann Wood from the Real Woman in Trucking Inc. says that there are enough drivers entering but carriers cannot retain them. Drivers' wages do not reflect the skills, sacrifices and long hours. "You cannot be paid by the mile and regulated by the hour".

In the EU road haulage sector, the shortage of drivers was around 21% of employment demand in 2018, according to the analyses by the International Road Transport Union (IRU)[13]. IRU expects that the demand for drivers will grow to meet the increasing freight transport needs and to fill in vacancies after retired drivers. This will create a shortfall of drivers, which may seriously affect the EU economy.

Other challenges for the sector include a lack of **parking and rest areas**, **delays at customer facilities**, **road congestion,** and a complex and rigid **regulatory framework**[ix] (Hours of Service regulations in the U.S. and a set of social and market access rules in the EU).

All these challenges call for urgent actions. Can automation technologies be part of the solution?

B. Potential benefits of trucking automation

The innovative technologies may be a big step forward in providing the right solutions to the above-described challenges in the trucking sector. A choice of automation technologies configuration will determine which problems will be addressed in the first place, how and to what extent. For instance, while highly automated trucks (without a human driver on board the vehicle) could help to address the **drivers' shortage** problem and **reduce carriers' high operating costs**, an automated driver's assistance technology could **improve driver's working conditions** (e.g. by reducing stress and fatigue).

Automating freight transport could **improve productivity** by speeding up the delivery of goods and increasing the frequency of goods movement, reducing at the same time the number of drivers needed. Driver's driving time and working periods are limited by law[x]. Driverless trucks do not have to follow driving time restrictions so they could drive almost continuously with breaks only for fueling, loading and unloading, maintenance, etc. Such trucks have the potential of doing the work of three human drivers, thus creating significant salary savings per truck and increasing truck's productivity.

Cross-country (in the U.S.) or cross-Europe journeys could be done in fewer days. For instance, in 2019, the Silicon Valley start-up Plus.ai carried out a delivery of 40,000 pounds of butter with its self-driving semi-truck from west (California) to east coast (Pennsylvania) of the U.S. within only 3 days. Normally such a journey of over 2,800 miles takes 5 days. **Speeding up deliveries** would bring **greater efficiency** for carriers and it would be beneficial for transporting perishable foods or live animals.

[ix] "2019 top industry issues", report of the American Transportation Research Institute.

[x] Under current Hours of Service regulations in the U.S. a truck driver cannot drive more than 11 total hours within a 14-hour window after coming on the duty. In the EU, Driving Time Regulation requires that truck driver does not drive more than 9 hours/day (10 hours/day only twice a week) and no more than 45 hours on average per week.

The Plus.ai lorry relies on sensors, cameras, radar and Lidar (light detection and ranging) technology and computer vision software underpinned by artificial intelligence

Source: BBC News, 11 December 2019 https://www.bbc.com/news/technology-50742080

Automated and connected driving technology could also **improve driving efficiency** thanks to more fluid truck movements (avoiding unnecessary maneuvers of breaking and speeding) or due to reducing the drag between trucks following each other closely in convoy and connected via communication technology (platooning). The drag reduction in platooning would help **reduce fuel consumption**, hence bring further savings in carriers' operating costs. According to the estimates of Securing America's Future Energy[14], platooning can reduce the fuel consumption by as much as 20%. According to ATA fuel consumption reports, applying average 10% fuel savings to all U.S. heavy trucks would result in savings of 4 billion gallons of fuel, which translates to $10 billion fuel cost savings per year.

Automation may also **increase the use of fleet**. Currently an average utilization of trucks, mainly due to driving time limits and other driving bans (e.g. weekend driving bans in some European countries), is about 50%. The utilization could increase to 80% thanks to the use of highly automated trucks. According to Locomation, one of the leading start-ups building automated convoys systems, with their system trucks could be in use for up to 22 hours per day, increasing asset utilization by up to three times or more than 90%.

Automation technologies in road freight logistics would improve supply and demand matching which would contribute to **reducing empty runs,** hence further increasing productivity. The start-ups like Uber Freight, Transfix and Convoy focus on freight-truck matching. Essentially, they are replacing traditional brokers by utilizing mobile technology and automating manual operations.

There are other key problems linked with the road freight transport, which technology developers and regulators hope to solve with the help of automation. These problems have wider societal dimension as they concern road safety, greenhouse gas (GHG) emissions and road congestion. In my research, I focused on impacts of automation on transformation of trucking jobs and businesses. Therefore, this report does not analyse impacts of automated driving technology deployment on reducing traffic accidents, reducing CO_2 emissions or improving traffic flows. However, as these three issues are essential motivations for automation technology development, it is appropriate to outline how ADS technology could contribute to solving them.

Road safety. The highways in Europe and in the U.S. are becoming safer with continuously falling numbers of road deaths. This is largely thanks to infrastructure improvements, speed limits, safer vehicles equipped with driver assistance technologies and the development of Intelligent Transport System for road vehicles and networks. However, with 40,000 people killed in roadway crashes in the US (in 2018) and 25,100 fatalities in the EU (in 2018), road safety remains a great concern. Trucks are involved in about 15% of deadly accidents on the EU roads. In the U.S., road traffic fatalities in crashes involving trucks reach 12% of all deadly accidents. Road users other than truck drivers cause the majority of those accidents. In general, more than 90% of all road accidents are due to human error, such as disrespect of the traffic rules, driving under influence of alcohol or drugs, driving and texting, fatigue, etc. Automated driving system technologies will eliminate human error and make drivers less tired and safer.

CO_2 emissions. Trucks are responsible for around 25% of greenhouse gas emissions caused by all road

> *"Self-driving vehicles don't get distracted. They don't get fatigued; they don't fall asleep. And, you know, they don't drive drunk" - Dmitri Dolgov, Waymo*

transport vehicles in the EU and 28% in the U.S. The study carried out by the University of California in San Diego estimates that 10% fuel savings resulting from using self-driving technology in all heavy-duty trucks in the U.S would reduce CO_2 emissions by 42 million metric tons per year. This would significantly reduce the environmental footprint of the trucking sector.

Road congestion. Traffic congestion on U.S. highways severely affects the trucking industry. According to a study by the American Transportation Research Institute[15] (ATRI), traffic congestion costs the trucking industry more than $63 billion in operating expenses, including costs of wasted fuel, labor costs and vehicle wear and tear. Further, it calculates that delays due to congestion lead to around 996 million hours of lost productivity. That is the equivalent of having 362,243 commercial truck drivers sitting idle for an entire working year. Automated driving technologies hold a promise of improving roads capacity and reducing traffic congestion by making traffic more fluid, increasing lane occupancy (e.g. reduced distance between connected trucks driving in platoons enables more vehicles to fit in) and reducing the number of accidents, which are the major cause of traffic congestion.

C. Trucking – early adopter of automated driving technologies

Researchers and innovators consider the trucking industry an early adopter of automation technologies. The automation has a great potential to solve the sector's challenges and bring benefits to the society in terms of reducing air pollution, roads congestion and road accidents. The application of the automated and connected driving technologies in the trucking sector, and in particular its long-haul segment, seems a most viable business case technologically and economically.

> *"Autonomous driving is likely one of the most significant technological shifts in the last 100 years with trucks being the first commercially viable application" – Itzik Parnafes, General Partner, Battery Ventures*

Firstly, it is easier to create automated driving system for operations in a limited operational driving domain with a limited number of variables. In other words, it is easier to teach a truck to drive on long stretches of highway in more predictable and less people-filled environment than on busy streets in a complex urban setting.

Secondly, the trucking industry is a huge segment of the economy and it promises quick and significant return on investment by increasing productivity (e.g. quicker deliveries, optimized use of fleet, fewer empty runs) and decreasing operating costs (e.g. savings on fuel and labor costs). This is particularly true for long-haul trucking, which produces a lion's share of total annual revenues in the trucking industry.

> *"Long-haul freight delivery is one of the most obvious and compelling areas for the application of autonomous and semi-autonomous driving technology."*
> *– Morgan Stanley Research.*

Morgan Stanley (2013) estimates that the broader deployment of 'autonomous' trucks could bring potential savings of $168 billion annually to the U.S. road freight industry. These estimated savings would come from labor ($70 billion), fuel ($35 billion), accident reduction savings ($36 billion) and productivity gains ($27 billion).

McKinsey (2018)[16] projects 40% increase in trucking profits by 2030. This is based on the optimistic assumption that 'full autonomy' (trucks driving without human driver on all highways and in all conditions) will be achieved at some point after 2027. In accordance with their estimations, 'autonomous' trucks total cost of ownership would decrease by 35% to 50% (mainly due to reducing driver's and fuel's costs) bringing savings between $85 and $ 125 billion within 10-20 years for the US for-hire trucking companies.

The technological and economic arguments explain why there is more appetite in the investment community for automated trucks than for automated passenger cars. In the last decade, the trucking industry was flooded with start-ups working on different combinations of automated and connected vehicle technologies (e.g. Peloton TuSimple, Embark, IKE, Kodiak, Starsky Robotics – the latter one closed down the business in February 2020). Numerous vehicle manufacturers (e.g. Daimler, Volvo, GM, Toyota, Honda, Mercedes, Hyundai), some automotive suppliers (e.g. Bosch, Delphi) and major firms (e.g. USPS, FedEX) invest intensely in research and development of trucking automation technologies. In the San Francisco Bay Area alone, there are about 40 companies working on automated vehicle technologies, including Silicon Valley giants like Apple, Waymo, Tesla, Uber. All race to monetize the technological opportunity of automating driving systems.

The envisaged date of commercialization of automated driving systems in the trucking industry is a moving target. The initial enthusiasm of the last decade about capabilities of automation technologies and anticipation for their quick deployment (e.g. Google announced in 2012 that in 5 years everybody will be using 'autonomous' vehicles) gave place to more realism about what kind of automation will be available and when.

D. Challenges for deployment of automated driving technologies

The main types of challenges affecting a development and deployment of automated truck technologies consist of technological, operational, infrastructure and legal factors. Innovators, manufacturers and regulators must address all these challenges before automated trucks can be adopted on a widespread basis.

Technology challenges. The marketing departments announcing an advent of connected and automated trucks are years ahead of where engineering departments are. Numerous tests reveal that technology is not yet ripe to be commercialized. The most frequently cited example of technology failure is the fatal accident of an Uber self-driving car (March 2018, at night, Tempe, Arizona) when a night vision sensor failed to recognize a person, and safety driver[xi] failed to react in time. This combination of technology and human failure resulted in the death of a pedestrian. Very soon after that, Tesla SUV with driverless technology on autopilot mode crashed into a road divider in Mountain View, California resulting in the death of its safety driver. There were no such incidents reported with involvement of automated trucks.

[xi] Safety driver is a driver whose task is to monitor the automated driving system and take over driving in case of system failure.

This does not mean, however, that technology works flawlessly in trucks. What it means is that testing automated big rigs is done with more caution and mostly with a presence of a safety driver and engineer in a cab monitoring the functioning of the self-driving system.

After the Uber accident researchers started working on infrared and thermal sensors to detect the heat of a human body in a night light. Innovators are facing numerous technological challenges with main components of the automated system, such as perception, path planning, mapping, accuracy of sensors, connectivity, etc. Development of automated driving technologies is a work in progress.

> *"It is not like a mobile phone app where […] if the mobile phone app doesn't work 10 percent of the time, big deal. This has got to work all the time. There is a pot of gold out there at the end of the rainbow for those who can actually get this to work. Now the challenge is how to get it to work safely." Steven Shladover, PATH, UC Berkeley*

Operational challenges. Operations by highly automated trucks (without a human driver) raise the question of how to deal with mechanical problems on the road, such as a tire blowout. The platooning system (2 or more trucks driving in convoy using connectivity technology and automated driving support system) poses several questions like how to deal with interruptions in connectivity or how to ensure interoperability of different platooning systems used by various carriers whose trucks may be platooned. There is also a concern about finding a cargo for two or more trucks that could be transported in the same time on the same route. In platooning across different carriers the question is about fair distribution of fuel savings. There is also a relevant concern about enforcement. How should control officers carry out safety inspections of driverless trucks being on the road?

Infrastructure challenges. Some configurations of automated and connected technologies may require upgraded or new infrastructure, such as lane markings or robust wireless communication networks, which would be necessary for ensuring flawless vehicle-to-vehicle communication and vehicle-to-infrastructure communication. For models of highly automated highway driving, there would be a need for developing pick-up and drop-off yards near highways, where trailers could be swapped between conventional trucks used for local first/last mile delivery and highly automated trucks transporting the freight on long distance on highways. Platooning also poses the challenge to old road infrastructure, and in particular bridges, some of which were not designed to hold the weight of 2 or more heavy trucks at the same time.

Legal challenges. The right regulatory framework is necessary to ensure that the innovative solutions are sufficiently tested and deployed in a fair and safe manner. Currently, in the US and in Europe there is a patchwork of laws on testing and adopting automated driving systems which makes it difficult to test automated trucks in cross-border operations (some states do not allow highly automated vehicles, without a human driver on board, on public roads). There is a big issue with liability for road accidents involving driverless trucks and caused by system failure. Currently, the liability for road accidents remains mainly with a driver and a carrier. The question is how to ensure that software developer, truck manufacturer, truck owner and anybody responsible for automated driving system inspection and maintenance are held liable (and to what extent) for the automated technology failure. In addition, the question is how the rules on driving and rest times should apply to drivers who operate automated trucks. Should the period of automated driving, when a human driver is in a sleeper berth, be accounted for driving time, work period, rest?

Other challenges. Other important challenges concern cybersecurity and public acceptance. In particular, the use of connectivity technologies (e.g. in platooning) which transmit huge amount of data, requires a high level of security protocols to avoid automated trucks being subject to malicious cyberattacks. Public acceptance is also an important issue as it determines safe interactions between automated trucks (in particular platoons) with other road users.

E. Automated trucking - SWOT analysis

The SWOT analyses (Strengths, Weaknesses, Opportunities, Threats), outlined in the table below, summarizes potential strengths, weaknesses, opportunities, and threats associated with automation in trucking industry.

	Internal		
Positive	**STRENGTHS**	**WEAKNESSES**	Negative
	Less stressful driving	Reliance on technology	
	Reduced driver's fatigue	Lack of data transparency	
	Less long periods away from home	Requires connectivity infrastructure and other physical infrastructure	
	Time for other activities	Much testing required	
	Less fuel consumption	Unclear legal implications	
	Reduction of CO_2 emissions	Vulnerability for cyberattacks	
	Increased productivity	Lack of IT related skills of drivers	
	Speeding up deliveries	Cost of technology	
	Better utilization of fleet	Difficult human-machine interactions	
	Reduction of idle time of truck and its driver		
	More fluid road traffic		
	Reduced road accidents due to human error		
	Attracting women and young people to trucking jobs		
	OPPORTUNITIES	**THREATS**	
	Manufacturing	Public disapproval of automated trucks	
	New business models	Accidents due to system failures	
	New jobs in and outside trucking industry	Job losses and displacement	
	New skillset	Mismatch of jobs and skills	
	Gender balance in trucking industry	Bankruptcies of small carriers	
	Growth of businesses related to trucking	Privacy concerns	
	Emissions control	Misuse of technology	
	External		

The benefits and growth opportunities of automated driving technologies must outweigh the current challenges and potential risks in order to achieve progress in the trucking sector and to the society. This, however, depends greatly on how well the industry, manufacturers and regulators are prepared for mitigating potential downsides of deployment of those technologies and turning the opportunities into sustainable growth.

III. Technology outlook

Automated driving technology is a complex combination of various components where machine (hardware) and algorithms (software) perform certain (or all) tasks of operating a vehicle safely. There is no one automated driving technology. Innovators and researchers have been working over the last five decades on a variety of technological solutions, some of which aim to assist a human driver in performing dynamic driving tasks (some of driver's assistance technologies are already in commercial use), while others may replace a human driver entirely in the future.

A. Brief historical overview of automation in transport

Automation in transport is not a novelty. The history of automation for passenger cars in the U.S. goes back to the 1930s when GM set out its vision of automated automobiles and began technical development work in collaboration with RCA Laboratories. In the 1950s first hands-off driving cars demonstrations took place. In Europe, during the 1960s, the United Kingdom's Transport and Road Research Laboratory was doing experimental automation work on cars. It tested a driverless Citroen DS that interacted with magnetic cables that were embedded in the road. In the 1980s Mercedes started being was very active in the field of automation of vehicles. In the 1990s the research and development efforts extended to public passenger transport and to freight transport and it accelerated in the 2000s. The following paragraphs present only a few most noteworthy initiatives and projects in the U.S. and in Europe, which have paved the way to the current automation state-of-art.

United States

In the U.S., the army pursued automated vehicle technologies since the 1980s. One of the noticeable demonstrations was the DARPA Grand Challenge competition funded by the Defence Advanced Projects Research Academy and organized in 2004 in the Mojave Desert region (California) of the United States. It was the first long distance (around 12 km) competition for driverless cars in the world. The next competition was the Urban Challenge in 2007 where the self-driving cars were tested in the urban area course of 96 km. In 2010, the U.S. Department of Defense started testing platooning trucks at the US Army bases.

Since 1986 California PATH (Partners for Advanced Transportation Technology) of the University of California in Berkeley has been involved in the research, development, and testing of connected and automated vehicles. In the 1990s it has re-focused its research efforts on truck platooning encouraged by the potential fuel economy. In 2000-2003 platooned trucks (level 1 automation) were tested on test tracks keeping a distance of 3 m between each other and using V2V communication and radar.

In 2013, the Federal Highway Administration (FHWA) of the US Department of Transportation (USDOT) launched the research projects to test fuel economy, traffic interactions and driver preferences in 2-truck and 3-truck platoons (level 1 automation). In 2016 America's first highly automated truck went for a drive from Fort Collins to Colorado Springs. With a professional driver's assistance navigating on and off the highway, this truck made the 120-mile journey.

Europe

The first Pan-European project in the field of driverless cars was PROMETHEUS (1987-1995). Since then the European automotive industry started introducing advanced driver assistance systems in the vehicles.

The first truck platooning research started in Europe in 1996 with the EU-funded CHAUFFEUR project, followed by CHAUFFEUR 2 project. Under these projects, the first connected "drive-by-wire" trucks (using communication protocols) were developed and in 1998 three platooned trucks, following each other with a distance of 10 meters, travelled in Southern Germany on public roads. These projects tested mainly technical feasibility of truck platooning.

The next project called KONVOI (2005-2009), funded by the German government, tested on public roads platooned trucks following each other with a gap of 10 meters. This project focused on analysing traffic interactions between the platoon and other vehicles. In 2009-2012, the EU-funded SARTRE project aimed to examine platooning in mixed heavy and light vehicles. In this project, the human-driven truck was followed by automated platooned cars and trucks. In 2013-2016, another EU project called COMPANION, led by SCANIA, aimed at developing co-operative mobility technologies for supervised vehicle platooning, in order to improve fuel efficiency and safety for goods transport.

Wirelessly connected trucks made their debut in 2016 within the European Truck Platooning Challenge. In this project the trucks from six major automakers: DAF Trucks, Daimler Trucks, IVECO, Man Truck and Bus, Scania and Volvo Group, drove in platoons through Sweden, Germany Belgium and the Netherlands. This project was to encourage harmonisation of platooning across the truck brands and the EU countries.

On-going work

The efforts on testing automated trucking technologies continue on both continents. The European Union has been funding numerous projects that support the development of automated driving. Member States also undertake initiatives individually to facilitate and speed up testing of automated vehicle technologies on public roads and their deployment on the market. The list of implemented and on-going projects and initiatives is long[xii]. The USDOT releases federal guidance for automated vehicles building, testing and adoption[xiii]. It also funds research projects exploring how to ensure safe and efficient integration of automation in the transport system.

The current research and work on vehicle automation is part of a broader digital transformation, which builds on the confluence of four main elements: cloud computing, Big Data, Internet of Things and Artificial Intelligence[17]. These four technologies enable real-time transmission and processing of huge amounts of data, two-way communication between vehicles and their environment (e.g. other vehicles, road infrastructure, and other road users), more exact positioning of the vehicles, and performance of dynamic driving activities by algorithms, etc. Availability and reliability of those technologies determine the pace and the form of automation in road transport.

Before looking into impacts of innovative driving technologies on jobs and businesses, it is important to understand what the automated driving technologies are about. The following sections provide an overview of main components of automated driving systems and outline main technological models on which researchers and innovators in the U.S. and Europe have been focusing their efforts.

B. Automation levels

Automated, autonomous, driverless, self-driving, connected vehicles - these are ubiquitous terms appearing in media, literature and discussions about the future of transportation ecosystem. Establishing clear and consistent terminology is crucial for common understanding and adequate use of different terms and definitions for the purpose of adequate public education and legislative work.

Shladover[xiv] stresses that the term “autonomous” vehicles is not a synonym of “automated” vehicles. Autonomous trucks, by definition, can carry out driving tasks autonomously, that is independently from a human driver or machine intervention and without a cooperation with other vehicles or road infrastructure.

[xii] https:// connectedautomateddriving.eu/cad-knowledge-base
https://trimis.ec.europa.eu/projects

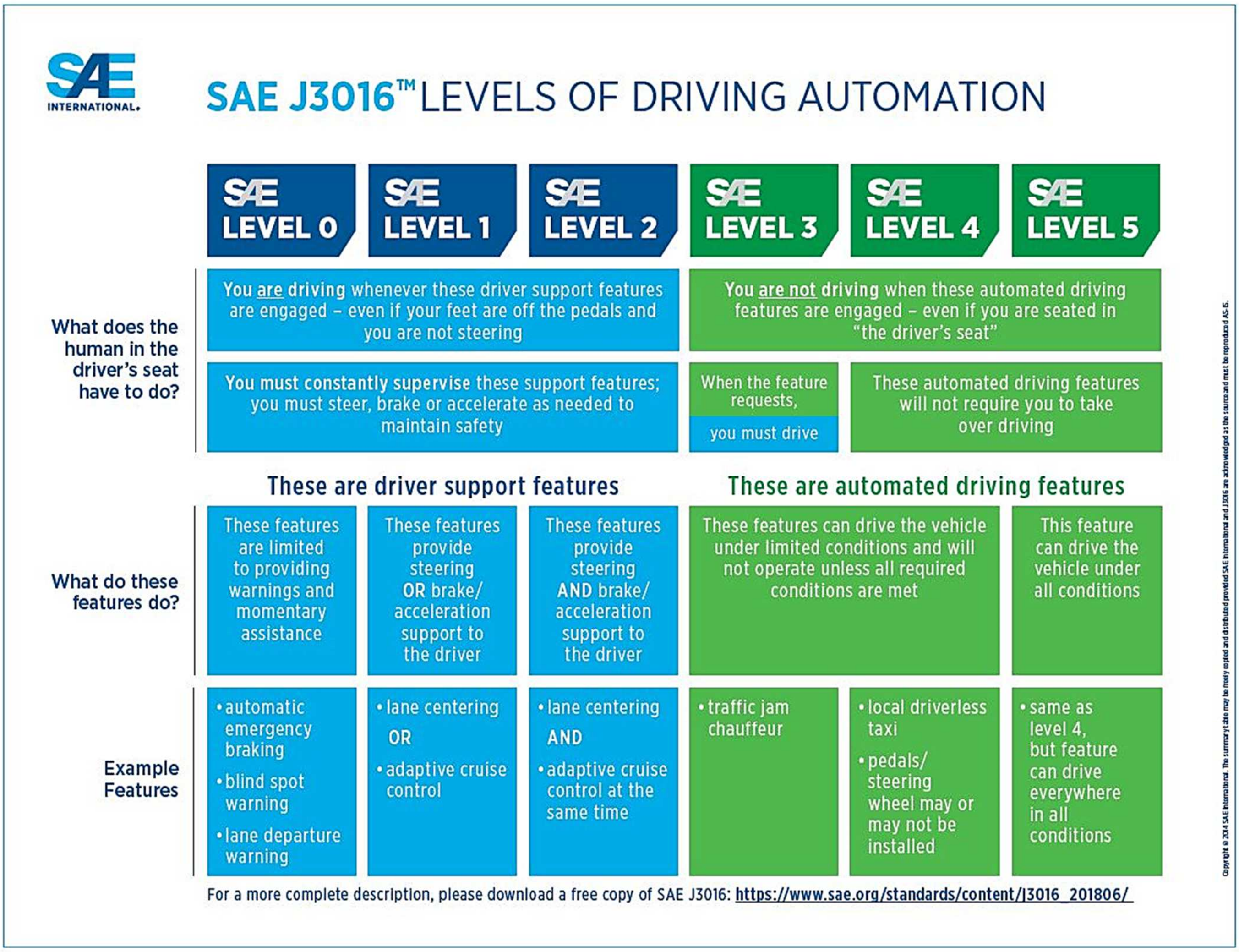
[xiii] The most recent USDOT guidance issued in January 2020 is “Ensuring American Leadership in Automated Vehicle Technologies. Automated Vehicles 4.0”

[xiv] The interview with Dr Steven Shladover, October 29, 2019Dr. Dr Shladover has been researching road vehicle automation systems for more than forty years, beginning with his masters and doctoral theses at M.I.T. in the 1970s. He is the Program Manager, Mobility at the California PATH Program of the Institute of Transportation Studies of the University of California at Berkeley.

For the purpose of this report, I suggest to rely[xv] on the automation levels established by the Society of Automotive Engineers (SAE)[xvi] to distinguish among the different concepts. The SAE definitions are precise about what roles are performed by the machine and by the humans.

Figure 1 below presents the illustration of SAE standard vehicle automation levels, from no automation (level 0) to full automation (level 5), and used worldwide by the road transport automation community. The updated SAE J3016 standard adds an explanation of the features in each of the six driving levels.

Figure 1. SAE J3016 levels of driving automation



Source: SAE Standards News: J3016 automated-driving graphic update, January 2019
https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic

Level 0 means **no automation** (eyes on, hands on), where a human driver controls all aspects of dynamic driving tasks, and technologies only support the driving by warning of safety hazards (e.g. lane departure warning, forward collision warning, blind-spot warning, emergency brake), but do not take control away from the driver.

Level 1 means **driver assistance** (eyes on, hands on), where an automated driving system controls one vehicle function – either steering or speed - using information about driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task (e.g. Adaptive Cruise Control, Stop&Go, Lane Keeping Assists, Lane Change Assist).

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xv Wherever the term 'autonomous' appears in this report it comes from the source to which I refer or quote.
xvi SAE automation levels have been defined in 2014 by the Industry standard (SAE J3016)

Level 2 means **partial automation** (eyes on, hands temporary off), where an automated driving system controls both steering and speed, using information about driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task (e.g. traffic jam assist, automated truck platooning).

Level 3 means **conditional automation** (eyes temporary off, hands temporary off), where an automated driving system performs all aspects of dynamic driving task with the expectation that the human driver will respond to a request to intervene (e.g. traffic jam chauffer, highway chauffer).

Level 4 means **high automation** (eyes off, hands off), where driving automation system performs all aspects of the dynamic driving task under certain roadway and environmental conditions, even if the human driver does not respond to a request to intervene (e.g. highly automated trucks in confined areas, in hub-to-hub operations, automated highways operations)

Level 5 means **full automation** (eyes off, hands off), where driving automation system performs all aspects of dynamic driving tasks under all roadway and environmental conditions (e.g. fully automated trucks)

Automated driving systems between levels 1 and 3 of automation supplement driver's capabilities. Automated system at level 4 replaces a driver in a specified context (e.g. only for highway driving, only for day-time driving), and automated system at level 5 replaces a driver entirely, for all driving operations at all times and in all driving conditions. In terms of benefits, it means that trucks at levels 2 and 3 of automation could bring significant improvements in terms of road safety, fuel efficiency and some improvements in driver's working conditions. Trucks at level 4 and 5 of automation, in addition to road safety improvements and efficiency gains, would bring significant labor costs savings to carriers by making drivers redundant. These two use cases of automation would have significant impacts on jobs and employment in the sector.

C. How does an automated driving system work?

The automated truck system has to imitate the human driver capabilities of sensing, thinking and acting in order to perform dynamic driving activity. Just like a human driver, it has to collect information, take decisions based on this information and execute them. The technologies must ensure that the whole system is able to perform the following distinct tasks flawlessly: "seeing" everything that is around a vehicle, "understanding" what it is seeing, "planning" the vehicle path and actual execution.

The general architecture of the automated driving systems consists of the following stages and layers:

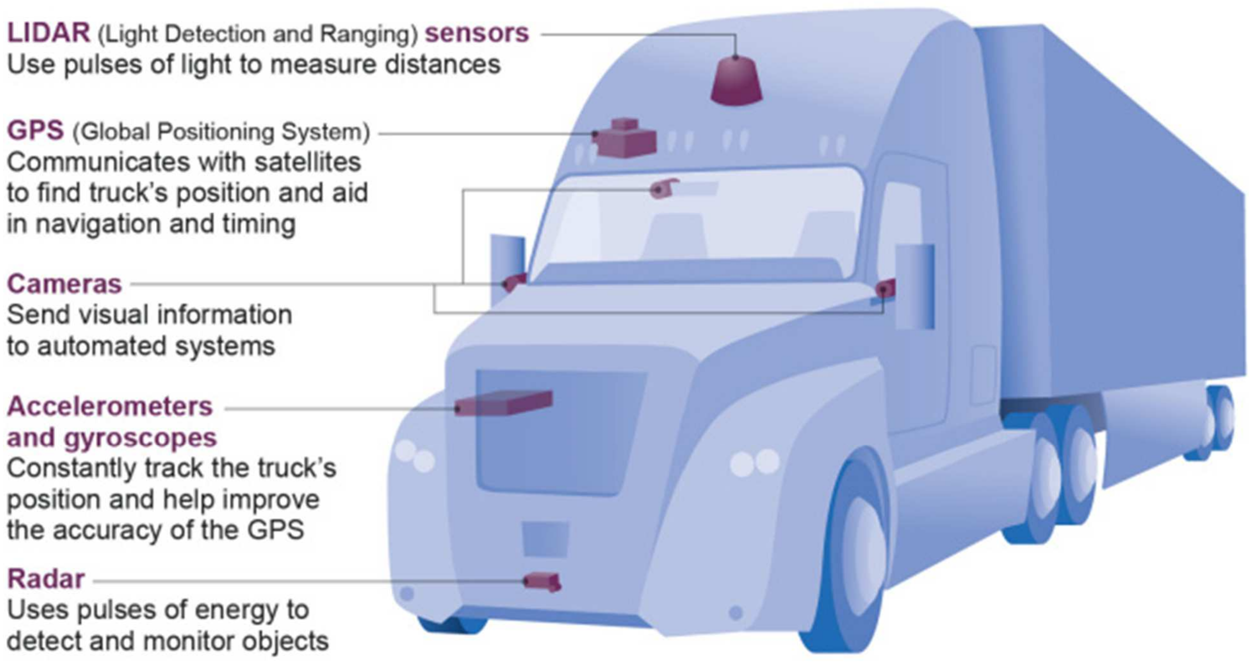
1. **Sensing stage** – observing and scanning the dynamic driving environment, including roadway, signage, other vehicles, road users, objects. This stage includes the localization component informing about where the vehicle is and what the vehicle relationship with other objects around are.
2. **Thinking stage** – interpreting information collected at the sensing stage. This process is composed of three layers: <u>perception</u> – understanding a world around; <u>prediction</u> – understanding the movements of the objects around and predicting the consequences of own and other road users' behaviours; <u>motion planning</u> – combining all data to come up with trajectories. This stage relies on processors, an operating system and algorithms.
3. **Acting stage** – executing the trajectory generated by the motion planning. The vehicle's actuators (breaks, throttle, steering) implement commands from the motion planning.

The currently available technologies that allow vehicles to sense, think and act include: sensor-processing technologies, processing software technologies, high-definitions mapping and in some cases communication technologies. The combination of those technologies and their main components determine the level and form of automation.

Vehicle sensor technologies include cameras, 3D radars, LiDAR (Light Detection and Ranging), night vision systems, infrared sensors, ultrasonic sensors, various motion sensors (e.g. accelerometers) and GPS units. These sensors identify stationary and moving objects and keep track of the lines and edges of the road. They must withstand all kind of weather and vision conditions to scan the environment unfailingly. The consequences of not seeing clearly due to night darkness, glare from approaching headlights, bad weather or dirt on the sensor can be deadly. To improve the performance of the system in poor visibility, researchers work on the use of infrared and thermal sensors. Engineers from Massachusetts Institute of Technology (MIT) are currently trying out a ground-penetrating radar to allow faultless sensing of the environment in bad weather conditions.

The perception system mostly relies on camera systems, which must operate in various light conditions. Perception range is very important. For heavy trucks at highway speed, it takes about 200 m to stop. Therefore, perception range should be long enough to ensure safe stopping. Some companies are already testing long-range perception systems. For instance, Plus.ai (automated trucking software start-up) technology involves a fusion-based perception system allowing automated trucks to track vehicles 1 mile (ca 1600 m) ahead and 800 feet (ca 244 m) behind. Another start-up TuSimple developed a camera system with night driving capabilities and ability to detect and process sharp images in real-time as far as 1,000 meters away. Waymo applies an omnidirectional LIDAR system comprising of short-range, high-resolution mid-range and long-range LiDARs. Based on the data from LiDARs' beams it creates a 3D map of the surroundings.

Figure 2. Main types of sensors in automated trucks



Source: Automated Trucking. Federal Agencies should take additional steps to prepare for potential workforce effects. GAI, March 2019

Researchers are exploiting the vulnerabilities of highly automated driving perception systems to external manipulation in order to alarm technologies developers. For instance, camera-based perception systems can be tricked by putting stickers on traffic signs to completely change their meaning. The LiDAR system can be fooled by shining its own light at the LiDAR's sensor. This can lead to an immediate halt of a moving vehicle "thinking" that an obstacle appeared in its pathway.

Connected vehicle technologies enable mutual communications with other vehicles (vehicle-to-vehicle, V2V), with infrastructure (vehicle-to-infrastructure, V2I) or with the entire environment (vehicle-to-everything, V2X). This system relies greatly on wireless networks (WiFI, mobile network, ITS G5) and cloud computing which are key enablers of real-time two-way communication. Except from on-board sensors, it requires road infrastructure with traffic and environmental sensors to support and guide automated vehicles. The current leading vehicle communication technology is "dedicated short-range communications" (DSRC). It enables exchange of safety-critical and time-critical information between roadway infrastructure and vehicles. In the US, the use of this technology for V2X communication has been tested in specially created Connected Vehicle Test Beds (e.g. Test Bed in Palo Alto, California, the nation's first testbed using signalized arterial roadway corridor with several intersections for testing traffic control systems and V2X communication). In Europe, the ECoAT project aims at the deployment of connected Intelligent Transport System (ITS) services on a testbed corridor linking the Netherlands, Germany and Austria[18].

Some developers (e.g. TESLA, TuSimple) prefer to develop stand-alone highly automated technologies without reliance on road infrastructure supporting their automated driving systems. As automated trucks cannot use the sensing information from external information sources (supporting road infrastructure), they need highly advanced sensing, thinking and processing technologies on-board the vehicle.

Other developers consider connectivity a crucial element for increasing safety and efficiency of automated driving system (e.g. Peloton uses V2V communication in its platooning system). Although requiring significant physical and digital infrastructure investment, researchers and some developers consider V2X communication a prerequisite to higher-level automation because it allows for a reduction of the number of necessary on-board sensors and enables system coordination. For instance, connectivity allows fleet managers to spot a problem if a truck operates outside normal parameters and take action prior to a breakdown. The challenge is to ensure connectivity in all geographic and weather conditions and design a fallback system for cases of mobile or satellite connectivity breakdown. To enhance connectivity in the future, researchers look into a possibility of using 5G mobile network and other communication technologies.

Processing software technology is necessary to process huge amounts of information gathered from sensors and communication units. The challenge is an accuracy in predicting all possible traffic scenarios to feed into algorithms allowing the automated system to react correctly and swiftly. Machine learning must cope with large, uninterpretable modalities, such as unpredictable behaviour of other road users and interaction with a highly complex transportation ecosystem (traffic lights, crowded intersections, road works, etc.).

Table 1 summarizes main technologies and their components currently used or explored for use in various trucking automation models.

Table 1. Example automated and connected vehicle technologies in on-road heavy-duty trucking

Technology	Components	Description
Sensors	Cameras	Used to identify other objects using visible light. Cameras have limitations compared to other sensor technologies and function poorly in darkness, extremely bright light, and certain weather conditions.
	Radar	Used to identify the velocity, direction, and distance of other objects by emitting high-frequency radio waves.
	LiDAR	Considered the most reliable and robust sensing technology. LiDAR measures the range and speed of objects using reflected light. Range and speed are measured based on the time that laser light takes to reflect. LiDAR systems can process and record images. (National Highway Traffic and Safety Administration [NHTSA], 2013).
	GPS	Used to identify vehicle position and velocity by communicating with satellite signals.
Communications	DSRC	Dedicated short range communications (DSRC) is two-way communications in 5.9 GHz band that allows for high data transmission over a moderate range. DSRC allows for V2V and V2I communications which can send messages and provide alerts to drivers in real time. The U.S. Department of Transportation (DOT, 2017a) considers this technology the basis for intelligent vehicle safety application integration.
	5G	The 5th generation wireless systems currently under development will allow for higher capacity and better coverage with less latency. 5G is expected to support device-to-device communications with increased reliability. 5G is believed to be a promising communications technology with applications for connected and autonomous vehicles within the next decade (National Academies of Sciences, Engineering, and Medicine, 2017).
Software	Algorithms, artificial intelligence	Millions of lines of software code enable autonomous and connected trucking. Computing software systems are used to process images captured from sensor technologies, interpret communications messages from other vehicles or infrastructure, and control vehicle functions in real time. Software refinement and validation is considered a much larger challenge than deploying sensor and communication hardware (Tesla, 2016).

Source: "Automation in the long haul: Challenges and opportunities of autonomous heavy duty trucking in the United States." Peter Slowik and Ben Sharpe, March 26, 2018

Hardware and software in the automated driving system must work in cyclical fashion, with the shortest possible response time and highest possible accuracy. A lag in reaction in a moving truck is a matter of life and death. For researchers and technology developers, safety is a primary objective and it is the most difficult one to achieve and to prove. Technological challenges are still huge and must be overcome before fully automated trucks are able to operate safely and reliably on public roads. Researchers and developers are working on making the system smarter, faster and more reliable by, for example, integrating emerging technologies such as deep and reinforced machine learning.

D. Application of automation technologies

Sensors, communication, and processing software enable a variety of vehicle applications. Several of these technological applications are already in commercial use, such as blind spot monitoring, adaptive cruise control, lane departure warning, lane-keep assistance and forward collision warning, etc. These technology applications are referred to as Advanced Driver Assistance Systems (ADAS) because they help a human driver in carrying out safely and comfortably the dynamic driving tasks.

For instance, Volvo Trucks offers enhanced emergency braking systems with collision warning using the sensor fusion technology. The system enables stopping of the vehicle up to a speed of 70 kmph to prevent collisions.

Currently ADAS technologies are used in trucks level 0, 1, 2 for commercial operations. Further advancements in the quality of sensors, communication units, algorithms and processing software will enable more robust technology applications and a higher level of automation in future.

Here is the overview of main current and future technology applications in trucking:

Lane departure warning – (level 0 technology) this system warns a driver when there is a risk of the vehicle unintentionally drifting outside the lane. It is level 0 technology (only alerts a driver and does not take over a control over driving) and is commercially available.

Automated lane keeping – (level 1) the system detects the lane markings and monitors vehicle position within road lane markings. If the vehicle starts drifting off the lane, the system corrects the lateral (steering) direction automatically.

Blind spot monitoring – (level 0) detects if other vehicles are located in driver's blind spot and notify the driver.

Automatic braking – (level 0) detects the speed and distance of vehicles ahead and automatically applies the brake, if necessary. It is level 0 technology because the control over braking is not continuous but take only for a brief intervention. (In Europe, automated emergency braking system is required on all new trucks since 2015)

Eco-driving system – (level 0) monitors human driving and informs driver how to achieve better fuel efficiency, for instance by moderating speed on highways and by smoothing acceleration and braking.

Adaptive Cruise Control (ACC) – (level 1) uses radar or lidar and ranging sensors to measure the distance and speed of vehicles driving ahead and to automatically adjust the vehicle's speed, controlling throttle and braking, in order to maintain a gap (distance between the vehicle and other vehicles ahead) set by a driver.

Predictive cruise control (PCC) – (level 1) combines ACC with GPS and topographical data inputs, changing vehicle speed to optimize performance in different types of terrain (e.g. hills, winding roads).

Traffic jam assist – (level 2) controls the longitudinal (braking and accelerating) and lateral movements of the vehicle to adapt to the traffic flow in low speeds below 30 km/h.

Traffic jam chauffeur – (level 3) conditional automated driving in congested traffic of up to 60 km/h on freeways. The system controls longitudinal and lateral movements of the vehicle to adapt the speed. The driver must activate the system and can switch it off at all times. The system does not prompt the driver to take over.

Cooperative Adaptive Cruise Control (CACC) – (level 1) combines three driver assist systems: (i) conventional cruise control, which automatically maintains the speed a driver has set, (ii) ACC and (iii) V2V communication, currently dedicated short-range communication (DSRC). Thanks to V2V communication, the system transmits and receives data with surrounding vehicles enabling the cruise control system to respond swiftly to changes such as speed and location of other CACC vehicles. Vehicle-to-vehicle communication enables automated coordination of vehicles movements and longitudinal adjustments through throttle and brake activations.

Platooning – (level 1, 2, 3, 4) – linking two or more trucks in convoy, using connectivity technology (V2V communication) and automated driving support system (CACC). The system allows maintaining the close distance between the lead truck and the following trucks, which adapt automatically and swiftly their speed to the changes in the movements of the lead truck. In level 1 truck platooning the system automatically maintains a constant time gap or clearance distances between the trucks (longitudinal control) and the driver remains in control of steering (lateral control). Level 2 truck platooning adds automatic steering control. This enables shorter longitudinal gaps, which is difficult to achieve with manual steering, as drivers have very limited visibility to steer confidently. Platooning functions may be applied in all levels of automation. Levels 3 and 4 trucks may be platooned with the lead trucks at a lower level of automation, provided that it is equipped with V2V communication technology.

Highly automated trucking (level 4) – this system can operate without human intervention or in cooperation with other vehicles (platooning), in limited environments (so called ‘geofences’), such as dedicated areas, highways, port hubs. Highly automated vehicles are not yet commercially available for the use on public roads, but they already operate in some off-road areas, such as mines or ports.

Remotely controlled trucks (level 3 or 4) – this system builds on highly automated driving system and connectivity technologies enabling remotely controlling the automated driving operation of the vehicle by an operator in a remote control centre. This technology can be used to control the entire route of the conditionally automated truck (level 3) or only for the first and last mile part of the route, while allowing the highly automated truck to drive itself on highways without an intervention of a remote operator (level 4).

Fully automated trucks (level 5) – the system can handle all dynamic driving tasks for the entire route and in all environmental, weather and traffic conditions.

E. Approaches to developing automated driving technologies

Researchers and developers vary in their views on feasibility, trustworthiness and economical attractiveness of potential applications of automated driving technologies. While some developers aim at **level 5** trucks (e.g. Plus.ai), because they promise the highest return on investment (economic gains due to elimination of labor costs and increase of the fleet use), researchers and other developers are doubtful that this technology will ever be applied in the trucking industry. For instance, Waymo and GM do not foresee investment in fully automated vehicles. They consider that it makes no economic sense to heavily invest in very difficult to achieve fully reliable fully automated (level 5) driving technology, which will not bring much greater gains than level 4 trucks.

For researchers the main problem is safety of the fully automated driving technology. It is extremely hard to measure and to prove that the machine is safer than a human driver is. In the U.S. there is about one death for every 100 million miles driven. Gathering enough data indicating that fully automated trucks are safer than conventional trucks would require hundreds of millions or even billions of miles of testing on public roads. Shladover estimates that, based on technological feasibility, level 5 (fully automated) trucks will not be introduced on the market before 2075 (if at all).

The question of safety is relevant also for lower level of automation technologies. Technologies may eliminate human error (main cause of accidents), but system failures with deadly consequences may occur if the technology is prematurely deployed in the real world environment. At the end, no driving system, like any navigation or aviation system, be it manual, partially automated or fully automated, can be 100% safe. The question is how safe is safe enough to decide on a commercial deployment of automated driving technologies.

Another concern related to the deployment of level 5 trucks is about the limitations of an automated decision-making system. Indeed, technology does not get tired or distracted but, on the other hand, it does not have common sense and thus cannot replace a driver’s instinct. This instinct and common sense is sometimes necessary to anticipate certain events and other road users’ behaviours to take an instant decision allowing a safe, even if not always lawful, manoeuver.

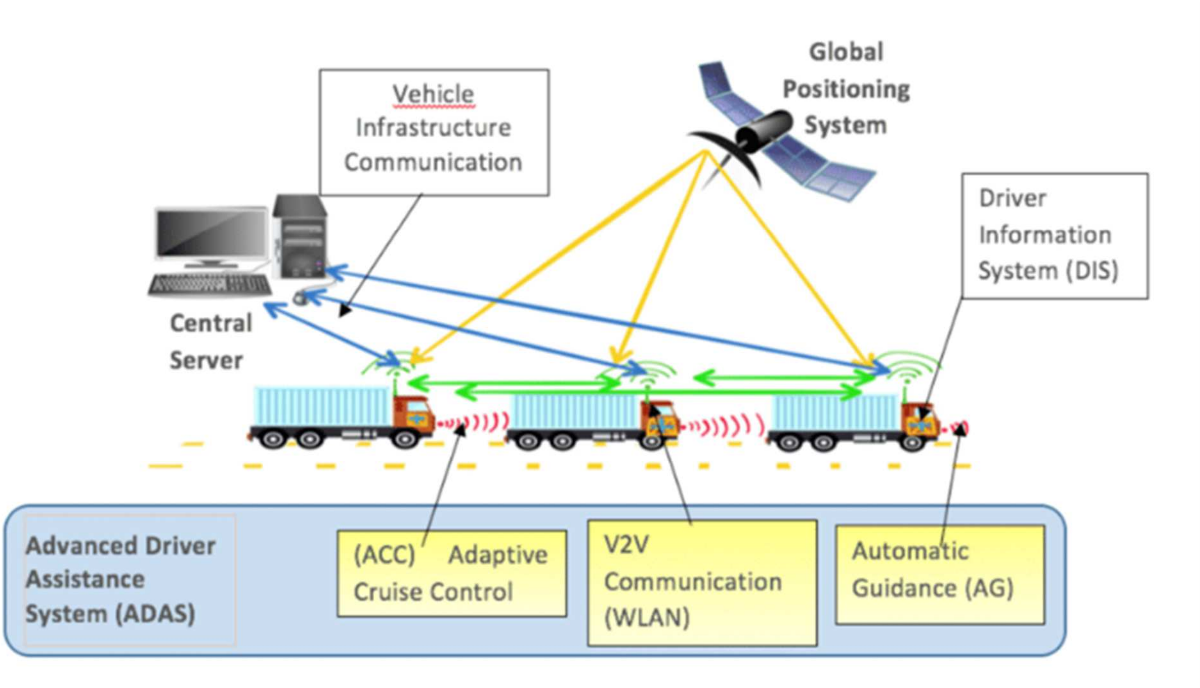
For example, due to a mechanical breakdown a delivery truck is partly blocking the road. A fully automated (level 5) truck approaches from behind the truck and stops. There is no traffic coming either way so the fully automated truck could go around the truck blocking the lane, but to do it would have to cross a double line on the highway. Since this operation is against the law, the fully automated trucks will not pass and will wait until the other truck is towed away.

The majority of investors and technology developers focus their current work on **level 4** trucks. TuSimple is the unicorn among level 4 trucks technology developers. Both in the US and in Europe developers concentrate on the use of highly automated trucks in specific restricted operation domains, in particular on highways and confined areas such as ports or open-air mines. The key challenge will be to expand the geographical (roads types, traffic conditions) and environmental (weather conditions) operating domains, in which the technology would be capable to drive safely.

Some researchers and technology developers consider that **level 3** automation should be skipped (e.g. TuSimple, Daimler Trucks). The main reason is the problem of human-machine interaction. This level of automation requires that a human driver is receptive to intervene and become the driver when the automation system cannot manage a situation that it encounters. Waymo sees level 3 autonomy as an infeasible engineering solution, because of the difficulty in safely handing control of the vehicle back and forth between an algorithm and a human driver.

Others find the most feasible technology application in **platooning** at different automation levels. In the U.S., Peloton is the lead developer of platooning technology. Peloton’s PlatoonPro technology uses V2V communication to connect the braking and acceleration between two trucks level 1 and 2 automation (so-called first generation platooning). The V2V link allows the truck to control the acceleration and breaking of both trucks at the same time, reacting faster than a human or even radar sensor could. Its technology also allows for coupling and decoupling with other trucks in the platoon, when necessary. Its latest technology called AutoFollow allows for connecting a human driven truck as the lead truck with the following driverless trucks at level 4 automation (so-called second generation platooning). A professional driver controls the lead truck, and V2V connectivity between trucks enables automated systems in the following truck to steer, brake, and accelerate using electronic signals from the human-driven lead truck.

Figure 3. An illustration of a platoon system



Source: "Automatic Truck Operation on Highways" Nji Sama Chifen, March 2017

Yet others consider the **remote driving** technology (e.g. Starsky Robotics, Einride) the right application, since in addition to improvements in road safety it also promises enhancement of working conditions by letting drivers operate trucks remotely from control centres and return home every night. In the U.S. the Californian Start-up Starsky Robotics was the pioneer in developing this technology, but after 5 years it closed down its business in January 2020. Starsky has not managed to raise sufficient funds for further work on its remote driving technology, whereas in the same year (2019) TuSimple has raised $215 million for developments of highly automated driving technology. It may seem that investors in the U.S. are more interested in funding development of driverless trucks, which promise big savings in labor costs. At the same time, in Europe, Einride gains investors' attention by successful demonstrating their remote driving technology, which allows one person to operate remotely two electric and automated trucks (called Pods) at once. The demonstration showed a potential of this technology to perform complex maneuvers, parking and pulling out from busy hubs. Einreide's goal is for a single operator to monitor and control remotely up to ten trucks.

Some experts regard remote driving a bridging technology between manually driven trucks and a fully automated model. Others consider it extremely dangerous as a remote driver can never have a full and instant sensing of the truck's driving environment.

Among numerous developers working on self-driving technologies for road freight transport, a few consider applying these technologies to **local deliveries** in urban areas. The work focuses on small electric delivery vehicles carrying small cargo, navigating on city streets at very low speeds (up to 25km/h). For example, in Berkeley, California, the first fully utomated, four-wheel robot Kiwi has appeared on the pathways of the campus of the University of Berkeley and the surrounding streets to deliver food.

www.kiwibot.com

In 2019, the new start-up Nuro, commenced testing its highly automated electric vehicle designed for small local contactless deliveries and used on the streets of some Californian cities (e.g. Mountain View, Palo Alto). It is the second company, after Waymo, which received permission from the California Department of Motor Vehicles to test a vehicle without a driver on public roads.

Source: https://nuro.ai/product

None of the above-mentioned technological applications are (yet) foolproof and immune from attacks. All of them have their advantages and downsides. In the next chapter, I will present a few scenarios for the application of the automated trucking technologies which appear to be most feasible from the technological perspective and desirable from the economic and social viewpoint.

IV. Scenarios for the deployment of automated trucking technologies

How close or how far are we to large-scale deployment of automated trucks? Some successful self-driving technology demonstrations would suggest that highly automated trucks are on the verge of commercialization. At the same time technological deficiencies revealed at test runs or simulated runs indicate that the technology is not ready for the commercial use to any verifiable degree of safety.

Despite the technological barriers and other uncertainties (regulatory, infrastructural, operational, and financial), some researchers and industry stakeholders have tried to predict when the automated driving technologies will be available for commercial use in the trucking sector. Here are some of those predictions:

- Organisation of Economic Cooperation and Development with International Transport Forum (OECD/ITF, 2017) envisage four scenarios. In the most optimistic scenario, driverless technology will be available for long-distance routes beginning in 2021 and in cities from 2022, while in the most prudent scenario driverless trucks will be deployed for long-distance routes as of 2030 and in urban areas from 2033.
- Dutch research organization TNO (2016) claimed that the highly automated (level 4) platooning operations would be carried out on the European motorways by 2025.
- American Trucking Associations Technology and Maintenance Council (2015) predicted that Level 3 trucks would most likely be deployed within a decade.
- McKinsey&Company (2018) estimated that fully automated trucks would roll out in four waves, where human-driven trucks platooning would be commercially available as of 2018, human –led platooning with following driverless trucks as of 2022, driverless trucks on interstate highways (constrained autonomy) and in platoons as of 2025, and fully automated trucks on all highways and in platoons as of 2027.

These guesstimates confirm a huge uncertainty about what type of technological configurations will be commercially available on the market and when. The four decades of research and testing and a gradual introduction of technologies show that automation in the trucking industry is an evolution rather than a revolution. Innovation is not about moving forward recklessly. It has to follow a build–test–learn cycle to deploy innovative solutions in the real world safely and effectively.

A. Main use cases of automated trucking technologies

In the highly diversified trucking market, no one automated trucking technology is a silver bullet to address all challenges of all trucking segments. Platooning technologies, level 4 stand-alone trucks, remotely controlled driverless trucks or level 5 trucks can be used in different configurations and operating domains depending on the type of freight transport operation and business model.

Three main types of technology applications seem to attract the most attention, efforts and funds from researchers, developers and industry stakeholders. The focus is mainly on platooning (with gradually increasing automation level), highway automation (with driverless trucks on highways) and remotely controlled driverless trucks.

Viscelli[19] in his report establishes six potential scenarios of adopting automated trucks technologies. All of them involve the application of the automated driving technologies in highway operations, and some add the use of automation technologies for operations in local areas.

For the purpose of analyses of the implications of automation technologies on the trucking workforce and businesses, I propose to consider eight business use cases, which build on Viscelli's scenarios and on my attempts to respond to the following key questions:

- What is the maturity level of technology?
- Which technological configuration is most desirable from the business and societal perspective?
- What are the most feasible incremental pathways?

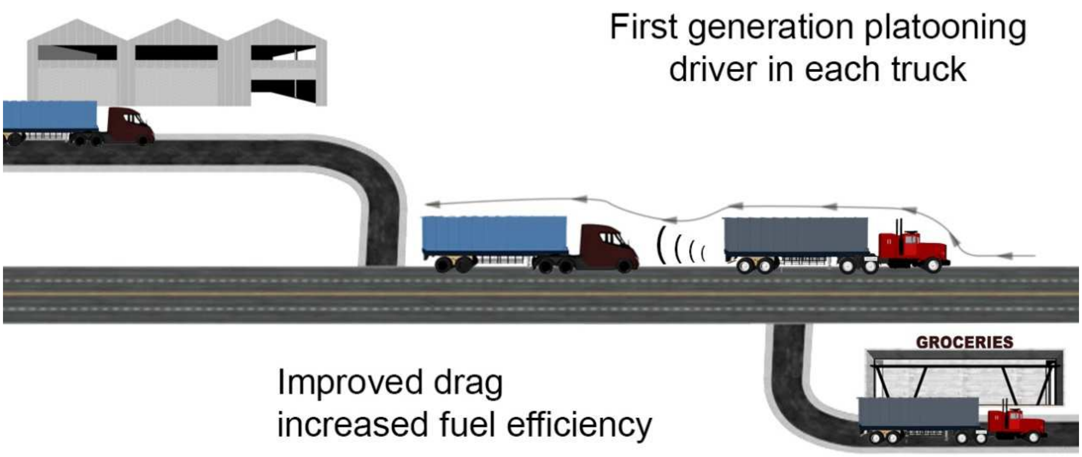
To respond to these questions I have reviewed the existing literature as well as industry news and interviewed several experts, researchers, automated technology developers, freight carriers' associations and truckers' organisations. I have also participated in the demonstration of platooning technology on the public roads in the Bay Area, organized by PATH, UC Berkeley.

The proposed eight business use cases have to be considered within the following caveats: evolving uncertainties about the technology's future (e.g. technological and regulatory hurdles), diversity of freight transport operations and growth in e-commerce in the post-pandemic era (the magnitude of effects of the lockdown due to COVID-19 is not yet known).

Use case 1: First generation platooning (on highways with low-level automation trucks)

This case involves trucks at low automation level (level 1 or 2), equipped with Cooperative Adaptive Cruise Control system (CACC, including Forward Collison Avoidance and Mitigation), which allows them to drive in convoy following each other at short distances (typically between 15 and 20 meters). CACC uses V2V communication/coordination enabling linking the braking and acceleration systems of the following trucks with the lead truck thereby maintaining a constant time-gap between the trucks. With level 1 automated trucks, the human driver in the lead truck drives normally, and drivers in following trucks keep control over steering (lateral control), but they have feet off pedals, as the system tries to follow the movements of the leaders as regards braking and accelerating (longitudinal control). If an automatic steering controls system is added (level 2), the drivers in the following trucks can take their hands off the steering wheel as well. At all times during the automated driving mode, the driver can override the steering, the brakes and the acceleration.

If vehicles are cutting into the platoon, a truck can disengage from the platoon without a human driver's intervention. A forward-facing video feed from the lead truck enables the following truck driver to see the traffic ahead of the lead truck. The system relies on robustness of V2V communication to ensure that following trucks are in contact with the lead truck. This use case concerns long-haul operations on highways solely, as driving in platoons on busy and tight city roads is neither physically possible nor economically desired. As CACC communication also allows for ad hoc forming/joining and dissolving/leaving platoons, there would be no necessity of establishing special staging yards or dedicated space at parking lots at the entry of highways where trucks could gather in order to form platoons.



Platooning technology has been tested for almost two decades now. These tests have proven several benefits. The most noticeable and immediate economic benefit is fuel savings. Several tests of truck platoons done by Peloton showed that, thanks to reducing the aerodynamic drag between the trucks following each other closely, the reduction in fuel consumption is about 4.5% for the lead truck and 10% for the following trucks.

Platoons can also increase road capacity as connected-in-platoons trucks keep a distance of around 15-20 meters instead of 50 meters. This can reduce road space requirements by half.

The Peloton's platooning technology (PlatoonPRO) also includes Network Operations Cloud (NOC) technology which provides the possibility of finding platooning partners on the road. NOC enables drivers to pair trucks or dissolve platoons at any time in response to changing weather, traffic, truck, or other conditions.

The technology should also help improve road safety thanks to instantaneous reaction of the connected automated braking system compared to the human reaction in case of emergency breaking. For instance, Daimler's Highway Pilot Connect system transmits a signal in only 0.1 second while it takes around 1.4 seconds for the human driver behind the wheel to react if a car brakes in front.

Platooning seems to be a perfect fit for long-haul exit-to-exit and hub-to-hub highway operations in which drivers run regular out and back routes.

There are still some challenges which developers and manufacturers are trying to solve to ensure that technology is ready for commercialisation. These concern connectivity issues, compatibility of different platooning systems to enable coupling multi-brand trucks as well as drivers' acceptance and other road users' behaviour. On the one hand platooning may improve driving experience thanks to enhanced communication between drivers, which creates a sense of teamwork. On the other hand, following a truck at a very short time-gap driving with a highway speed may be stressful.

Public acceptance is also a concern. Some platooning tests revealed that passenger car drivers behave dangerously by cutting-in aggressively between the platooned trucks. The connectivity failures and vulnerability of V2V communication to hacking and other cyber-attack is a remaining challenge. The manufacturers collaborate with telematics providers to work out secure and robust connectivity solutions.

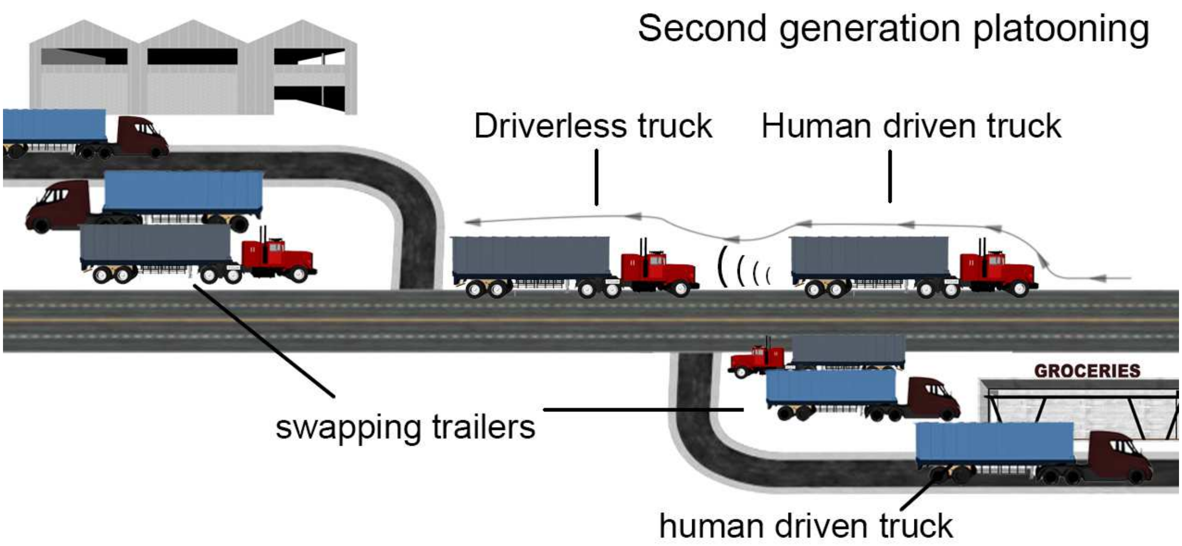
Compatibility of platooning technologies is more of an issue for the European carriers than the American ones. In the U.S. big carriers, who will be most likely early adopters of this technology, have enough trucks of the same brand to be able to form a convoy. In Europe, there is a predominance of small fleets, which do not have large numbers of a single brand trucks. It is less probable that carriers can find load for two or three trucks of the same brand, which should go on the same routes at the same time. The on-going European project ENSEMBLE focuses on developing EU standards to enable multi-brand platooning by creating a multiband V2V communication protocol.

Overall, potential significant benefits of fuel economy, road congestion, safety and relative maturity of technology suggest that the first generation platooning may be deployed for commercial operations rather soon.

Use case 2: Second generation platooning (on highways with highly automated following trucks)

In this business use case, a platoon is formed of a human-driven truck (at least level 1) followed by highly automated driverless trucks (level 4) to drive in synchronicity on highways. The lead human-driven truck communicates and coordinates driving tasks with the following driverless trucks via V2V networks, wireless communications, sensors and artificial intelligence. In platoon, the human driver in the lead truck drive snormally and the following driverless trucks try to follow the movements of the leader as regards steering, accelerating and braking. V2V connectivity between the trucks allows automated driving systems in the following trucks to steer, accelerate and brake using the instant signals from the human-driven lead truck. When the driverless trucks leave the platoon or are disconnected they can drive entirely as stand-alone highly automated trucks.

This use case requires that driverless trucks operate only on highways. This means that a local driver has to bring a truck (or a load by conventional truck) to a dedicated space (e.g. staging yard) at the entry to the highway, where highly automated trucks can join a platoon or from where they can drive stand-alone on the highway to join the platoon on the road. After finishing the highway part of operation, the load can be again taken over by local drivers at a dedicated space (staging yard) at the exit from the highway, in order to carry the load to its final destination. This use case envisages two possibilities: (i) a human driver drives a highly automated truck on manual driving mode on local roads to/from the staging yard, or (ii) a human driver brings a trailer with a conventional non-automated tractor to the staging yard, uncouples the trailer and couples it with a highly automated tractor, which carries the load over the long distance.



The leading platooning technology developer in the U.S. – Peloton – offers its AutoFollow system which enables forming human-led platoons with driverless following truck. According to Peloton, their technology will double the driver's productivity by doubling the amount of freight one driver can haul in one trip. This is possibly the most significant economic advantage of the Autofollow technology, but not the only one. Others concern fuel savings and increased efficiency of the fleet use, mentioned in the previous platooning use case.

Human-led auto-follow platooning would help address the issue of shortage of drivers, as less drivers would be needed to carry out the same amount of freight. It is even more important in the context of forecasted increase in demand for freight transport and projected growing shortage of drivers, both in the U.S. and in Europe.

In terms of jobs and working conditions, the technology would require an increase in driver's skills, in particular in the field of operating and controlling automated driving systems. The driver in the lead would be responsible for operating a combination of trucks and for the security of freight and of equipment. The increased responsibility and increased competencies would make the drivers more valued. Some long-haul jobs would disappear or would be shifted to local deliveries, where more drivers would be needed to bring highly automated trucks (or the load) to and from the dedicated yards near highways.

In terms of safety and security of transport operations, having a human driver in the lead truck would help to address the problems of weather conditions or unexpected incidents on the highways, in which case stand-alone highly automated trucks could have problems with safely continuing the journey. Also in case of breakdowns, fueling and other maintenance and control tasks, it is more beneficial to have a human driver overseeing the whole system and reacting appropriately.

Contrary to the previous use case, this scenario requires a specific infrastructure such as dedicated yards near the highways where driverless trucks could be brought/taken over by local drivers for first/last mile delivery carried out in more complex driving environment (urban/rural roads).

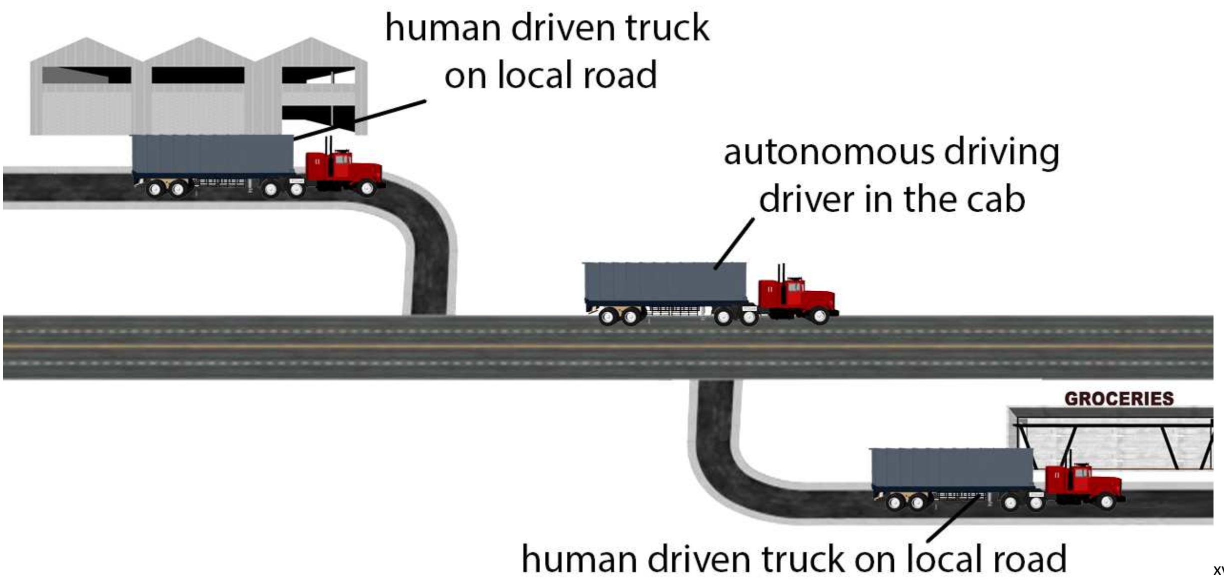
Use case 3: Conditionally automated trucks

This case involves conditionally automated trucks (level 3) which drive in cooperation with a human driver for the entire route. The driver would drive the truck manually mainly in local areas and would switch on the automated driving mode when driving on highways provided there are good weather and traffic conditions. The driver would have to stay behind the wheel being alert all the time and ready to take over the dynamic driving tasks when the system prompts to do so.

Economic benefits of this technology application are minimal. Driving fluency could slightly improve fuel consumption, but the largest cost – labor – would remain unchanged. There is also no expectation of productivity gains. The machine-human interaction remains a big challenge which puts into question possible improvements in safety and working conditions. Therefore, there is not much interest in the trucking industry to invest in this technology, even if some could see level 3 trucks as the bridging technology between human-driven trucks (level 1 and 2), and driverless trucks (level 3 and 4).

Use case 4: Exit-to-exit highly automated trucks with a human driver in cab

In this use case the highly automated truck (level 4) operates stand-alone on highways, and a human driver takes over full control for driving in local areas, in difficult weather and performs other tasks such as fueling, loading/unloading. Unlike in the preceding use case, the human driver is constantly on board the truck, but does not need to remain behind the wheel. The driver may as well sleep in the bunk while the truck is driving in highly automated mode on highways.



[xvii]

This use case would not have significant impacts on employment and would not bring major labor costs savings for operators. It could speed up the goods delivery as the truck could continue driving while the

[xvii] 'Autonomous' driving mode should be understood here as a stand-alone automated driving, not requiring human driver's intervention (or even a presence) and not relying on cooperation (via wireless communication) with other vehicles or road infrastructure.

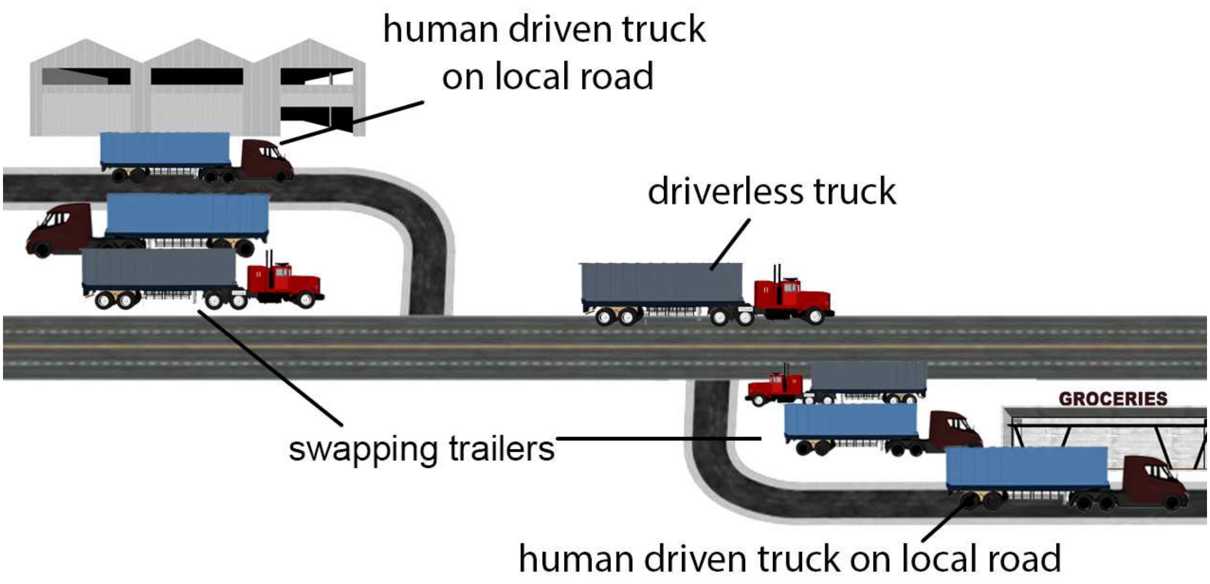
human driver rests in the back of the cab. Quicker and more frequent deliveries would increase truck and driver productivity so carriers could have efficiency gains.

On the one hand, driving the truck on long-haul routes in this use case seems less demanding and tiring for the human driver, as a majority of the journey the driver would spend inactive and/or in the sleeping berth. On the other hand, spending several continuous hours in the moving truck, being constantly exposed to vehicle's noise and vibrations, would have detrimental effects on driver's health and safety.

This use case would also require substantial regulatory changes concerning driving and resting times of drivers, and in particular changes of definitions and calculation of rest, break and work periods. Currently the EU law forbids taking a rest in a moving truck. The potential benefits from level 4 trucks would be very modest if the same rules on driver's hours continued to apply without any changes.

Use case 5: Exit-to-exit highly automated trucks and human-led truck for first/last mile delivery

In this use case, level 4 automation trucks would operate stand-alone only on highways, starting and ending at the areas adjacent to the highway. This use case requires that a human-driven conventional tractor pulls the truck trailer between loading/unloading point (e.g. distribution centre, intermodal hub, production facility, etc.) and the staging yard at the entry/exit of the highway. At the staging yard the driver swaps the conventional tractor with level 4 automation (driverless) one, which then transports the cargo on long distance on highways.



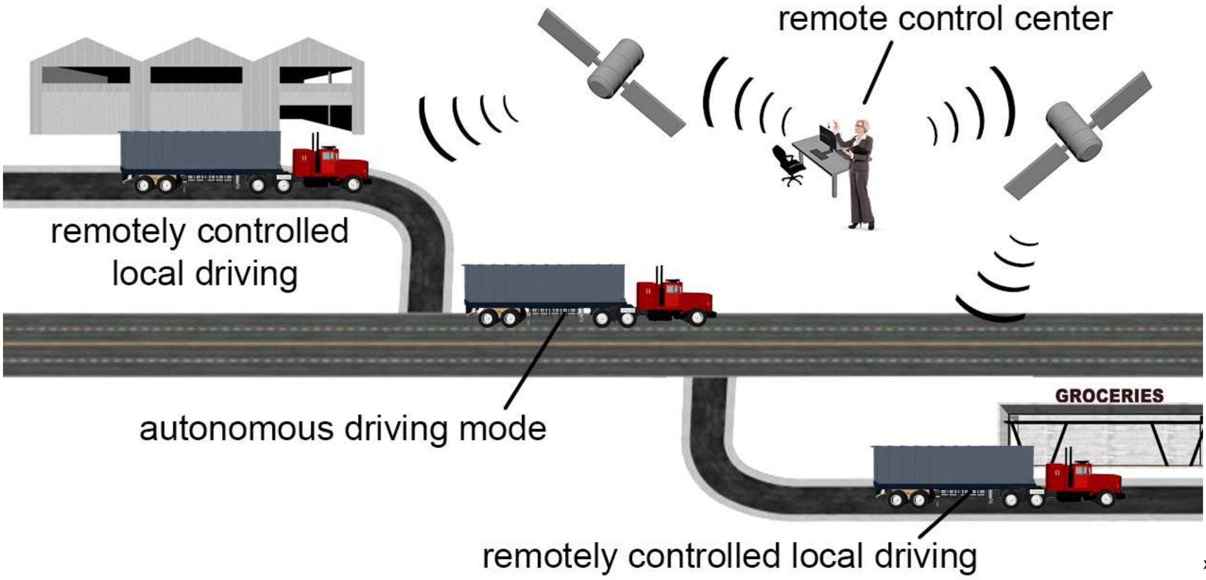
This technological application would have tremendous impacts on jobs, creating labour cost savings for carriers by eliminating long-haul drivers. It would also significantly increase productivity as highly automated trucks could drive constantly on highways without obligatory breaks and rest periods of fixed minimum duration, which human drivers have to take when driving a truck. This use case would increase the need for short-haul drivers and for operators at the staging areas.

Improved driving efficiency and safety are also great advantages of this technology. A study carried out by the University of California in San Diego revealed that highly automated trucks (using self-driving technology of TuSimple start-up) reduce fuel consumption of heavy-duty trucks by 10-20% compared to the fuel use of traditional trucks.

Main developers focusing on this use case are: TuSimple, Waymo, Aurora, Uber ATG, Plus.ai. TuSimple intensively tests its self-driving technology by performing commercial operations with level 4 trucks for its main customer UPS. All these commercial test operations are carried out with a human safety driver and a technology engineer in the cab.

Use case 6: Exit-to-exit highly automated trucks with remotely controlled local operations

In this use case highly automated trucks (level 4) would drive stand-alone on highways, starting and ending its journey at staging yards at the entry/exit of the highway. Human operators in control centres would remotely operate those trucks for the part of the journey on local roads. The remote drivers (operators) would also have to be available to take over remote control of dynamic driving tasks on highways in case of bad weather conditions or other circumstances, which make it impossible to continue driving in automated mode.



xviii

Such a combination of level 4 automated driving on highways with "tele-driving" on local roads could bring significant benefits in terms of improving working conditions and reducing labor costs. "Drivers" operating trucks remotely from the control centres would be able to return home every night instead of spending long periods (weeks and months) on the roads away from their homes. Since one driver could remotely operate several trucks, carriers would reduce significantly their labor costs by reducing the number of drivers needed.

Some long-haul drivers would lose their current jobs or their tasks (and probably also pay) and would be limited to non-driving tasks, such as fueling, vehicle inspections, coupling/decoupling, loading/unloading, and others, which remote operators would not do. The main task of the operator would be to remotely pilot automated driverless trucks in local areas or in emergency cases on the highways. A remote operator's job would require practical driving experience to understand truck's real-world environment as well as IT skills and automated driving technology competencies.

Additional productivity gains for carriers would result from the increased fleet usage. Trucks could be constantly in use, being operated remotely by operators in control centres working in shifts. Trucks would not have to stay idle waiting until a human driver finishes the obligatory daily rest of 9-11 hours.

However, this use case entails additional costs as carriers would have to invest not only in automated driving technology but also in control centres. Big carriers could embrace such technology benefiting from the economy of scale.

[xviii] See footnote xvii

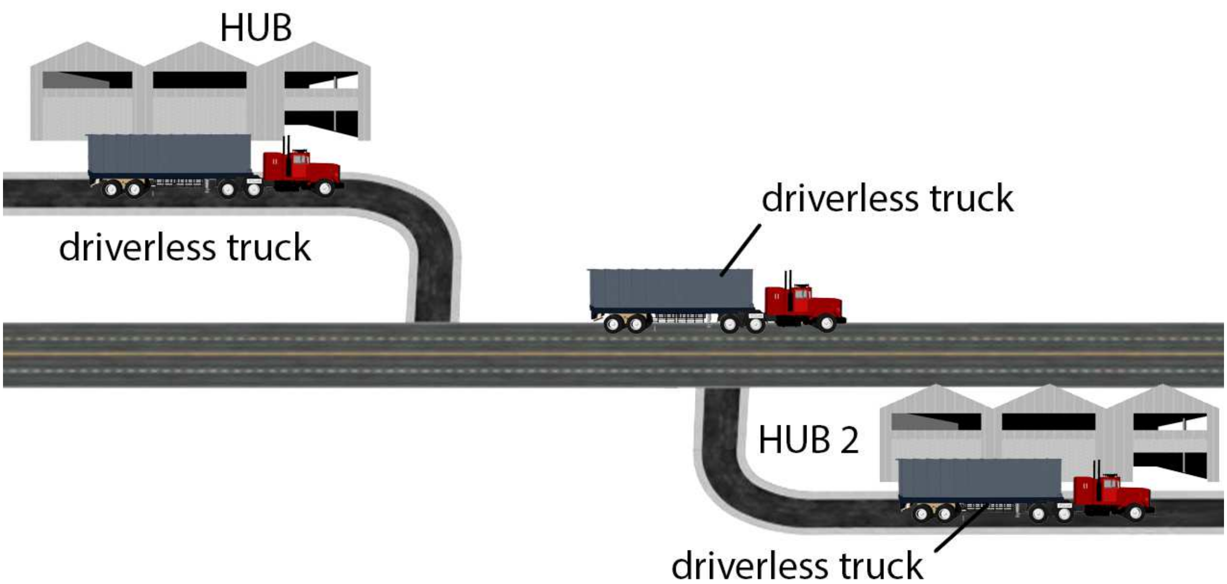
This business use case relies vastly on connectivity. Providing a robust communication network to safety standards is still a big technical challenge. There are serious concerns about cybersecurity and risks of hijacking trucks by taking over communication links and a remote control over automated trucks. Some researchers warn that remotely controlled driverless operations are very dangerous, as the operator in control centre can never have 100% awareness in real-time of the truck's real-world situation. Remote drivers will miss vision, sound and kinestethic sensations making it difficult to fully perceive the truck's environments. A full situational awareness would require not only super reliable connectivity with no or minimal latency but also super sensitive and reliable sensors and cameras and very experienced on-the-road drivers.

Until recently, Starsky Robotics in the U.S. was the leader in developing this technology (it closed down in January 2020). Starsky, however, was developing a system of supervised trucks automation at all times that is for the entire truck's journey and not only on local roads. It emphasized that remotely controlled automated driving is the only human-centred technology, which puts driver's well-being at the front. In Europe, Einride in Sweden develops this technology for their electric trucks, but it concentrates on operations on short distances and at low speeds.

Use case 7: Hub-to-hub highly automated trucks

In this model level 4 trucks operate stand-alone between freight transit hubs or distribution centres. Such hubs are typically located outside urban areas and are linked with nearby highways adapted for heavy-duty trucks roadways. The roadways from hub to the highway are usually short distance, less congested and requiring low-speed driving so there is no necessity of a human driver to bring the truck to the highway from the hub or from the highway to the hub. Only the first and last mile of delivery, typically in urban areas, would be done manually by local drivers.

Unlike in exit-to-exit automated operations, this model does not rely on parking areas and does not need new roadside infrastructure (staging yards) for trailers swapping. It relies on existing infrastructure at transfer hubs. However, with increasing freight demand and speeding up deliveries, the existing hub infrastructure may prove to be insufficient. Main developers interested in this technology application are IKE, EMBARK and KODIAK Robotics as well as Daimler.



Use case 8: Automated local deliveries

Automation of local deliveries has been until recently the least economically attractive and the most technologically challenging application. Designing a fully automated driving system that would safely operate a big rig in a complex urban environment (with mix traffic, traffic signals, pedestrian crossings, roundabouts, diverse signage, driveways, cyclist, pedestrians, etc.) is extremely difficult. However, few developers started designing small custom-built unmanned vehicles, which could navigate in urban traffic at low speeds delivering parcels, food and small cargo (e.g. Nuro, Kiwibot). In the beginning of 2020 the self-driving vehicle developer Waymo and shipping giant UPS launched a pilot program to use automated Chrysler Pacifica minivans to transport packages around the Phoenix metro area.

The COVID-19 pandemic, which put a huge pressure on deliveries of goods, shed a new light on thinking about automation of local deliveries. The extended period of the so-called "social distancing" and "shelter-in-place", when people had to self-isolate at their homes, led to increased demand for delivery of food, groceries, household items and medical supplies. Truck drivers, like all other people, are at risk of contamination by the virus, when performing their delivery jobs. In this context, the new type of demand for contactless delivery services emerged. This opens the door to scaling up the automated driverless vehicles for local deliveries and first and last mile deliveries, as part of the entire transport operation. For instance, in mid-March 2020 Nuro has launched two initiatives to provide contactless delivery to health care facilities in Sacramento and San Mateo. In mid-April Cruise (the self-driving subsidiary of General Motors) redeployed some of its self-driving cars to make food deliveries from two food banks in San Francisco, with safety drivers on board the vehicles.

Other technological use cases

There are two technological configurations that I have explicitly excluded from consideration, because either their impact on jobs and businesses seems insignificant or their deployment is many years away from a broad real world application. One concerns the use of highly automated and/or remotely controlled driverless trucks (level 4 trucks) in off-road domains, and another concerns the use of fully automated vehicles in all road and all environmental conditions (level 5 trucks).

Highly automated trucks in off-road domain are already in use. They operate in confined areas such as mines, ports and terminals, very short distances and at low speeds. They are thus limited to a very local movement of loads and do not form part of the trucking industry as such. For example, driverless remotely controlled trucks are used in ore mines in Western Australia. The control centre is located 1200 km away from the operating domain. In the Port of Rotterdam, the automated ship-to-shore cranes carry containers from the ship to the shore, and driverless automated vehicles transport containers between yards and quays. These operations are remotely supervised from the control centre. It is conceivable that more such specific confined areas, such as intermodal hubs (rail, ship, port, airport), will introduce automated driverless vehicles, mainly for the safety at work reasons and to address shortage of drivers. However, the impacts on employment will be insignificant, as many drivers will just move from vehicles to control centres or will haul other loads outside these confined areas.

Deployment of fully automated trucks (level 5) that would be able to operate safely and flawlessly in all road and weather conditions seems to be elusive. It is (still) difficult to imagine a 40 ton truck, without a human driver in a cab or in a remote control centre, navigating safely in urban environment with all its complexity: traffic lights, intersections, traffic jams, narrow lanes, buses, passenger vehicles, scooters, mopeds, pedestrians, dogs and other intentional or unintentional road users. There are several factors justifying this view. Firstly, such operations would require predicting the unpredictable. Millions of scenarios of all road users' behaviours, road incidents would have to be fed into the algorithms and then tested in real-world environment. The use of deep machine learning could contribute to making some progress. However, such software engineering is still in its infancy. Secondly, there is no strong business case for the investment in such vehicles, as the development of level 5 automation requires significant efforts, funds and time while the improvements in all aspects (safety, efficiency, etc.) compared to level 4 automation is minimal.

B. The choice of use cases

Two key questions should drive the choice of the technology application:

1) What changes do we want to see by introducing innovative technologies?
2) Is the adequate technology available and mature?

Desirability and feasibility of technology application are two key deployment factors which will help to shape purposely the digital transformation of the trucking industry. This transformation should not aim at maximization of economic gains solely, but rather at achieving a balanced combination of economic, social and environmental benefits.

Most feasible and desirable use cases

Among the above-described business use cases, three appear to be best candidates for a commercial launch in a short to medium term.

First generation platooning (use case 1) is the long tested technology. It has proven several benefits in terms of fuel efficiency, productivity gains and better working conditions (teamwork). Commercial deployment of platooning is allowed in 27 States. These states encompass around 80% of annual US truck freight traffic. There is a strong business case, in particular for big carriers, such as FedEx, UPS, Walmart, Amazon, which dispatch big number of trucks on daily basis for hub-to-hub operations. These trucks could be easily platooned bringing productivity gains and contributing to a reduction of congestion and environmental impacts. Smaller carriers could also benefit from platooning with the help of fleet consolidator organizing multibrand platoons and a distribution of fuel savings among carriers. In Europe, analysis of the European transport network show that 40% of kilometres travelled could be carried out in platoons[20].

Second generation platooning (use case 2) is the natural follow-up of the human driven platoons. The required technology for following driverless trucks (level 4 automated trucks) is at advanced stage of development and testing. This technology application could not only further increase productivity gains (e.g. greater fuel efficiency by further decreasing the gap between trucks, more efficient fleet use) and decrease environmental impacts, but could also enhance job-quality. Despite probable losses of some long-haul jobs it could also increase the number of local delivery jobs and create new jobs such as platoon coordinator or fleet consolidator. In 2020, in the US there are few States which allow for automated following in platooning (Arizona, Texas, Utah).

Exit-to-exit highly automated highway operations with human driver for first and last mile delivery (use case 5)
The development of high automation technology (level 4 automation) is a goal of many technology developers. For carriers the automation of long-haul journeys on highways is a sweet pot, as it promises huge labor costs savings and productivity gains by better use of the fleet and quicker deliveries. However, there is an infrastructural issue which should be first addressed, namely availability of dedicated parking lots or staging yards adjacent to highways to safely swap trailers between conventional and level 4 automation tractors. This scenario would impact significantly (more than in previous use case) the employment structure in the sector, by eliminating many long-haul jobs, shifting some of them to first and last mile deliveries performed in connection with highly automated highway operations.

The following two business use cases also fulfil the criteria of desirability, but they would require additional investments in order to be ready for deployment.

Hub-to-hub highly automated highway operations (use case 7) involves the same automation level of driving technology as exit-to-exit use case with human driver for local roads. However, the deployment of this use case depends on solving the issue of highly automated driving on small local roads between the hub and the highway. It would be a desirable use case for carriers as it would bring further labor cost savings. In the same time, the impacts on jobs losses and displacement would be greater than in exit-to-exit model thus bringing greater costs linked with unemployment and reemployment of displaced drivers.

It cannot be excluded, however, that some carriers will push for this model, in particular those with big fleets and/or with own distribution centres like Amazon or Zalando.

Automated local deliveries (use case 8) has gained its importance (desirability) recently in the context of COVID-19 pandemic. However, the technological solutions are still at the early stage of development. The attractiveness of automating local deliveries may increase in the aftermath of Covid-19 pandemic and demands of post-Covid 19 economy recovery (e.g. growth in e-commerce, growth in demand for contactless parcel or food or groceries deliveries).

Least likely use cases

Exit-to-exit highly automated operation with remotely controlled driving on local roads (use case 6) is the least likely to be deployed soon, if at all. There is not much interest among stakeholders to focus on this technology, as piloting the truck safely from the remote control centre in complex urban areas is still technologically very difficult. In addition, this use case would entail considerable costs of establishing control centres and reliable communication systems.

Conditionally automated trucks (use case 3) are neither of the interest to developers nor to carriers. This technology application raises serious unsolved (yet) human-machine interaction issues and does not offer significant benefits for anyone.

Exit-to-exit highly automated driving with a human driver in the truck (use case 4) should not be a desirable application mainly due to driver's health and safety concerns. It would also require major regulatory changes to allow a driver to spend several hours continuously in the moving trucks and to ensure adequate classification of the time spent in the truck driving on automated mode.

C. Phases of deployment

The rate of adoption of automated trucking technologies depends on several deployment factors: readiness of technology and infrastructure (supply side), readiness of the sector to apply those technologies in real life (demand side) and regulatory framework (e.g. liability rules, insurance issues). Demand for technology depends on many aspects, including cost of technology and available funding, expected return on investment, growth forecasts, and fleet life cycle. The pace of adoption will vary between different segments of the trucking industry and types of carriers.

> *"Technology availability (supply), customer interest (demand) and public acceptance and regulation (policy) all need to come together before new technologies can be applied." (ITF, 2018)*

An additional element affecting the start date and the pace of commercialization of automated driving technology is the current economic fallout turning off many sectors of the world's economy due to COVID-19 pandemic. Falling trade, plunging auto sales and lower industrial production already affect the freight transport demand and it may continue during the post-pandemic economic recovery. Innovators may have problems with raising money for further technology developments and testing. Automakers may reduce investment in automated vehicle technologies with automotive sales being down by 20-40%. Many potential clients (carriers) may not afford investing in CAV technology, with their revenues plummeting dramatically due to COVD-19 outbreak-elated lockdowns.

In fact, many developers and automakers slowed down their work on developing and /or testing self-driving technology (e.g. Waymo, Cruise) and some refocused their efforts on producing ventilators for hospitals (GM, Ford, Tesla). TuSimple decided to continue to haul critical commercial loads for major shippers (USPS, UPS, McLain FOODS) with their self-driving trucks. It's part of their testing process during the pandemic.

Considering all these deployment factors it is difficult to predict a timeframe for commercialization of particular technologies and for their widespread adoption. One element is certain, the automated driving technologies, as all innovations, will be deployed in phases, where the initial uptake is slow and then spreads rapidly to achieve a high level of penetration. Assuming that there is a favourable regulatory environment facilitating testing and deployment of automated trucking technologies, including in cross-border operations, the following deployment stages seem viable:

1. Initial phase of slow uptake – from now to 10 years (2020 - 2030)

This phase will see a gradual deployment of the first generation platooning. Carriers with big fleets will be early adopters of this technology. The compatibility of platooning technologies and emergence of fleet consolidators facilitates multi-brand platooning allowing smaller carriers to use this technology. The adoption and widespread use of digitized freight-vehicle matching platforms (such as Uber Freight) helps to expand the use of platooning among less-than-truckload carriers.

Self-driving trucks will start being used for test commercial freight carriage on highways (exit-to-exit and hub-to-hub operations), but with a safety driver and engineer on board the truck to monitor the system. Second generation platooning (automated following) is tested on dedicated highways. The growth in e-commerce will lead to an increase in first/last-mile deliveries and incentivize work on automation in this segment.

Carriers evaluate specific deployment factors such as cost savings, need for additional investments and safety assurance and give feedback to technology developers and manufacturers. The work on improvements of the technology continues.

2. Rapid adoption phase – 10 to 15 years from now (2030 - 2035)

Self-driving technology will become more within reach of smaller carriers due to falling costs. Stanford University started working on shrinking the size of components of rooftop Lidar, which should enable cheap and massive production of this sensor. Lidar, which is crucial for trucks to avoid hazards, is the most expensive component of the self-driving technology.

Driverless trucks level 4 (highly automated trucks in restricted operating domains) will start commercial operations on dedicated lanes and/or on dedicated highways in auto-follow platooning (second generation platooning) and in exit-to-exit scenarios. This will speed up deliveries and will lead to significant increase in demand for first/last-mile deliveries. Shorter shipping times and reduction of labor costs attracts also smaller carriers specializing in transport of refrigerated and perishable goods who invest in highly automated trucks to reduce food spoilage and remain competitive.

The development of staging yards and dedicated spaces at the entry/exit of the highway for coupling and decoupling trailers and digitalization of freight matching further encourages investment in highly automated driving technology. Pilot tests start for the use of highly automated trucks for hub-to-hub operations and for local and regional deliveries of parcels and small cargo by smaller automated vehicles (light goods vehicles).

3. Market penetration phase – 15 to 25 years from now (2035 – 2045)

The costs of automated driving technology reduce significantly. Highly automated trucks are widely used on all highways for exit-to-exit, hub-to-hub and platooning operations, by big and small carriers. With the increased volume and speed of long-haul operations, the first and last mile delivery segment is booming. More human drivers are needed to drive highly automated trucks to the ultimate destination navigating city streets, local and pedestrian traffic and loading docks. Human drivers are also necessary for long-haul operations for transporting specialized equipment or oversized load. The parcel and small cargo deliveries in urban areas are done by the specialized driverless small weight/size and low speed vehicles.

V. Impacts on workforce and on businesses

What does the deployment of automated and, in particular, highly automated driving (driverless) technologies mean to truckers and to carriers? How will the role of a truck driver change? How will business models evolve? Will the mass deployment of automation in trucking sector lead to mass destruction of trucking jobs or will it bring opportunities for new, fewer, but better jobs? Will the automation lead to the polarization of the haulage market where rich get richer and poor go bankrupt? These are zillion-dollar questions.

As the history of past technological disruptions shows, all innovations bring both positive and negative impacts on the labor market. As conveyed by Groshen, at al. (2018), technology itself is not deterministic of any particular outcomes. It is how the technology is implemented which determines the consequences for jobs and skills in short and long term. Policy and employers' choices matter.

Undoubtedly, the automated driving technologies will gradually replace, transform and create work in the trucking sector and all other linked sectors. In this chapter, I will outline the potential changes in the quality and quantity of jobs under the automated driving technologies use cases and deployment scenarios described in the preceding chapters.

A. Lessons from previous industrial disruptions - will this time be different?

David Autor in his essay "*Why Are There Still So Many Jobs? The History and Future of Workplace Automation*" upholds that automation technologies have not wiped out a majority of jobs over the decades and centuries. He states that automation not only substitutes for labor (which is the main intention of automation) but it also complements labor and raises productivity in ways that lead to higher demand for labor, and to adjustments in labor supply. He warns that even if automation does not reduce the quantity of jobs in the long run, it may greatly affect the quality of jobs.

The classic example of the effects of introducing automation technology in the 19th century is the mechanization of a weaving industry. The power looms automated about 98% of the labor needed to weave a yard of cloth. Did the power loom put weavers out of work? No, the number of factory weaving jobs soon increased by 400%. Why? Because the factory production has become cheaper than handmade suits and hence the demand for them increased, so the number of workers needed to operate and maintain the looms increased[xix]. However, the picture would not be complete if one failed to mention the short-term negative effects of the mechanization. One of them was de-skilling and job displacement, as skilled hand-loom weavers were replaced by unskilled factory workers (including children) and the weavers wages fell dramatically. Ultimately, the wages increased proportionately to productivity growth but it did not happen automatically and was facilitated by policy measures and other processes at that time, including limitations on child labor and an introduction of the right to unionize.

Another example is the introduction of information technology in the banking sector in the 20th century. Automated teller machines (ATMs) were introduced in the 1970s, almost simultaneously in the U.S., UK and Sweden. They were widely deployed in the 1990s eliminating numerous bank teller jobs. In the U.S. the number of bank teller jobs decreased by one third from 1986 to 1996. Then, in the late 1990s the employment pattern reversed and the number of bank teller jobs started growing even if the number of ATMs grew significantly. How was this possible? As ATMs brought a significant reduction in operating costs of bank branches, the banks started opening more branches, expanding the number of customers and banking services. This development was encouraged in addition by a bank deregulation in the US allowing banks to open more branches. Job losses were quickly more than offset by the larger number of new branches and new banking products (like credit cards, loans, and investment products) resulting in net growth of banking jobs.

[xix] "Are Robots Going to Hurt or Help? Let's Talk Driverless Cars with Jennifer Granholm", October 2017, University of California Television,

These and other examples of past innovations, such as mass production of automobiles in the beginning of the 20th century, introduction of cash barcode scanners in 1980s, computers processing a company's payroll and other business data, show that in the long term the number of indirect jobs created due to automation is greater than the number of direct jobs lost[21].

> *James Bessen at Boston University studied the impact of computers, software and automation on 317 occupations. In all those jobs the employment increase and only in one job, the employment was lost: elevator operator.*

Another lesson from the past is that fast implementation of automation technologies leads to sudden job displacements, while gradual introduction and diffusion of technologies allow workers, communities and governments to better anticipate the changes and adjust to the new situation, bringing more jobs and skills.

Will this time be similar? Or will the technology behind the driving automation - artificial intelligence – create a totally different trajectory of transforming the trucking industry in terms of quantity and quality of jobs? Whatever the case may be, job creation typically lags behind job destruction. At any rate of diffusion of automation there will be immediate direct effects and long-term difficult-to-predict indirect effects. There is no scenario in which negative effects can be totally avoided. Therefore, it is crucial and timely to take steps to mitigate risks of future job losses, displacements, de-skilling or job polarization and to help adjusting the labor force to new ways of working and doing business.

B. Likely impacts on jobs in the trucking industry

This section sets out potential impacts on current and future employment in the trucking sector. It is important to remember that these impacts will not be distributed evenly across the whole trucking industry and all geographical areas. The labor markets in regions, where the majority of jobs are in the trucking sector, will be hit sooner and stronger by the short-term employment effects of automation than other states and countries. For instance, in the U.S. driving a truck is the most popular occupation in 25 states (e.g. North Dakota, South Dakota, Arkansas, Nebraska, Iowa, Wyoming, Mississippi, Tennessee). Similarly, in some European countries the trucking sector is a major employer (e.g. Lithuania, Latvia, Estonia, Slovenia, Poland, Bulgaria). This may lead to a geographical concentration of job losses and displacements where certain local, regional or even national economies are affected more seriously than others may be.

In the same vein, some trucking segments will be impacted by the automation more significantly than others will. Following the use case scenarios, the jobs in long-haul operations will be the most at risk of displacements in contrast to jobs of local drivers or drivers of specialized vehicles.

Impacts on current trucking jobs

To discuss the probable impacts on jobs and working conditions in the trucking sector it is important to keep in mind that this wave of automation technologies will not replace all driver's tasks, but only one of them – the dynamic driving task. Hence, instead of talking about job automation we should talk about driving task automation. Depending on the segment of the trucking sector, driving activity takes from less than 50% (e.g. local multi-stop deliveries or deliveries to construction sites) to even 90% (long-haul operations) of all driver's tasks. The tasks that will remain in the competence of drivers (or rather automated truck operators) may include vehicle maintenance, overseeing the system, monitoring and control of the transport operation, loading and unloading, cargo securing, vehicle and system inspection, fueling, administrative work, and contact with clients. Hence, it could be assumed that a considerable number of truck drivers (truck operators) will continue to be employed because of tasks other than driving that drivers perform currently or will perform in the future[22].

The uptake of automation technologies scenarios focus on long-haul operations, where driving constitutes the great majority of driver's tasks. This is also the segment which is known for difficult working conditions (e.g. due to long periods away from home, poor access to adequate rest areas and hygiene facilities) and faces the biggest shortage of drivers and high turnover rate. The current shortage of drivers for long-haul jobs, upcoming wave of retirements in the driver's population, as well as forecasted growth for freight demand are the main factors which allow assuming that the gradual introduction of driverless trucks will not cause significant job losses.

In the first phase of slow uptake of automation technologies the changes in quantity of trucking jobs would be insignificant and the quality of jobs would improve. The gradual introduction of self-driving trucks for long haul highway operations will still require the presence of human driver to monitor the safe operation of the system. What will change is the necessary upgrade in driver's competencies. Long-haul drivers involved in platooning operations and in pilot operations by level 4 automated trucks will need to acquire new skills to be able to monitor software and hardware of automated driving system and to be able to use appropriately advanced safety systems. This may require additional certification of drivers to demonstrate an understanding of how to operate the automated trucks technology.

The self-driving technology is expected to make driving tasks less stressful, less exhausting and more comfortable hence improving working conditions. The upgraded skills and new responsibilities (e.g. supervising the self-driving system) will make drivers more valued and better rewarded. These potential improvements in working and pay conditions will make driver's jobs more attractive and encourage young people and women to pursue the truck driver/operator's occupation.

Despite initial significant investment costs of technology, carriers start realizing productivity gains thanks to fuel savings and better freight matching (hence reducing empty runs). Decreasing operating costs and growing number of carriers using the automated and/or connected technology leads to decreasing freight transport prices. Decreasing prices create more demand for freight transport services. To meet increased demand carriers will seek either to employ more drivers or to invest further in driverless technology. In any case, the increased demand for freight will lead to an increase in the number of available jobs for local deliveries. Hence, this first phase technology will not change the total number of driver's jobs, as there will be still the need for better skilled long-haul drivers and for more short-haul drivers.

In the second phase of rapid diffusion of driverless technologies in specified use cases (i.e. exit-to-exit and hub-to-hub operations on certain highways, second generation platooning, small driverless local delivery vehicles) the job losses and displacements will become noticeable. The successful test operations with human-supervised driverless trucks in the first phase lead to a broad use of these trucks without drivers' intervention for long-haul highway operations. The majority of long-haul drivers will lose their driving jobs. Some of them will maintain their jobs refocusing on current and new non-driving tasks and others will move to the local deliveries segment which will need even more drivers to satisfy the increasing demand for first/last mile operations. Yet, there will be a group of drivers who will become unemployed, at least for a certain period of time.

However, the shift of long-haul drivers to non-driving tasks may have twofold effects in terms of working conditions. Drivers with upgraded skills (e.g. safety drivers) will take up more sophisticated and better-paid jobs of monitoring, maintaining, inspecting the automated driving system, coordinating platooning operations, consolidating fleets, etc. Others will continue with their non-driving tasks such as basic vehicle maintenance, loading and unloading trucks, inspecting loads, administrative work and operating non-truck equipment. These jobs do not require new skills and, as the most valued part of driver's job – driving a truck - is taken away, these workers may experience decrease in their wages.

Long-haul drivers taking up first-last mile delivery jobs will also experience the reduction in remuneration as short-haul and local deliveries typically are less paid than long-haul jobs. Hence, on the one hand, the shift from long-distance trucking to local trucking jobs will enable drivers to be home every night instead of being on the road for long weeks and months. On the other hand, their wages and job satisfaction will most likely decrease.

In the third phase, the decreasing price of AV technology will allow for a widespread use of highly automated trucks for highway operations. There will be, however, no new significant wave of driver's job displacements as the lessons from previous phases and emerging new jobs opportunities within and outside the trucking sector will help to prepare for re-employment of displaced drivers.

In general in this phase, the direct negative effects of job losses from the previous phase should be gradually absorbed by new job opportunities in the short-haul segment and by new trucking or AV-related jobs as well as other sectors of economy.

The small driverless vehicles for local deliveries will not replace truckers but other types of drivers, such as UBER Eats or DoorDash drivers. They may be re-employed taking tasks such as loading, maintaining the delivery vehicles, monitoring the delivery operations, client support services, etc.

It is important to note that actual impacts on individual long-haul truckers will depend greatly on employer's choices. Carriers may take a "fire-and-hire" approach or a "retain-and-retrain" strategy. In the first case, carriers may decide to dismiss unneeded long-haul drivers and employ new workers with higher education and ICT skills to work with the automated driving technologies. This approach enables carriers to save time and money necessary for retraining their drivers. Others may decide to keep their experienced drivers and invest in upgrading their skills (unless these drivers are kept to perform usual non-driving tasks). It is expected that carriers who will enjoy significant returns on investment in automated driving technology should devote part of their profits for preparing their drivers replaced by automated trucks for other good quality jobs.

To sum up, in mid and long-term the significant productivity gains (thanks to reduced fuel and labor costs, increased efficiency of fleet use, speeding up deliveries) of carriers using highly automated trucks will lead to a decrease of prices and consequently increase in demand for trucking services. The increased volume of long-haul freight transport by highly automated trucks on highways will generate greater demand for first/last mile and local deliveries by conventional trucks with human drivers. It can thus be assumed that direct job losses will be greatly offset by growing demand for drivers in first/last mile and local deliveries as well as by new positions of highly automated truck operators and other trucking-related jobs.

However, drivers who will remain to do non-driving tasks and those who will move to a local deliveries segment will earn less than before. In the same time, higher skilled drivers who will take up new tasks as technology operators will earn far more. These job displacements may result in job polarization with high-skills high-wage jobs at one end and low-skills low-wage jobs at the other end, eliminating middle-wage middle education jobs, which trucking jobs were always about.

Estimates of job losses and displacements

Viscelli estimates that within 25 years, in the U.S. about 294,000 long-haul drivers (out of around 2 million of all truckers driving heavy and tractor-trailer trucks) may lose their current jobs as a direct result of introducing highly automated trucks. This concerns around 211,000 for-hire truckload jobs and around 83,000 less-than-truckload and parcel delivery jobs which are typically best-paid trucking jobs. Further, he argues that taking into account the aging workforce, the growth of e-commerce and growing demand for trucking services, there will be enough jobs, in particular in local delivery segment, to accommodate these displaced drivers. However, their wages and working conditions will likely deteriorate as local and for-hire trucking jobs suffer from destructive competition, which makes carriers lower driver's wages or shift costs to workers by using them as independent contractors (false self-employed).

Another study (IKE, Hodgson) suggests ambitiously that by 2030 nearly 210,000 long-haul trucking jobs could be replaced by automation. However, around 136,000 new short-haul jobs would be created in their place. Further, Hodgson estimates that 78,000 drivers will age out of the industry over the next ten years. Hence, the net 74,000 job losses will be more than offset by expected retirements.

ITF (2017) estimates that by 2040 in Europe, the number of truck drivers will decrease from the current 3.2 million to 0.5 million in a disruptive scenario and to 2.3 million in a slow-deployment scenario. Hence, the range of direct jobs displacements may be from 2.7 million and 900,000 jobs. In the US, in the same period, the number of trucking jobs may drop from 2.4 million to less than 0.5 million and to 2.2 million in respective deployment scenarios. Hence, the estimation range of direct jobs displacements would be between 1.9 million and 200,000 jobs lost.

The Groshen employment report (2018)[23] predicts that a majority of drivers replaced by the automated driving technology will regain employment. Until about 2040 the displacement and reemployment rates will be fairly low. The gap between the number of displaced and re-employed workers will peak at 380,000 displaced workers in 2047 in an aggressive scenario and 170,000 in 2051 in a slower deployment scenario.

Yet the most recent report (GAO, 2019) specifies that estimates for the US job losses range from under 300,000 driver jobs lost to over 900,000 jobs lost over 10 to 20 years or more. The GAO report also indicates that job losses could first occur in the southwest United States, where the technology will be deployed first because of good weather and long highways in those states.

These estimates and their assumptions lead to the conclusion that rapid deployment of automated driving technologies will cause more severe and longer enduring negative effects of job losses and displacements. The gradual and orderly introduction of highly automated trucking technologies should facilitate the adjustment of the labor market and absorption of freed workforce replaced by highly automated trucks.

New job and new skillsets

The widespread use of driverless trucks and of small driverless vehicles for urban deliveries will generate the need for new trucking-related and AV-related occupations, such as specialized technicians, technology installation and maintenance workers, engineers, automated driving systems operators, platooning coordinators, fleet consolidators. If attempts to introduce remotely controlled driverless trucks persists, there will be the need for remote trucks operators and other remote control centre workers.

The emerging AV-related jobs will require new skillsets including ICT (Information and Communication Technology) skills and the capability to understand how the AV technology works and how to interact with it, competencies to monitor, maintain and/or repair the automated driving system. The new skillset may not be within the reach of many displaced drivers due to too low level of education, poor access to training, financial problems preventing them from skills upgrading as well as individual reluctance to changes. High school is the highest level of education for 65% of US truck drivers in the US and 60% of truck drivers in Europe.

> *Truck drivers are potentially at a skills, age and education disadvantage when considering the jobs that will emerge in future. ITF, 2017*

It can be envisaged that there will appear new jobs and services, which will not require an entirely new skillset, but will build on the experienced drivers' skills and know-how. For instance, there could arise a need for emergency services for highly automated trucks, to deal with on-the road mechanical incidents like repairing flat tire, re-fuelling the truck, inspecting and securing the cargo at roadside. SAFE (2018) expects that new jobs will be created in three broad categories: new transportation jobs, new AV-related jobs and new jobs providing other goods and services. New transportation jobs will be a direct result of increasing demand for transportation services brought by decreasing costs and prices. New employment opportunities will appear for fleet dispatchers, repair and maintenance workers and for tasks that are currently bundled with driving tasks, such as package delivery, freight inspection, customer service, new supply chain specialists. AV-related jobs may include tasks such as software and hardware installation, maintenance and supervision. New jobs and services that will be created in trucking-related sectors are difficult to predict, as they will be a result of new demand for new services.

C. Impacts on businesses and road haulage market

The deployment of automated trucking technologies will have implications on the trucking companies and consequently on the organization of the road haulage market. While some carriers will strive and thrive, it is inevitable that some others will go out of business.

The automation of freight operations will change the cost structure of trucking companies, the workforce organisation, the fleet management, and the competition conditions. To absorb the changes and benefit from automation of trucking operations, carriers will have to rethink and reorganize the way they have been doing their business so far. A new approach to local deliveries will be required to maximize the potential for eliminating long-haul driving tasks.

Small carriers, more than big ones may need to collaborate to survive and benefit from the economies of scale. For instance, platooning, cargo and fleet consolidation possibilities will require closer collaboration between small carriers and establishing a system for fair distribution of costs and savings. It is conceivable that truck-sharing freight transport models will emerge. These possible future developments would be in line with the concept of collaborative economy encouraged by the European Union.

Large fleets, large truckload carriers and less-than-truckload carriers operating on long-haul fixed routes will most probably be early adopters of the automation technologies in the described in Chapter IV deployment scenarios. Their financial capacity enables them already to invest in research and development and to test automated driving systems in commercial operations (e.g. UPS). They will be able to absorb big, at the beginning, costs of automated driving technology by retrofitting the most modern trucks in their fleet and buying new trucks with AV technology built-in. Their big fleets, with several trucks of the same brand, make it relatively easy to engage in platooning. Small carriers and owner-operators will not be able to afford the initial high cost of AV technology, which currently ranges from $ 20,000 to even $ 250,000 for the complete system.

If the promised productivity gains and economic returns of automated technologies are realized and the price of technology decreases, other carriers will also have to adopt automation to remain competitive. However, for owner-operators it may still be the matter of throat-cutting development. Big carriers will have already gained huge competitive advantage thanks to operating costs savings and productivity gains. It will become evident for small carriers that they will not be able to continue their long-haul trucking business as usual. They may go bankrupt, join big companies, or re-focus their business on first/last mile and local deliveries or other trucking-related services.

Autonomy will be a magnifying glass for inefficient operating or decision processes

As small carriers constitute around 90% of all trucking companies, it is evident that their transformation or “evaporation” will have an impact on the structure of the haulage market. One of the possible scenarios is consolidation of the market, with a few big long-haul carriers, a few big local and first/last mile delivery companies and some specialized freight operators. Another possible scenario envisages consolidation of long-haul operations in the hands of a few big trucking companies at the expense of owner-operators and fragmentation of the local, first/last mile deliveries segments among many small carriers and a few big companies as part of their long-haul business operations. Specialized transport and urban small cargo deliveries will remain scattered.

Ultimately, prospects will depend greatly on the combination of short-term and long-term policy choices which should be based on the continuous research and on collaboration between all stakeholders.

D. How automation may address the current issues in the trucking sector

The fundamental question is whether all these changes due to automation of trucking operations will address the problems of the trucking sector, which it faces currently. The simplified question and answer (or problem and solution) matrix could look as follows:

Challenge	Automation as (partial) solution
Shortage of drivers	Yes, as less drivers will be needed for long-haul operations and those who will be replaced by automation will move to local deliveries segment.
Difficult working conditions	Yes, as drivers will not have to stay long periods on the road. The issue of poor access to rest areas and hygiene facilities will lose its importance. The use of advanced driver's assistance systems in modern automated trucks will make driving safer, less stressful and less tiring.
Poor pay conditions	Partially yes, as drivers with upgraded skills will take up better paid jobs (e.g. platooning leader, AV-related tasks) and those with low-skills may see their wages stagnant or even decreased (e.g. downgraded drivers to do simple non-driving tasks or local drivers)
Bad image of the sector	Yes, as improved working conditions, use of advanced technologies, possibilities to work close to home, will attract young people and women. However, this improvement may be overshadowed by deteriorating employment and pay conditions in the local delivery segment, which may occur in the absence of mitigating measures.
Fierce cost-based competition	Yes for long-haul segment. Price based competition will continue, but cost savings will not be realized through decreasing drivers' wages, but through more efficient use of technology and capital (the fleets). In local delivery segment the wage-based competition will persist.
Misclassification of drivers (false self-employment)	Yes for long haul segment, as drivers will be replaced by automated trucks. However, the use of drivers, falsely classified as independent contractors, may grow in local delivery segment as long as the wage-based competition will persist and if no mitigating measures are undertaken.
Empty runs	Yes, the empty runs will decrease gradually with the emergence and increasing use of digital freight-vehicle matching platforms and with the introduction of a digitalized fleet and operation management system

This is a very simplified illustration of how automation may contribute to solving current problems of the trucking sector. At the same time, the automation will bring new challenges (described in the preceding sections), such as job losses and displacements, jobs-skills mismatches, market share losses by some carriers. To address these new automation-derived challenges there is a need for adequate policy framework promoting the technology development and deployment and mitigating possible negative effects of jobs and business losses which mass adoption will inevitably bring.

VI. Policy considerations - how to facilitate the transition to automated trucking sector

If, as a history of technological revolutions demonstrates, the introduction of automation brings net growth in employment in the long run, then why should we worry? Would it not be better to let the labour market adjust in response to trucking automation instead of trying to predict the unpredictable and regulate the unknown? Certainly not! The past innovations have typically been accompanied by some regulatory changes which allowed for growth of employment (e.g. banking deregulation in the U.S. enabled the expansion of the banking sector and increase in bank tellers' jobs and new banking jobs). This time, more than ever, we need a favourable regulatory framework to ensure safe and fair deployment of trucking automation, because this time we deal with a broader digital transformation of the world's economy, which may impact jobs in other sectors of the economy at the same time.

> *It is imperative to avoid using the vision of a long-term post-adjustment future as an excuse not to deal with the dislocations caused in short term by the adoption of AVs. – E.Groshen*

Clearly, the magnitude and the scope of direct and indirect effects on the workforce and on the businesses in the trucking sector depends largely on socio-economic and political choices. We are now better equipped than ever with knowledge, lessons from the past and forecasting tools as well as policy and financial means to shape, manage and monitor the changes that the automation is bringing for the trucking sector and society. Instead of debating on whether the driving automation technology is creating or killing jobs and businesses, we need to discuss how to provide the citizens with the right tools, such as skillset and resources, to facilitate the transition to new forms of work and doing business in the digital age.

Here is the big role of policy makers who should collaborate closely with the industry stakeholders, software and hardware manufacturers, innovators, researchers and truckers' organisations to make well-informed decisions to facilitate the process of automation in the trucking sector. The regulatory aim should be, in general, to ensure that the sector and society make the most out of the creative potential of automation technologies, and to reduce the destructive effects of their deployment.

A. What are the governments doing now to assist trucking automation?

A good regulatory environment is innovation-friendly, technology and business neutral. Countries across the world have different approaches to regulating the design, adoption, testing and deployment of automated vehicle technologies. Governments are juggling between establishing forward-looking rules and taking backward-looking measures. The progressive (forward-looking) policy-making may provide legal clarity for companies and enable governments to handle fair and safe deployment of automation technologies, but, at the same time, it may hamper innovation and result in a necessity to revise the rules. The ex-post (backward-looking) policy gives more flexibility for technology development and application, but less certainty for companies and governments in managing the implementation of automated driving technologies.

Currently, there is a patchwork of different rules in different countries, states, regions and even municipalities. This patchwork of rules makes testing and deployment of AV technologies in cross-border and international freight operations difficult and costly. For instance, some states allow for testing driverless vehicles on public roads and others do not, some allow for platooning operations in commercial transport and others do not. For automation of the long-haul trucking segment in particular, the harmonization of the new AV-related rules as well as existing traffic rules is crucial.

In the US, the draft legislation on AV technology has been under negotiations for the last four years. Republicans (backed up by the AV technology and automotive industries) aim to create one federal overriding standard while Democrats (backed by safety advocates and lawyers) want to ensure that AVs are safe and their producers are held liable for any safety issues. In the meantime, the Federal Government has taken an approach of voluntary guidelines for AV industry and state governments. In 2017, the United States Department of Transportation (USDOT) released *Automated Driving Systems 2.0: A Vision for Safety (ADS 2.0)* – a voluntary guidance to industry and technical assistance and best practices to States with regard to safe testing and integration of Automated Driving Systems (ADS). In 2018, the new version of guidelines *Preparing for the Future of Transportation: Automated Vehicles 3.0 (AV 3.0)* introduced guiding principles for AV innovation and presented USDOT's strategy to deal with barriers to potential safety benefits and progress. The recent version of guidelines dated January 2020 – *Ensuring American Leadership in Automated Vehicle Technologies (AV 4.0)* – sets out ten US Government principles to protect users and communities, promote efficient markets and facilitate coordinated efforts in AV technology growth and leadership.

The guidelines highlight that realizing the full potential of AV technology requires close collaboration and information sharing between industry, States, territorial governments, academia, innovation developers and Federal Government. The Federal Government promotes voluntary technical standards and encourages technology developers to make Voluntary Safety Self-Assessment public to increase transparency and build public acceptance. It also relies on a self-certification approach rather than type approval of AV technology. The non-regulatory instruments (guidelines and voluntary standards) aim to advance the integration of AV technologies into transportation systems by offering a flexible framework for AV industry, but they are not enforceable and there are no requirements for compliance.

All US Government activities and funding programs in the field of AV technology focus (rightly so) on areas such as safety, security, cybersecurity, infrastructure and connectivity. Apart from some studies on potential implications of automation on jobs and employment, there are no specific measures to address those implications and prepare the workforce for the changes. The general employment and training programs administered by the Department of Labor (DOL) are designed to respond to mass layoff and help workers upgrade their skills. For instance, Rapid Response provides career counselling services, job search assistance and information about unemployment insurance and training opportunities to help deal with the effects of layoffs and business closures. Additionally, under the Workforce Innovation and Opportunity Act (WIOA), funds can be made available to provide training of workers at risk of layoff. However, these general instruments may appear inadequate to deal with workforce effects of automated trucking and to provide displaced truck drivers with new skills and new jobs opportunities.

Apart from federal guidelines, there is a patchwork of state laws governing truck automation. In 2018 there were 27 states that had passed AV laws or executive orders outlining policy for automated driving. For instance, some states allow for testing of automated driverless vehicles on public roads and others only with a safety human driver on board the vehicle. The allowable following distance for trucks driving in platoons is different in different states. Overall, laws and rules governing AV technologies are at their infancy and they need harmonization and more focus on workforce adaptation measures.

In Europe, the AV policy-making efforts are also dispersed among Member States, although there are attempts to provide a consistent EU-wide framework. The European Commission adopted in 2018 the Communication *On the road to automated mobility,* which sets out the Commission agenda for connected and automated mobility. The proposed actions deal mainly with vehicle approval, safety, cybersecurity, liability and data sharing issues. The Commission, in collaboration with Member States, intends to establish a new approach to certifying automated vehicles, which should be more flexible than the current rules on vehicle approval to allow for technological improvements.

As in the US, the EU Member States have different rules on safe distance between vehicles on a public road. Therefore, countries participating in European truck challenges had to grant exceptions from their relevant national rules on safe distance to drivers participating in the challenge. Following the European truck platooning challenge, all EU Member States signed in 2016 a Declaration of Amsterdam to create a common regulatory framework facilitating the introduction of connected and automated driving, such as truck platooning, on Europe's roads. This means that EU countries must work on compatibility of safety requirements, liability issues, communication systems and services.

According to the KPMG International Autonomous Vehicles Readiness Index (AVRI)[xx], the Netherlands is regarded the world's leader in preparedness for AVs as regards policy adoption, investments and public awareness. The second in the ranking of AV preparadness is Singapore, followed by Norway, USA and Sweden. In general, the European countries are highly ranked as regards policy and legislation, and technology and innovation.

The Netherlands is working with Germany and Belgium to launch truck platooning commercial operations — where one human-driven truck leads a convoy of automated driverless trucks — to transport flowers on major "Tulip Corridor" routes from Amsterdam to Antwerp and Rotterdam to the Ruhr valley.

Amid several non-regulatory and regulatory initiatives being undertaken by governments across the world, aiming at automation of the trucking sector, there are hardly any measures addressing implications for trucking jobs and businesses. It appears that employment impacts of automated trucking have been largely omitted from the nascent rules and measures. Clearly, while the research and stakeholders collaboration should continue as automated trucking technology evolves, the policy makers will have to consider necessary workforce-related and risk mitigating measures to achieve the objective of the effective deployment of technologies.

B. What measures could facilitate the transition of the trucking workforce and businesses?

It is difficult (but not impossible) to design industry-specific workforce-related measures based on guesstimates about the future and lessons from the past. When considering any policy measures it is useful to reflect on key questions:

- How can we better anticipate the future impacts on trucking workforce and businesses?
- What kind of transition assistance and where will it be needed the most?
- Who will pay for transition of displaced workers ?
- How to prevent technological unemployment and degrading employment practices?
- What should be the role of social partners?

The policy considerations suggested below build around these key questions and are grouped into four main areas: research and collaboration; proactive labour market (industry-specific) measures, passive labour market measures, legislative measures.

[xx] Countries are regularly assessed on 25 different measures within four pillars: policy and legislation, technology and innovation; infrastructure and consumer acceptance.

Research and collaboration

To better anticipate and manage the transformative effects of deployment of AV technologies it is crucial that researchers, innovators, manufacturers, governments and industry stakeholders collaborate closely and share data and information. It is particularly difficult to encourage technology developers to share information about their technologies as this entails risks of stealing their trade secrets and using information to build competing technology. However, sharing data and information is crucial for policy makers to anticipate the date and establish the conditions of commercialization of the AV technologies as well as identify barriers in the existing regulations to safe deployment of these technologies.

The continuous dialogue and consultations with the trucking industry stakeholders, including workforce representatives, training institutes and technology developers is necessary to ensure that workforce-related policy measures address the specificities and expectations of the particular trucking segments most affected by the automation. Knowledge about what commercial drivers are likely to be affected and what skills might be needed to operate automated trucks or to transition to new jobs will help to design training programs and elaborate effective educational tools.

Potential actions could include:

Stakeholders' information sharing platform

Such a cooperative platform should enable governments, researchers, manufacturers and industry stakeholders (potentially also public at large) to: (a) share information about the findings of recent research, studies and projects dealing with implications of automation on trucking workforce and carriers, (b) share reports on results of testing of automated trucks[xxi], (c) exchange views about future skillsets required and new jobs and career pathways. For policy makers it would be also important to know technology developers plans that would affect future demand for trucking jobs and skills required in these jobs.

Comprehensive database about employment in trucking sector

The comprehensive data on employment, trucking enterprises and job vacancies in particular trucking segments would help to anticipate the number of (long-haul) truck drivers whose jobs may be most likely affected by automation and the number and type of new job opportunities. This database could also include information on tasks performed and skills required in different types of trucking occupations as well as information about truckers' age, experience, level of education. This knowledge would help to predict which skills and how they could translate into other occupational areas or new jobs and new skillsets.

Close collaboration between governments

National cooperative platforms and databases mentioned above would equip national governments with better knowledge facilitating efficient cooperation between them. Coordination of efforts of different states and different departments within those states (innovation, transport, labour and other departments) in anticipating the AV-related challenges in trucking sector would be beneficial in creating national and cross-border policies, programs, initiatives (EU level, federal level in US) to address these challenges.

Trucking Jobs Automation Council

[xxi] To ensure access to technology-related information National Highway Traffic Safety Administration (NHTSA) issued policy guidelines pushing automated vehicle manufacturers into sharing data about their failures with each other and with the government. In California Department of Motor Vehicles (DMV) requires remanufacturers testing their automated vehicles to submit a report an annual report summarizing the disengagement of the technology during testing.

The main task of such a body would be to advise governments on the choice of strategies to manage the transition towards automated trucking. This advisory body should bring together AV technology experts, trucking industry representatives (workers and employers), manufacturers, training institutions and policymakers. It should prepare regular analyses of trade-offs between benefits of trucking automation (productivity, safety and environmental improvements) and costs of job and business losses and displacements. It should help preparing action plans for governments to develop a future trucking workforce, create good quality jobs and to identify funding resources supporting job and business models transitions. Such Council (or councils at the level of individual states) could also monitor an extended social protection net programs and help design specific training and career counselling programs described below.

Passive labour market measures

This group of measures consist of existing and potential future instruments to deal with layoffs, jobs displacements and companies' bankruptcies.

Social protection net

The immediate relief measures in situations of layoffs and jobs displacements are unemployment benefits (cash transfers). However, many displaced truckers, in particular bogus self-employed or owner-operator contractors, may not qualify for such transitional aid. This is because the current social protection systems are designed for traditional long-term employee-employer relationships. The technological developments and the continuing rise of non-standard work (contract work, part-time work, and on-demand work) necessitate a modernization of welfare systems to ensure that all current and future trucking or trucking-related jobs are covered by the social protection system. The social protection rights should be tied to the worker (legally employed) and not to the employment contract. The social protection net could also provide free or subsidized health care and other supplemental financial support for unemployed drivers actively seeking retraining and re-employment opportunities. The concept of basic universal income should also be considered in policy debates as a potential measure to counter job displacement and technological unemployment caused by automation of work in general.

Layoffs warning system

Such a system, which typically applies to employees, should be extended to independent contractors (or dependent self-employed) in the trucking sector. All truckers should have the right to be informed in due time by the trucking companies about their plans to invest in automated driving systems and the accompanying plans to reorganize their workforce which may result in layoffs. The longer notice period would enable drivers to start looking for new jobs and training opportunities and would help avoid massive layoffs and overloading social protection systems.

Early retirement pensions paid for labour market reasons

For older drivers that are closer to retirement, the retraining and re-employment may not be a viable option. Such drivers should have a possibility of early retirement or a "retirement buyout package" instead of job training benefits[24].

Trade union activities

Despite the current decreasing unionization trend, the trade unions could also play an important role in ensuring that displaced drivers have good quality jobs and adequate social protection regardless of their employment status and form of work. This would require significant transformation of the trade unions and extending their membership and activities to cover also (dependent) self-employed, non-standard workers, contract workers, or platform workers. To all truckers at risk of automation, the trade unions should equally offer information, trainings, legal advice, social professional network and possibilities to bargain collectively pay and working conditions. Ultimately, trade unions' mission should be to protect workers and not jobs, which are inevitably at decline.

Job counselling

There exist one-stop centres and labour agencies or workforce development institutions, which help job seekers to find jobs or gain necessary skills to return to work. However, existing institutions need strengthening and better knowledge about anticipated types of jobs and required new skillsets to be able to serve the cohorts of truckers and small carriers at risk of losing their jobs and businesses. Specific job-matching and career counselling programs for truckers combined with adequate training opportunities would be useful to help more efficiently displaced truckers to start a new career path.

Active sector-specific labour market measures

Alongside the strengthening of the existing workers councils and workforce development organizations, the policy makers and trucking industry organisations (employers' associations, employees' organisations, small businesses organisations, etc.) should take measures aimed at job creation and new skillsets development.

Training and education

Well-designed vocational training and education programs could help tremendously improve employability of current truck drivers whose jobs are at risk of automation and form a future workforce for automated trucking and other AV-related jobs. They should also aim to help small carriers to reorganize their business model to remain competitive. Establishing such training curricula requires coordinated efforts of governments, training institutions, employers, school-age educators and adult middle career schools. The school-age education system should pay greater attention to developing digital literacy and STEM (Science, Technology, Engineering, Mathematics) competences of the future workforce.

For current truck drivers whose jobs are at risk of automation, different types of training should be offered. One type of training programs should address the skills needs in the transition period when trucking jobs will be partly automated and where drivers will need to learn how to use semi-automated driving systems and become acquainted with technology. For instance, Scania has already launched the training programs for professional drivers to make them familiar and able to use the latest technologies such as driver's awareness systems, collision avoidance systems and others. Employers should be encouraged to offer on-the-job training for their drivers at risk of automation. Financial incentives, such as training program grants or labour tax reductions could be considered to promote "retain and retrain" strategies among trucking firms.

Another type of vocational training programs should be designed based on the identification of current and anticipated near future job vacancies, within and outside the trucking sector. Yet another type of training curriculum should be more forward-looking and focus on anticipated new skillsets required for new jobs and services emerging with deployment of automated trucking technologies (e.g. operating automated trucks, platooning coordinators, installing and maintaining AV software, etc.).

An example of a forward-looking training is a new automated driving certificate program developed by the PIMA Community College in partnership with the automated technology developer TuSimple. This program was launched in September 2019. Its aim is to teach experienced professional truck drivers (holding Commercial Driver's Licence prior to enrolment) how to operate and work with automated trucks. The certificate program comprises five classes: introduction to automated vehicles, industrial safety, computer hardware components, electrical systems, transportations and traffic management. The course will prepare those drivers for jobs such as training the automated system as test drivers, operating the vehicle in situations where automate driving is not suitable and remotely monitoring the system from a command centre.

"The program offers driving professionals a smooth transition into an emerging field that requires different skillsets in addition to existing truck driving knowledge, by providing training." TuSimple

Automated driving levies

The workforce transition programs (re-training and skills upgrading programs, job counselling, extended social protection net, etc.) require dedicated funding. The goal of fair distribution of AV benefits suggests that carriers who will have huge productivity gains thanks to replacing their drivers by highly automated trucks should contribute financially to transition programs assisting drivers to return to work or start new career paths. This could be done by introducing automated driving revenue tax, which means that part of revenues from automated operations would provide an employer's contribution to the special trucking automation transition fund. This is not an entirely new idea, as already Bill Gates suggested applying the so called "robot tax" to ease the social costs implied by automation's displacement effects. Robot tax strategy implies taxing robots at a similar rate to what workers would have been taxed had they not been replaced by automation.

Exemptions from an automated driving revenue tax could be applied to employers who decide to create a "retain and retrain" strategy, provided that they keep truck drivers and offer them adequate training and skills upgrading opportunities.

ITF (2017) developed the concept of a permits system. It proposes that governments could influence the speed of deployment of automated driving technologies by issuing a limited number of permits for carriers who want to carry out driverless freight transport operations. The permit scheme would increase the cost of investment in automated driving technology (cost of technology increased by cost of permit) hence reduce a demand for driverless operations. This would help limiting the number of driver's jobs losses and raising revenues for financing training and upskilling of drivers who lost their jobs due to automation.

New jobs creation

Governments could create the dedicated automated trucking fund or subsidies to help small carriers transition to automated trucking operations by investing in technology and transforming their business models. Another initiative could be establishing a seed fund for start-ups creating automated trucking-related services, and AV-related jobs as well as to unemployed truckers who wish to start their own business.

As human-led automated platooning operations appear to be the source of high quality trucking jobs, the governments could take measures encouraging carriers and their customers to invest in these technologies.

Similarly, as more local delivery and first/last mile jobs will appear, the governments could incentivise manufacturers and carriers to invest in electric trucks to be used in this segment. This would not only help reduce the environmental footprint but also improve working conditions of local truckers.

Labor standards

To prevent job and haulage market polarization, protect truck drivers from the risk of deterioration of working conditions, the governments should establish and monitor compliance with the labour standards. One of the risks associated with shifting dismissed long-haul truck drivers to short-haul segment or to non-driving tasks is forcing them to become independent contractors (false self-employed) or on-demand workers. Unless the social protection system is modernized (covering also dependent self-employed and other non-standard workers), this type of practice should be actively discouraged. Policy makers should make it clear who is an employee and who is an independent contractor to prevent unfair employment practices which shift operating costs on workers and deprive them from their social protection rights.

Modernization of regulatory framework

Several existing regulations and rules (at national, European and international levels) will have to be revisited to ensure that they do not hamper the deployment and adequate use of automated trucking technologies.

The US regulations (Federal Motor Vehicle Safety Standards) require the presence of a human driver on board the vehicle. In the absence of modification of these rules or at least adaptation of the definition of a driver to driverless operations the use of driverless trucks becomes illegal.

Both in the US and in EU the trucker's work is regulated as regards the maximum driving times, minimum breaks, and rest periods. These limitations should not apply to operations performed in highly automated driving mode (driverless trucks). For semi-automated operations, where drivers are in the vehicle monitoring the automated driving system, the definitions of driving and rest should be adjusted. The time spent on board the truck moving on automated driving mode should not account for driving time limits but should be counted as paid working time of the driver who must remain in the truck. In addition, in the US the driver is paid (typically) for driving tasks (loaded miles driven). The question arises how the driver should be paid for the time sitting inactive in the back of the cab while the truck is on automated driving mode.

The current European rules do not allow, in principle, taking break and rest periods in a moving truck. In line with these existing rules, driver's non-active time spent in a truck driving itself cannot qualify as rest period and may result in the law's violation if the driver does not stop the truck to take an obligatory rest. In such a case, promised efficiency gains of using automated trucks would not be realized. In general, the definitions of driver, carriage by road, driving time should be adapted to reflect semi-automated and highly automated truck operations.

Other European rules that would need to be revised are those on initial qualification and periodic training of professional drivers. Operating semi-automated trucks or remotely operating or monitoring operations of driverless trucks would require new skills from such drivers. The skills to operate automated driving systems, ability to understand the technology and others based on future skill changes, should become a part of obligatory training curriculum for such drivers.

Equally, the EU rules on the access to the profession of road haulage operator and on the access to the international road haulage market would need to be adapted. The professional competence requirements of carriers and of transport managers would need to include as a minimum AV technology literacy and automated fleet management skills. The rules on financial standing and on stable establishment would likely need to be adapted to the new automated trucking reality. The recent ideas of adding requirements of sufficient parking space at the carrier's operational centre or making trucks return to the operational centre regularly would become impractical given that highly automated trucks could be almost constantly in circulation to realize productivity gains and meet the demand for freight transport.

The automation also affects the rules on the use of electronic recording device (tachograph in the EU and ELD - Electronic Logging Device - in the US) registering driver's activities. Currently these devices record automatically driving activity, which accounts for driver's driving time limits. These records are subject to control of driver's compliance with the driving time limits and breaks in driving. The software of these devices should be adapted to enable differentiation of manual driving from automated driving activities and remotely controlled driving. The EU rules on roadside inspections will also need to be modernized. Enforcers will need new instructions on how to conduct such inspections, how to qualify driver's time on board during automated driving mode and how to classify potential violations.

These are only a few of the most eminent rules applying to trucking operations which will certainly need governments' attention to prepare for automated driving future. The key policy choices are:

A) To modify and extend existing regulations and adapt definitions and specific provisions to automation of freight operations. These rules would apply to drivers and operators involved in conventional freight carriage operations and those performing semi-automated and highly automated trucking operations. However, as those regulations were not initially intended for automated truck operations there may occur undesirable consequences of such law extension and difficulties with enforcement;

B) To establish a specific set of standalone rules applying exclusively to automated trucking operations. Such a new data-driven regulatory framework could be better adapted to real needs and specificities of automated trucking. However, the promulgation of new laws typically takes a long time which may mean that once the new laws are adopted, they already lag the technology which would have evolved.

Both policy choices have their advantages and disadvantages. Whatever the policy choice will be, the regulators must provide legal clarity on these issues before automated trucks hit the roads for commercial operations.

VII. Conclusion

Since the 1960s when the introduction of standard containers revolutionized the freight transportation, nothing has considerably changed in the way the trucking industry functions. The connected and automated driving (CAV) technologies will be a new game-changer transforming the trucking world and catalysing the innovation in many interlinked sectors.

Delaying the automation in the trucking sector should not be an option. The potential of trucking automation to bring progress to the businesses, workers and the society is huge. At the same time, if the technological innovation is mismanaged, it can cause destruction and increase social and economic inequity. Adopting CAV technologies means investing as much in people and a regulatory framework as in technology. This is a joined responsibility of technology developers, software and hardware manufacturers, policymakers, trucking organizations, trade unions and carriers themselves to help the trucking world navigate these changes safely and effectively.

Endnotes

[1] Frank Levy and Richard Murnane (2004), “The New Division of Labor”

[2] PBS Airdate: October 23, 2019, “Look Who's Driving. As self-driving cars take to the streets, investigate how they work, and if they are safe.” https://www.pbs.org/wgbh/nova/video/look-whos-driving/

[3] Economic and Industry data by American Trucking Association, https://www.trucking.org/economics-and-industry-data

[4] United States Government Accountability Office (March 2019), “Automated Trucking. Federal Agencies should take additional steps to prepare for potential workforce effects”

[5] ITF (2017) “Managing the Transition to Driverless Road Freight Transport”,

[6] EU transport in figures, Statistical pocketbook 2019

[7] Steven Viscelli (September 2018), “Driverless? Autonomous Trucks and the Future of the American Trucker”

[8] Economic and Industry data by American Trucking Association, https://www.trucking.org/economics-and-industry-data

[9] ITF (2017) “Managing the Transition to Driverless Road Freight Transport”,

[10] ATRI (October 2018) “An Analysis of the Operational Costs of Trucking”,

https://truckingresearch.org/wp-content/uploads/2018/10/ATRI-Operational-Costs-of-Trucking-2018.pdf

[11] OECD/ITF (2017), “Managing the Transition to Driverless Road Freight Transport”, OECD/ITF 2017

[12] Michael Bennick, “Trucking was once a middle class job. Can’t it still be?”

[13] IRU, “Tackling Driver Shortage in Europe”

[14] Securing America’s Future Energy (June 2018), “America’s Workforce and the Self-Driving Future. Realizing Productivity Gains and Spurring Economic Growth”,

[15] ATRI (May 2017), “Cost of Congestion to the Trucking Industry: 2017 Update”

[16] McKinsey&Company (December 2018) “Distraction or disruption? Autonomous trucks gain ground in US logistics”, , https://www.mckinsey.com/industries/travel-transport-and-logistics/our-insights/distraction-or-disruption-autonomous-trucks-gain-ground-in-us-logistics

[17] Thomas M. Siebel (New York 2019), “Digital Transformation. Survive and Thrive in an Era of Mass Extinction”

[18] OECD/ITF (2015), “Automated and Autonomous Driving. Regulation under uncertainty”

[19] Steven Viscelli (September 2018), “Driverless? Autonomous Trucks and the Future of the American Trucker”

[20] Alexander Dorl, Deutsche Bahn

[21] Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future,* June 2018

[22] Securing America’s Future Energy (June 2018), “America’s Workforce and the Self-Driving Future. Realizing Productivity Gains and Spurring Economic Growth”,

[23] Erica Groshen, et al., *Preparing US Workers and Employers for an Autonomous Vehicle Future,* June 2018

[24] Steven Viscelli (September 2018), “Driverless? Autonomous Trucks and the Future of the American Trucker”