Autonomous Trucks: An Opportunity to Make Road Freight Safer, Cleaner and More Efficient

WHITE PAPER

MARCH 2021

Cover: Getty Images

Contents

Executive summary

Creating suitable regulatory frameworks will be crucial to facilitate the roll-out of autonomous trucks.

In 1915, moving a tonne of grain from Egypt to Rome could be achieved approximately 10,000 times more effectively than it was in 200BC. In all the intervening years, however, the final 20 miles of the route (from an Italian seaport to the inland location of Rome) had become only *five* times more effective. This is because the first and last legs of the journey were made in the same way right up until the First World War as they had been during the Roman Empire: by horse-drawn cart. Everything changed with the invention of the tractor, which saw widespread use during the war.

The logistics sector is currently experiencing a similarly seismic paradigm shift: autonomous freight by road. The technology involved has the potential to significantly decrease the cost of transporting goods over land, a change that may underpin what turns out to be the most widespread impact of self-driving technologies on many people's lives.

It is not surprising that self-driving trucks didn't initially catch the public imagination. Most people have never been in a truck before, let alone a self-driving one, and few give them more than a passing thought. However, trucks affect everyone's lives: from the food we eat to the clothes we wear, nearly everything we buy reaches us via a truck. This means that automating the movement of goods may have as deep an impact on our lives as automating how we move ourselves.

Creating suitable regulatory frameworks will be crucial for facilitating the roll-out of autonomous vehicles (AV). All stakeholders, from truck manufacturers and technology providers to governments and civil society, will have to collaborate in developing these frameworks.

As part of the **AV Movement of Goods Project**, which concluded in 2020, a series of multi-stakeholder workshops were held by the World Economic Forum to identify key enablers of the automated movement of goods (one was the development of a digital identity for trucks, an area that will be explored in further publications). This paper aims to explore the challenges related to autonomous trucking and to summarise the potential benefits of automated logistics.

1 Why trucking is ripe for automation

Driverless vehicles should help to solve a number of issues that currently inhibit the road haulage industry

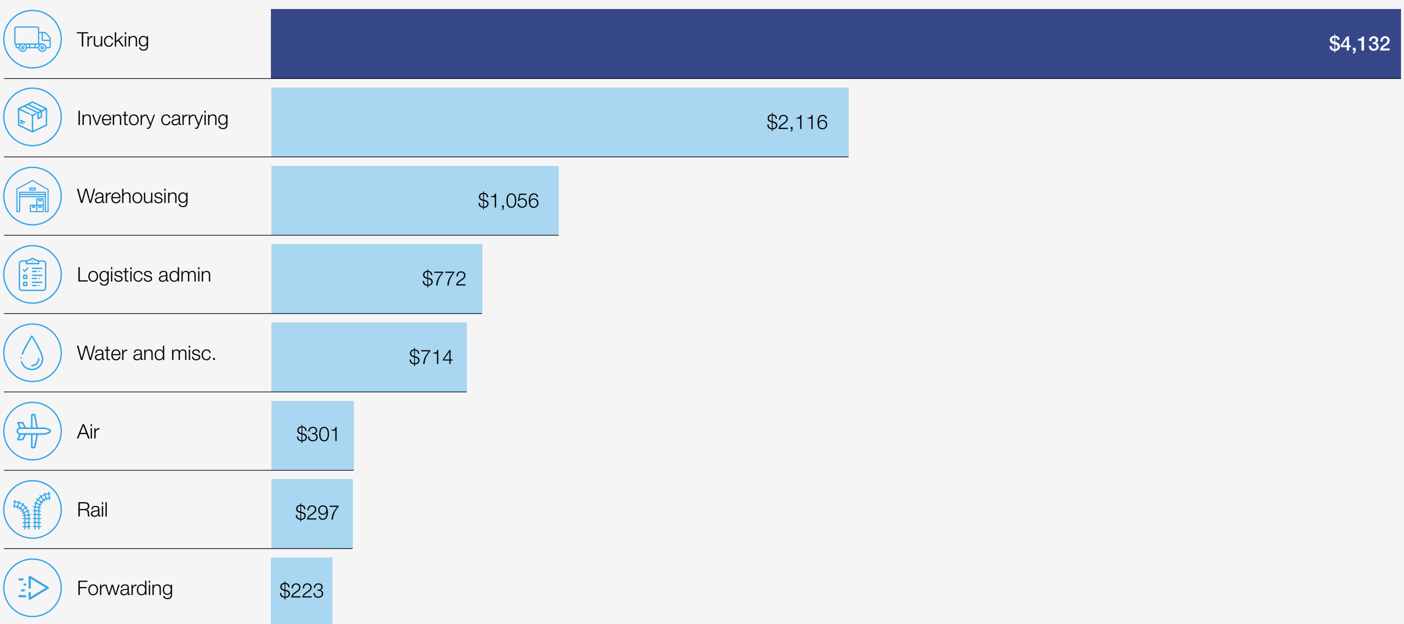
1.1 Composition of the industry

Worth $9.6 trillion in 2018, according to Armstrong & Associates, the global logistics market currently represents approximately 12%[1] of the entire world's GDP. However, it's believed that the market's current size is overinflated due to the fact that supply-chain inefficiencies create elevated cost structures; as technology continues to create new efficiencies in the way that goods are moved from A to B, this makes forecasting the future size of the logistics market challenging. The trucking industry currently accounts for 43% of total logistics costs globally, with a total value of $4.1 trillion, and is projected to reach a size of $5.5 trillion[2] by 2027.

According to the American Trucking Association (ATA), trucking is the dominant mode of US inland freight transport, accounting for 67.7% of the sector[3] (amounting to 11.8 billion tons of carried freight in 2019), and it is forecasted to remain dominant for the next decade. In 2019 the industry accounted for $791.7 billion[4] in revenue in the US, and in the next 30 years is expected to grow by 40%.

FIGURE 1 **Global logistics by mode/functions, 2018**

Global logistics by area, 2018 ($ in billions)



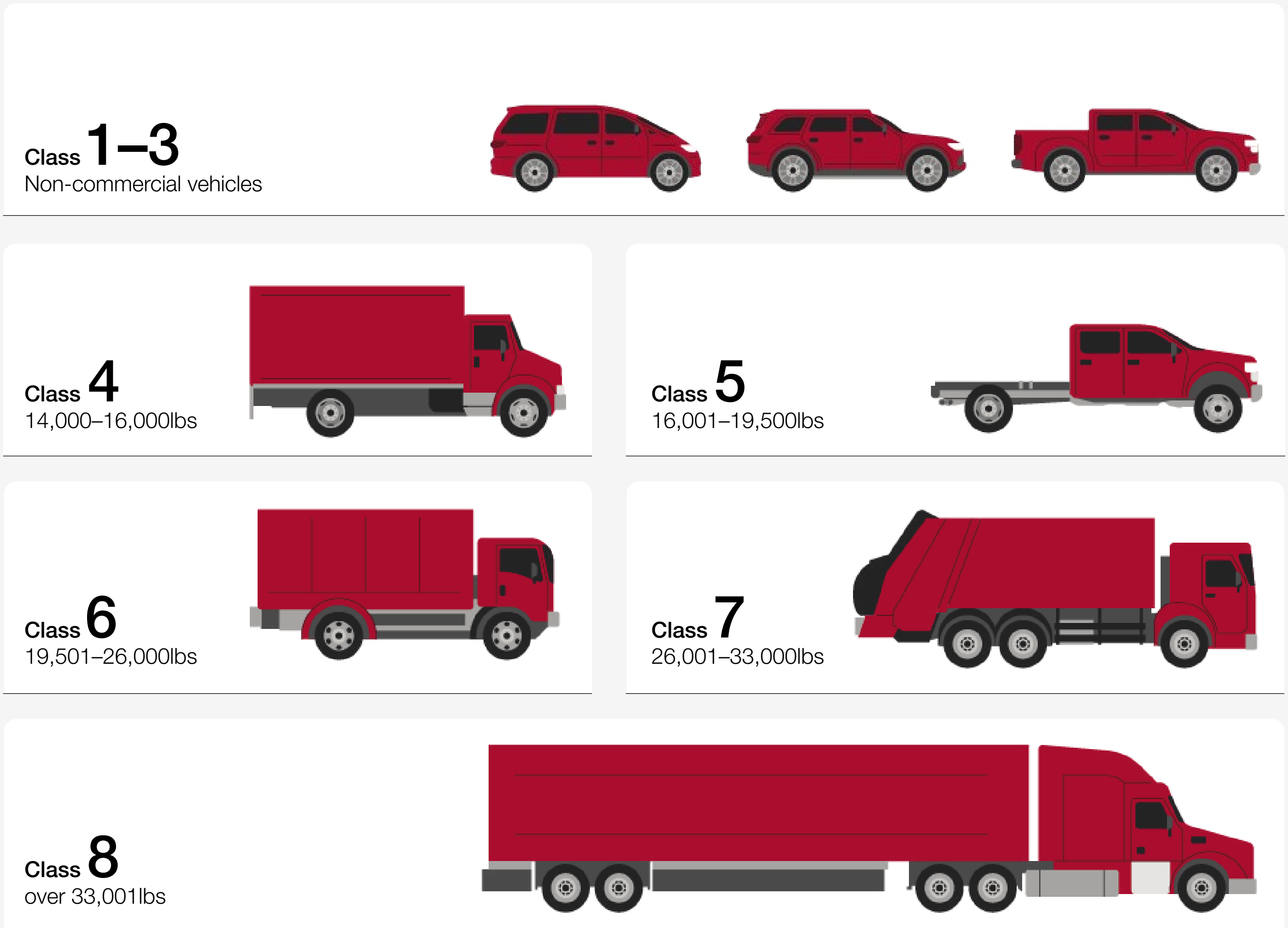
Source: Armstrong & Associates

1.2 Classification of vehicles (classes 1 to 8)

To cater to a wide variety of buyers needing different capacities and applications, trucks come in all shapes and sizes. The most common way to categorize them is by the maximum overall weight[5] that can be borne by the vehicle, known as its Gross Vehicle Weight Rating (GVWR). Global markets have distinct safety requirements, meaning the use of this weight-based classification can vary. The high freight capacity and simpler operating environments of the heavy-duty trucks defined as “Class 8” vehicles makes them the primary target for the commercialization of autonomous vehicle technology.

This paper aims to focus on Class 8 vehicles with a GVWR of more than 33,001lbs (14,969kg).

FIGURE 2 **How vehicle types are divided into classes by weight**



1.3 Increased trucking costs are creating room for disruption

❝ Rising costs are opening the door for disruption – operators will seek innovative solutions to improve efficiencies and reduce their costs.

According to the American Transportation Research Institute (ATRI)[6], the operational costs of the trucking industry in the US have increased 18% since 2010. As illustrated by the table below, this change is due to a general upwards trend in per-mile costs throughout a range of areas.

Similarly to the passenger car market, trucks are increasingly offering new technological features to improve the safety and comfort of drivers, from telematics (remote vehicle services, monitoring and location data) to advanced driver assistance systems (ADAS). Between 2010 and 2018 this has increased the cost of Truck/Trailer Payments (a metric for the per-mile cost of road haulage) from $0.184 per mile ($0.30 per kilometre) to $0.265 per mile ($0.43 per kilometre) – an increase of 44%.

The increase in the overall complexity of trucks and their systems has gradually caused a concurrent increase in maintenance and repair costs, which have risen by around 38% in almost a decade. Vehicle-based costs increased 11% in the same period, despite the decrease in fuel costs. There has also been an increase in driver-based costs: driver wages and benefits increased from $0.608 per mile to $0.776 per mile, representing a 28% rise when comparing 2018 to 2010.

Rising costs are increasing opportunities for disruption – trucking companies and large operators will seek innovative solutions to improve efficiencies and reduce their outgoings.

TABLE 1 **Average marginal costs per mile, 2010–2018**

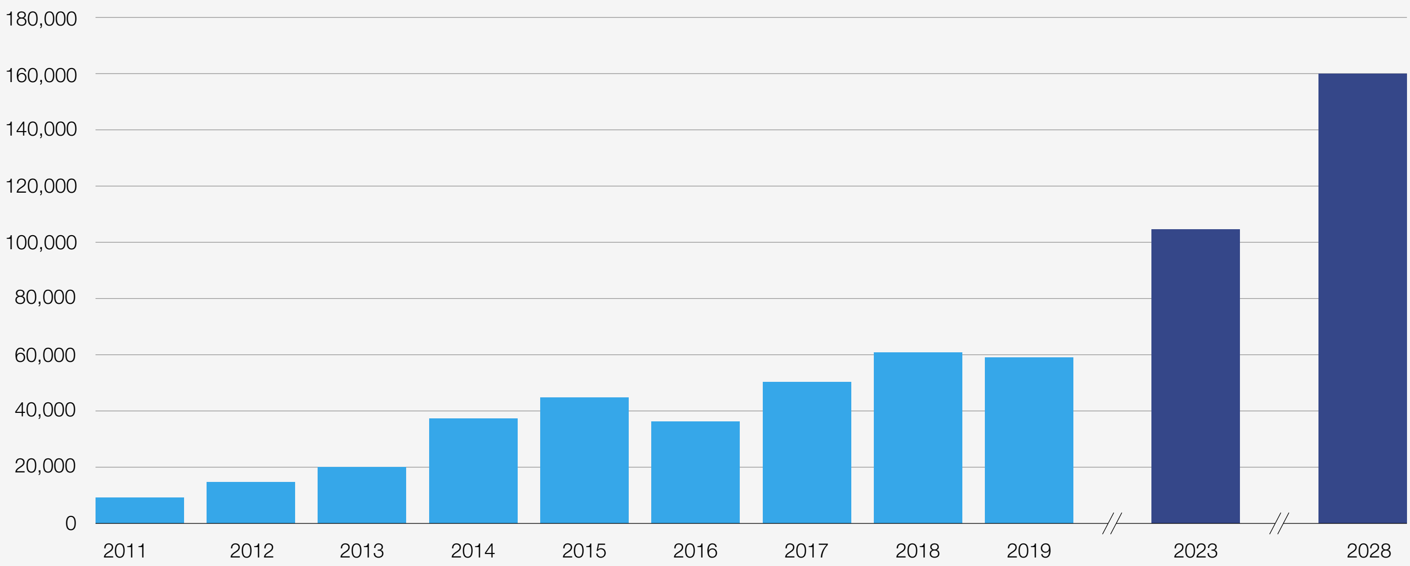
Motor Carrier Costs	2010	2011	2012	2013	2014	2015	2016	2017	2018
Vehicle-based									
Fuel costs	$0.486	$0.590	$0.641	$0.645	$0.583	$0.403	$0.336	$0.368	$0.433
Truck/Trailer Payments	$0.184	$0.189	$0.174	$0.163	$0.215	$0.230	$0.255	$0.264	$0.265
Repair and maintenance	$0.124	$0.152	$0.138	$0.148	$0.158	$0.156	$0.166	$0.167	$0.171
Truck Insurance Premiums	$0.059	$0.067	$0.063	$0.064	$0.071	$0.074	$0.075	$0.075	$0.084
Permits and licences	$0.040	$0.038	$0.022	$0.026	$0.019	$0.019	$0.022	$0.023	$0.024
Tyres	$0.035	$0.043	$0.044	$0.041	$0.044	$0.043	$0.035	$0.038	$0.038
Tolls	$0.012	$0.017	$0.019	$0.019	$0.023	$0.020	$0.024	$0.027	$0.030
Driver-based									
Driver wages	$0.446	$0.460	$0.417	$0.440	$0.462	$0.499	$0.523	$0.557	$0.596
Driver benefits	$0.162	$0.151	$0.116	$0.129	$0.129	$0.131	$0.155	$0.172	$0.180
Total	**$1.548**	**$1.706**	**$1.633**	**$1.676**	**$1.703**	**$1.575**	**$1.592**	**$1.671**	**$1.821**

Source: ATRI

1.4 Driver shortages are increasing

In the US alone, the trucking industry employs 7.95 million people, more than 3.5 million of whom work as truck drivers, an occupation dominated by men, who hold more than 90% of truck-driving jobs.[7] In 2018, the trucking industry in the US was short of approximately 60,800 drivers, an increase of 20% on the previous year, according to a study[8] by the American Trucking Association (ATA). This US driver shortage is forecasted to increase 160,000 by 2028, and that is without considering the impact of the COVID-19 pandemic. The situation is the same in most of the world's rich and developed countries, with the trucking industries in northern Europe, Australia, New Zealand, the United Arab Emirates, Saudi Arabia, Oman and Qatar all facing driver shortages.

FIGURE 3 | **Truck driver shortage in the US**



Source: Trucking.org

FIGURE 4 | **There are a number of different factors causing the trucking industry to suffer a shortage of drivers:**

Age

- The median age of 'over the road' (long-distance haulage) truck drivers is 46 – versus 42 for all US workers
- Private fleet drivers have a median age of 57
- Current age requirement to drive a tractor-trailer across state in the US is 21
- The average age at which a new driver begins their training is 35

Gender

- Women make up 6.6% of all truck drivers – versus 47% of all US workers
- The share of female drivers is fairly stagnant, increasing from 4.5% to only 6.6% since 2000
- Some trucking companies have put an emphasis on recruiting women, but even these fleets have only approximately 20% female drivers

Lifestyle

- In the period when they are new to the industry, many drivers are assigned routes that put them on the road (and away from home) for a week or two
- Driving creates a lifestyle that isn't for everybody

Alternative jobs are available

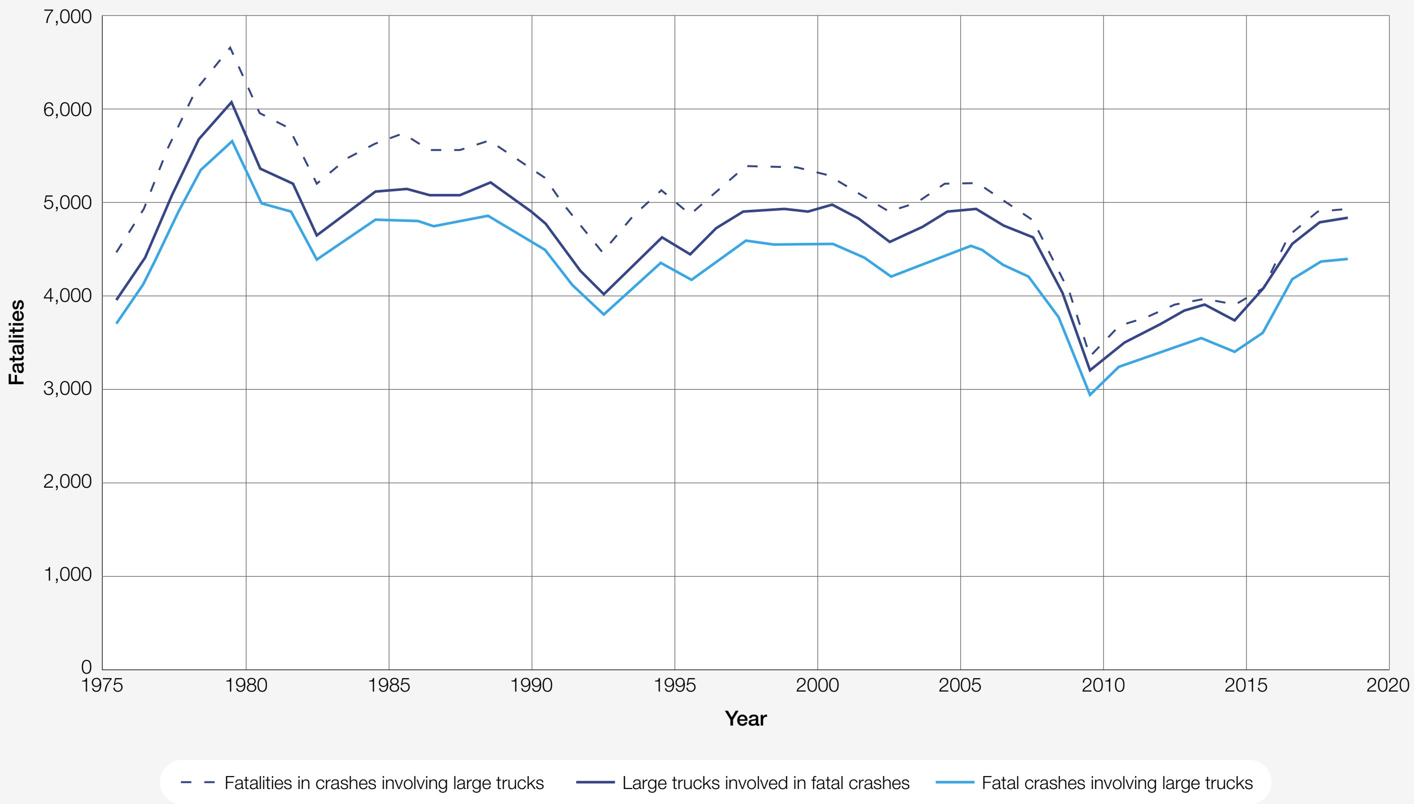
- Several years ago, the trucking industry was one of the few industries that was actively hiring people
- Today, with the job market much improved, more alternatives are available for both current and would-be truck drivers
- Until the Covid-19 crisis began, the unemployment rate recently hit the lowest level since December 1969

1.5 Drivers' mistakes are expensive

Operating a Class 8 truck is a complex task that requires significant skill. The sheer size and weight of these vehicles means that the consequences of accidents are particularly severe, with high fatality rates, so drivers receive a lot of training. The financial costs related to truck crashes are also high – when they happen, fleet owners have to not only pay for vehicle repairs but also loss of consignment, as well as driver downtime and depreciation in a vehicle's value. As a result, trucks are increasingly being equipped with new safety features and driver-alertness systems to further reduce the chance of a crash.

In the US in 2018, more than [150,000](#) people were injured in crashes involving large trucks, and [4,951](#) were killed, a figure that has been increasing since 2009. This rising trend can partly be attributed to the increasing vehicle miles travelled (VMT) in the US (by contrast, between 2016 and 2018, fatality rates per 100 million VMT by large trucks remained stable: 1.62 in 2016, 1.65 in 2017 and 1.62 in 2018).

FIGURE 5 **Fatalities in crashes involving large trucks in the US; source: US Department of Transportation/Federal Motor Carrier Safety Administration**



Source: : US Department of Transportation/Federal Motor Carrier Safety Administration

In 2017, the US National Highway Traffic Safety Administration (NHTSA) stated[9] that "[94%](#) of serious crashes are due to dangerous choices or errors people make behind the wheel". This suggests that human error is the primary cause of the vast majority of vehicle accidents, and raises key questions for those involved in the development of autonomous vehicles (AV):

– How many of those serious crashes could realistically have been prevented by a large proportion of the vehicles involved being autonomous?

– How high does the safety target need to be for AVs to be considered beneficial enough by the public to win their acceptance?

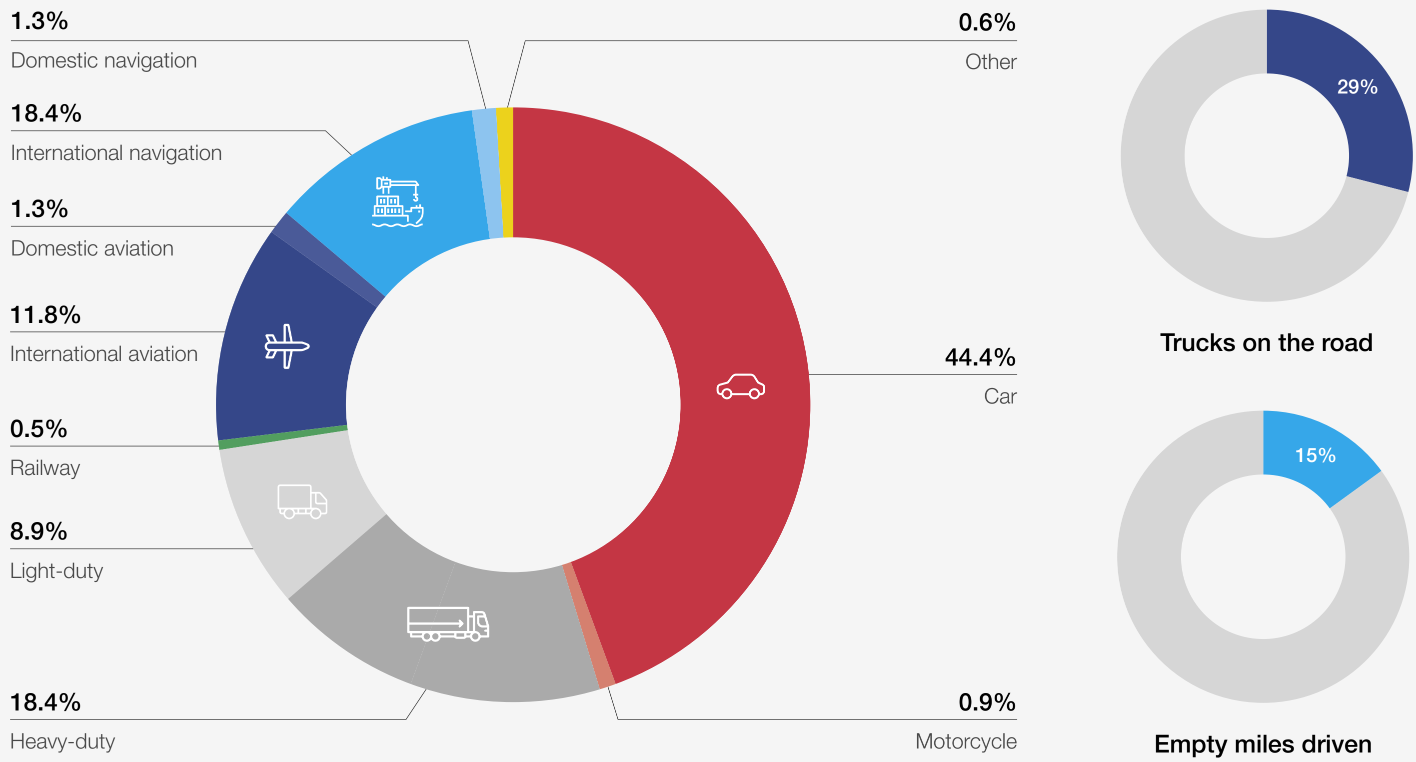
– How safe is "safe enough"?

These questions continue to underpin the efforts of regulators, NGOs, academics and developers in the pursuit of producing AVs safe enough to be put into common use, including heavy-duty freight trucks.

1.6 How automation can help mitigate environmental impacts

Globally, the transportation sector is a significant contributor to greenhouse gas emissions (GHG). In the US, approximately 27% of the nation's GHGs are produced by the transportation sector, and a rise in both the number of vehicles and vehicle miles travelled (VMT) have resulted in its being responsible for 47% of the increase in *all* harmful emissions since 1990.[10] Of the GHGs produced in the US by transportation alone, 23% come from the road transport of goods in light and heavy-duty vehicles. In the EU, this share is even higher, at 27.3%.[11]

FIGURE 6 **Share of GHGs produced by the different parts of the transport sector in the EU**



The heavy-duty industry is seeking solutions to increase the utilization of trucks to reduce "empty miles" and "deadheading" (driving with an empty trailer) – an estimated 15% of trucking miles are currently driven with no load – as illustrated in the figure shown above. Improved route optimization and more efficient vehicles can help lower that figure.

As a result of regulations, maintenance, usage issues relating to employees and technology, and other factors, trucks in Europe are on the road only 29%[12] of the time, a share that compares badly with similar businesses or manufacturing operations. These low utilization rates not only decrease the efficiency of operation and distribution for the rest of the supply chain, but also increase the number of trucks on the road, as well as the emission of GHGs.

Automation can help address these inefficiencies. A 2018 study by PwC indicates that autonomous trucks could be on the road up to 78% of the time, a figure nearly three times greater than the current industry average in Europe of 29%.[13]

This potential for greater efficiency will have wide-ranging implications in the trucking industry for all stakeholders, including the end consumer. It will also usher in a new kind of business dynamic for logistics operators, who will be able to operate with a smaller fleet of vehicles that consume less fuel (if they are not already completely electric) and run fewer empty miles – both of which will help to lower the trucking sector's GHG emissions.

1.7 Automation will impact multiple stakeholders

The trucking sector comprises three critical categories of stakeholders: the core value chain, regulatory bodies and unions.

FIGURE 7 **Overview of the key stakeholders in the trucking ecosystem**

Value chain

– Tier 1 suppliers
– OEMs
– Fleet operators
– Shippers
– Customers

Regulatory bodies

– Federal/State DoT
– NHTSA (for US)
– FMCSA (for US)
– EPA (for US)
– OSHA (for US)

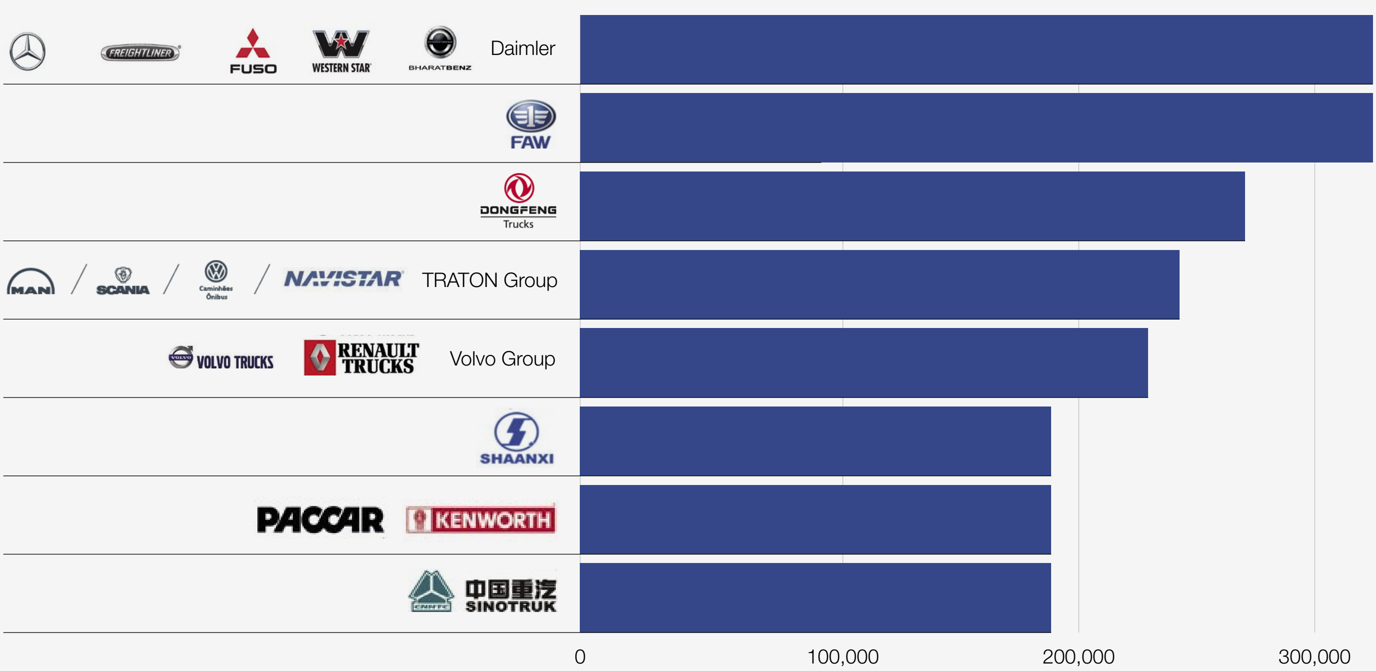
Unions

– OEM/Tier 1 manufacturing unions
– Driver unions (e.g. Teamsters in US)

Core trucking industry stakeholders

Manufacturers (OEM)
Truck manufacturers produce a considerable volume of vehicles every year. In 2019, the eight largest OEMs produced over 1.2 million vehicles between them.

FIGURE 8 **Forecasted production for heavy-duty truck manufacture in 2019[14]**



Operators
Fleet operators purchase trucks from OEMs to transport goods. There are three categories of fleet operators:

FIGURE 9 **Categories of fleet operators**

Courier and parcel

Postal and small goods transport companies (e.g. UPS, FedEx and USPS); in the US, this business is consolidated by the top three suppliers.

Private

Businesses carrying their own products (e.g. Amazon and Walmart), accounting in the US for more than 700,000 items a year.

For-hire

Companies that are paid for transporting goods they are not themselves selling (e.g. C.H. Robinson Worldwide, XPO Logistics and DB Schenker); the for-hire operator market is large and extremely fragmented: more than 890,000 for-hire carriers are registered in the US, with more than 90% of those carriers operating six or fewer trucks.

Brokers and dispatchers
Brokers and dispatchers deliver essential coordination activities in the for-hire sector. In order to locate fleet operators to move their loads, brokers work with shippers to find an operator willing to take the load, using either a physical or digital marketplace. Digital brokerage start-ups such as Navlungo[15] and Transfix[16] are seeking to disrupt the brokerage industry through automation of its conventional business process, increasing brokerage speed, transparency and profitability.

Stakeholders will each have their own agenda and priorities regarding automation, and there are differing perspectives on its benefits in relation to trucking. That said, a range of transportation companies, supermarkets and other businesses are already running pilot studies[17,18] to explore how the technology might be used, and some are even investing in start-ups to develop their own autonomous trucking solutions.

2 E-commerce will drive change

The rapid global increase in online purchasing will force the trucking industry to adapt to meet demand

Low vehicle utilization, regulations, rising fuel costs and an increasing shortage of drivers are preventing the trucking industry from meeting the growth in demand driven by a boom in e-commerce.

Global annual sales of trucks have been following a rising trend for over 20 years, reflected in a compound annual growth rate of 3.85%, as demand grew from 1.49 million units in 1996 to an all-time peak of 3.43 million in 2018 (during these two-plus decades more than 6 trillion trucks were sold worldwide). There was a decline of 3% in 2019, mainly due to falls in Asia, with a sharp drop in demand in India, and a dip in demand for medium-duty trucks in China.

While this recent decrease is a minor deviation from the long-term rising trend, the expected downturn in 2021 as a result of the COVID-19 pandemic will probably take demand substantially below its historic level. A strong contraction is expected in the sales of heavy-duty trucks worldwide, with 1.8 million units forecasted in 2020 vs. 2.4 million in 2019, a downturn of 25% year on year.[19]

There are three major trends that are driving transformation in the trucking industry around the globe:

E-commerce is growing

- China's e-commerce market is the largest in the world, with a volume of $1.94 trillion in 2019 (it currently enjoys a year-on-year growth of 27%, and represents 25% of China's GDP)

- E-commerce in the US is also at an all-time high; in 2018, retail revenues hit $315 billion (forecasted to reach $565 billion by 2023)

- As customer habits shift towards online purchasing, so too will their expectations for rapid shipping and delivery around the world

Drivers are in short supply

- Driver shortages have become a major problem in the industry globally

- In China, there is a shortfall of 4 million drivers

- The EU has a shortage of 150,000 drivers

- In the US, the driver shortfall is around 60,000 and anticipated to increase

Automation technology is developing

- Electrification and automation are receiving the highest investment in the sector, a trend also seen in the wider automotive industry

- Fuel and driver rates account for 24% and 43% of motor carrier costs respectively, and both are increasing, further emphasizing the need for logistics providers to cut costs

- With automation it is anticipated that the trucks-on-the road uptime ratio of 29% could increase to 78%

These three trends, combined with low vehicle utilization rates, regulations, rising fuel costs and an increasing shortage of drivers are preventing the trucking industry from meeting the growth in demand driven by a boom in e-commerce. As such, existing industry stakeholders, as well as new entrants, are looking to automated technology to provide fresh solutions. By increasing fleet utilization and driver capacities, and improving fuel savings, automation would enable trucking operators to more easily solve a range of daily challenges.

3 How to automate a truck

Enabling a truck to make driverless journeys will rely on a complex interaction between specialist hardware and software

To do this you need an automated driving system (ADS) comprising three elements: computing hardware, software systems and a set of sensors.

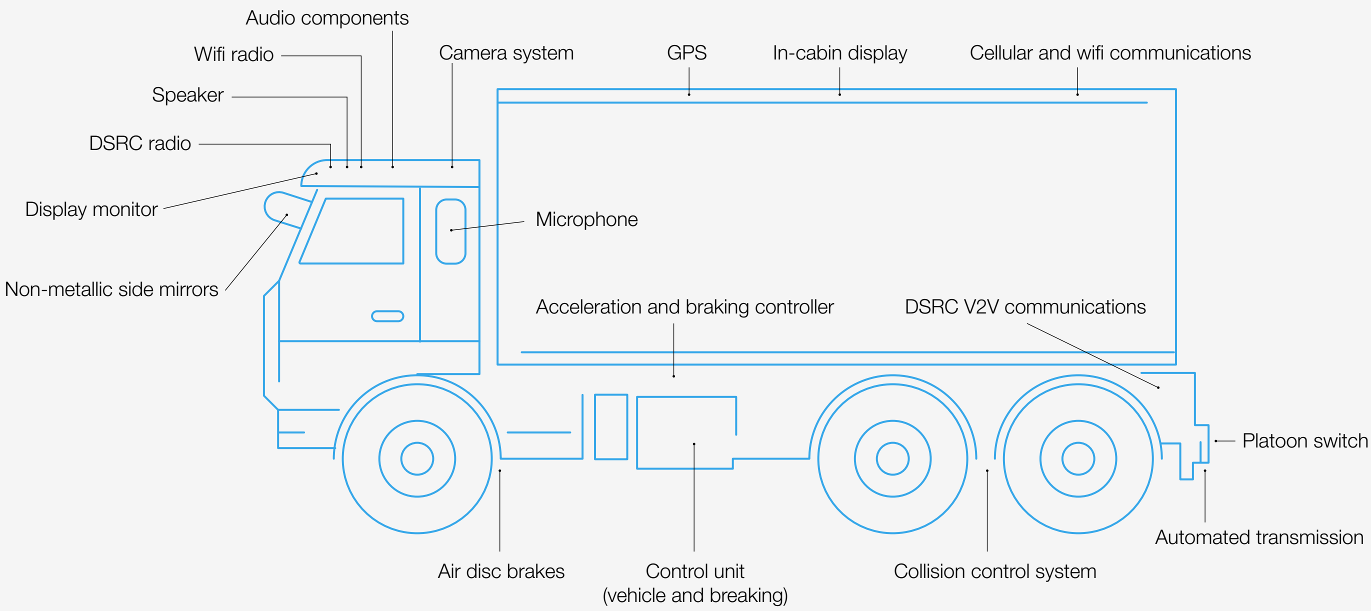
As both the requisite hardware and software are still being developed, it is impossible to offer a clear estimate on the final cost of developing an autonomous vehicle. However, as the technology matures over the next few years, it is expected that costs will significantly decrease.

All or a combination of some of the following hardware could be used, depending on a range of factors including the developer's engineering and design choices, the use case and vehicle type:

- LIDAR remote sensors (high, mid or low resolution)
- GMSL multi-stream camera
- Ultrasonic sensors
- Thermal imaging
- Long/short range radar
- GNSS (Global Navigation Satellite System)
- ECU (control unit for the driver-assistance systems): the 'brain' of the truck

The cost of a system made up of different combinations of these hardwares is estimated to be between $60,000 to $150,000 per truck, depending on application and sensor configuration. By contrast, it is far harder to forecast software costs on a per unit basis given the vast range of OEM investments and venture-funded AV start-ups involved in the development landscape. However, industry analysts are able to project *development* costs for software, estimating that creating a robust "Level 4 Highway Pilot" system (i.e. one capable of handling the majority of driving situations independently) would require an investment of at least $100 million.

FIGURE 10 **Example of the elements required to automate a truck**[20]



4 Automation's benefits for the trucking industry

Driverless trucks offer the chance to reduce costs and emissions, as well as to enhance logistics and lifestyles

4.1 Benefits across the board

The trucking industry faces a wide range of issues that automation would help mitigate or even eradicate; the various benefits are grouped below.

The increased efficiencies enabled by automation will have a range of impacts on the daily lives of consumers:

- The time it takes to receive packages will be reduced
- Delivery costs will decrease
- There will be more choice about which country to buy something from, given delivery cost will be a less important factor in calculating overall cost
- The state of the environment will improve as greenhouse gas emissions are reduced

FIGURE 11 **The benefits of using automation technologies in trucking**

Safety	– Reduced number of road accidents and fatalities – Prevent or minimize severity of accidents
Productivity	– Prognostics and diagnostics help reduce vehicle downtime – Leverage potential of network operations and accessibility
Comfort and convenience	– Offers a user-centric approach to comfort – Driver-assisted technologies create a less stressful and less tiring work environment
Experience	– In-vehicle infotainment and connected interactive systems – Enables non-driving activities such as office work, sleeping and eating
Environment	– Reduces fuel consumption and therefore emissions – Minimizes the carbon footprint of vehicle journeys
Maintenance and repair	– Increased diagnostic data can enable preventative and more efficient maintenance – New revenue opportunities related to software handling
Fleet logistics	– Improved productivity, asset utilization and profitability – Increased data for fleet-performance analytics
Driver benefits	– Increased safety – More efficient use of operator hours
Manufacturer opportunities	– Increased revenue from service-based business models – In-depth insights into a customer's vehicle use and lifestyle can expose new sales opportunities
Supplier opportunities	– New market opportunities for software-based solutions

4.2 How automation could adapt the supply chain

When we analyse the typical supply chain in the US (similar to those in Canada and Australia, etc.) it is clear that there are four different kinds of journey; a simplified schematic of a supply chain is shown below.

The “middle mile” (in which freight is transferred from hub to hub) constitutes the longest portion of the supply chain in places such as the US, Canada, Australia, Saudi Arabia, etc. The longer this section is, the better the use case gets for automation. Given the routine, hub-to-hub nature of this leg, it is expected that autonomous long-haul trucks (Level 4) will eventually travel unmanned from depot/warehouse to depot/warehouse while being monitored by fleet employees who can address any issues that may arise. These driverless trucks will move along the highway in geofenced lanes (which will allow constant virtual monitoring).

The operation of autonomous trucks in this context will help significantly reduce the problem of driver shortage that currently plagues the trucking industry. Additionally, truck drivers (or engineer operators) will have improved work conditions, and the number of days they are away from home will be reduced. There are further opportunities for efficiency gains in freight transportation, resulting in lower shipping costs for all stakeholders. Moreover, traffic flow could improve due to better-utilized assets and a potential increase in night operations.

FIGURE 12 **Schematic of a simplified manufacturer-to-end-customer freight supply chain (2020)**

First mile

Move goods to hubs and warehouses along fixed freight corridors

Minimal impact from domestic traffic measures

Middle mile

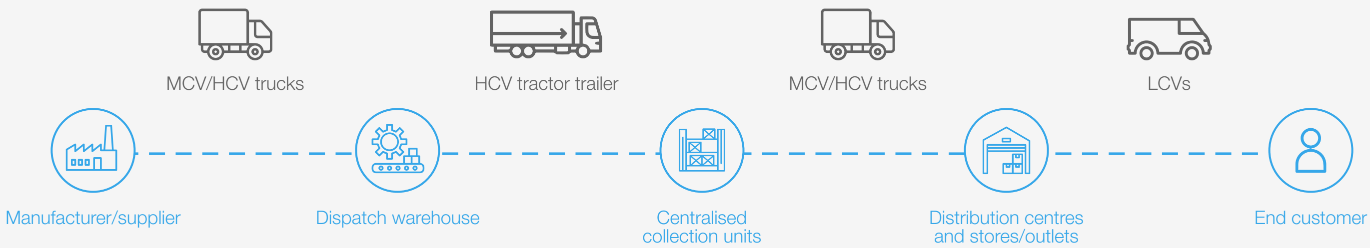
Exchange of goods between major regional hubs; transport of goods along interstate highways, cross-border corridors and freeways

Relatively uninterrupted operations; minimum human effort needed

Last mile

Frequent stops/multiple delivery points; each trip varies according to the route and delivery order

Dense distribution of pedestrians and cyclists, plus intersections, sharp turns and traffic lights; in the future, delivery bots, drones and storage kiosks would be used



Distance	Less than 60 miles	More than 300 miles	Between 60 and 90 miles	Less than 30 miles
Speed	Moderate	High	Moderate	Low
Terrain	Industrial/Semi-urban	Highway	Semi-urban	Urban
Ease of automation	Moderate	High	Moderate	Low

In terms of finances, when calculating benefits for different applications of autonomous trucks the following assumptions could be made for an example in the US (*See Table 2*).

As previously mentioned, of the $1.821 per mile carrier cost in the US, driver wages/benefits and fuel costs are the biggest cost elements, accounting for $0.776 and $0.433 respectively. The base scenario shows significant improvements on existing costs and it is expected that automation will have a marginal net positive impact for the logistics industry, and therefore for the end consumer too.

TABLE 2 **Cost per mile % change**

	Worst scenario	Base scenario	Best scenario
Reduction in fuel costs	-5%	-8%	-10%
Reduction in driver costs	-50%	-79%	-90%
Saving on insurance	0	-5%	-10%

5 A rapidly growing industry

Industry experts anticipate that trucking will be the first sector to use commercial applications of automated driving

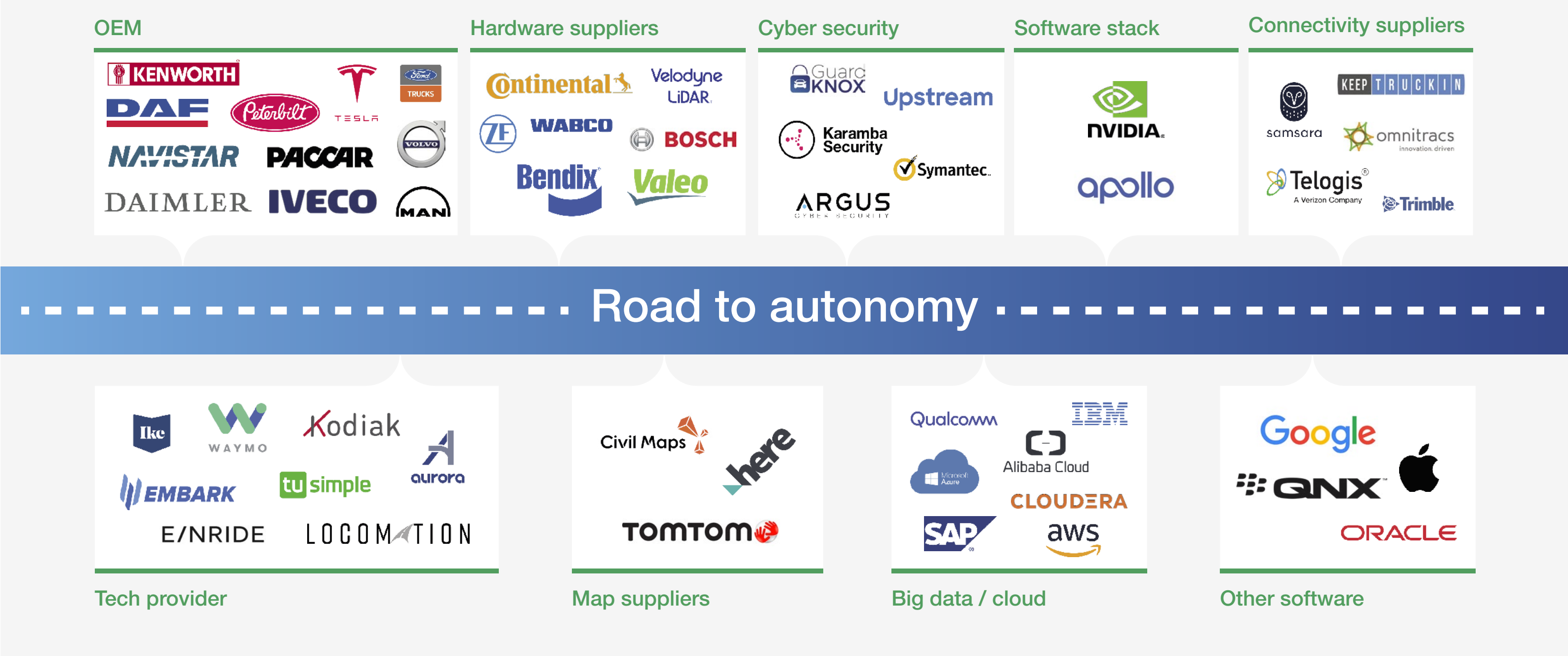
Globally, the autonomous driving sector has seen an estimated $33.8 billion investment since 2010, and, after a decade of development, commercial applications of the technology are beginning to emerge. Industry experts anticipate that trucking will be the first sector to use commercial applications of automated driving, for a number of reasons.

Together with technology providers, OEMs are increasing their efforts to push things forwards and are also beginning to join forces. Daimler and Waymo recently formed an alliance[21], one similar to the strategic partnership announced in 2020 between TuSimple[22] and Traton Group (Volkswagen AG's heavy-truck unit).

Hardware suppliers, software developers, map suppliers, cloud partners, content suppliers and connectivity providers will all play important roles in delivering a market-ready autonomous truck. The following graphic shows most of key players in the world of autonomous trucking in 2020:

FIGURE 13 **Most of the key players in the global ecosystem of autonomous trucking**

Autonomous trucking global ecosystem, 2020



5.1 A means of applying automation to trucking

In the last few years, technology developers have been running a series of AV-related pilots: manned-conditional autonomous trials, centralized remote operations, interstate long haul and geofenced distribution with regulatory supervision. Some of the tech providers plan to commercialize their solutions before 2023, whereas many OEMs have longer term plans for the deployment of automated solutions. As a result, the coming decade will see a significant increase in the testing of autonomous trucks across a range of use cases.

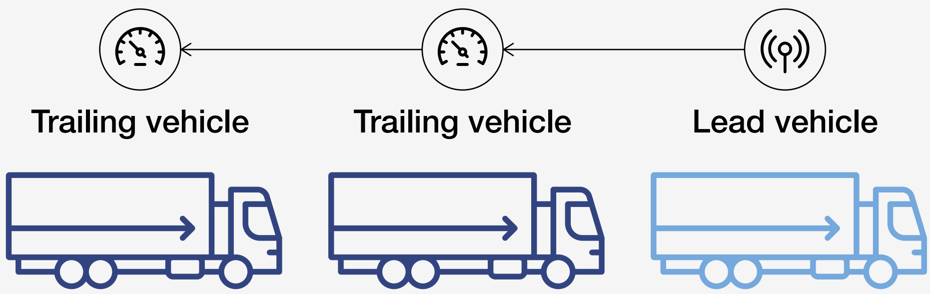
Truck platooning is considered to be the first viable commercial application for AV technology.[23] First-generation versions of this convoy technology have been developing steadily for some time, and are currently poised for commercial launch.

Platooning relies on one driver manually operating a "lead truck", supported by active safety systems. The "follow" drivers steer, monitor the road, and respond as needed to other traffic (for example, changing lane to allow traffic to merge onto the highway), but the platooning system regulates all these vehicles' speed, allowing them to closely mirror the lead truck's pace and thus minimize drag. Because this system simply controls the vehicle's speed, it constitutes an SAE Level-1 driver-assistance system. Drivers are ultimately responsible for determining when to engage the system, and "follow" drivers must agree to platoon. These systems are forecast to decrease the total cost of ownership by 1%[24] mainly as a result of increased fuel efficiency.

FIGURE 14 **Truck platooning[25]**

Truck platooning is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems. These vehicles automatically maintain a set, close distance between each other when they are connected for certain parts of a journey, for instance on motorways.

The truck at the head of the platoon acts as the leader, with the vehicles behind reacting and adapting to changes in its movement – requiring little to no action from drivers. In the first instance, drivers will remain at all times, so they can also decide to leave the platoon and drive independently.



Platooning is considered to be the first viable commercial application for AV technology.

In second-generation "automated following" platooning systems, the follow trucks operate autonomously at SAE Level 4 (meaning they do so without the need for human intervention in their intended operational domain), while the lead truck is driven normally. The Operational Design Domain (ODD) is tightly defined, encompassing the lead truck and any activity in the inter-vehicle gap. The lead truck driver is supported by advanced driver-assistance systems (ADAS), such as Forward Collision Warning (FCW) and Forward Collision Mitigation (FCM). Fuel savings and enhanced driver productivity in the lead truck, and labour savings in the follower trucks greatly enhance return on investment rates. As a result of these enhanced efficiencies, the total cost of ownership (TCO) is forecast to decrease by 10%.[26,27]

Both start-ups and OEMs are actively developing platooning solutions; major players such as Volvo, Scania, MAN and Ford Otosan[28] have already tested prototypes.

5.2 Achieving high-level automation in stages

Autonomous trucking will not have a single launch date – incremental pilot schemes will gradually lead to deployments in supported geographic areas.

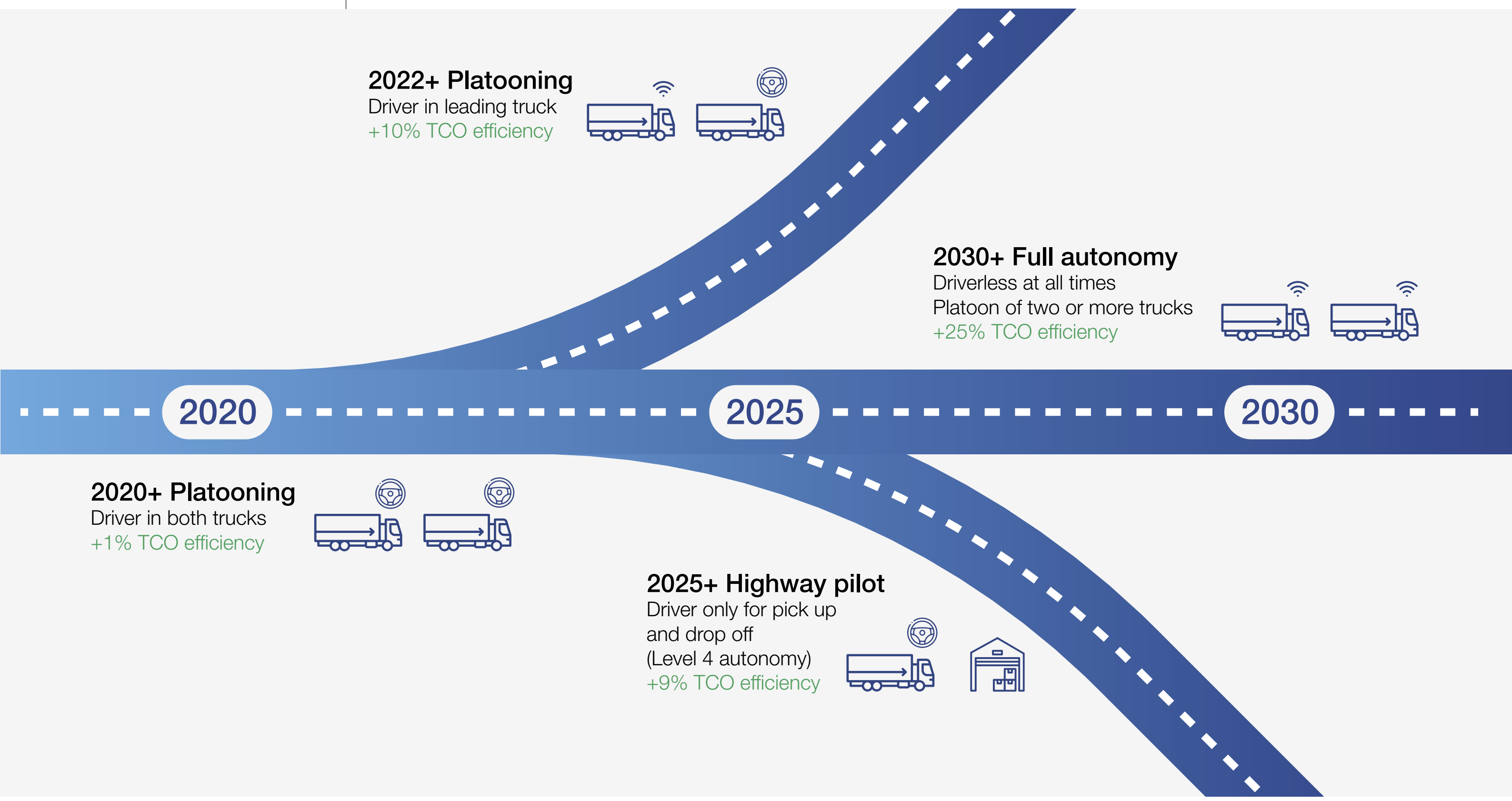
Industry stakeholders anticipate that from 2025 onwards, autonomous trucks will be deployed in a constrained fashion (SAE Level 4) on international/interstate highways, and in selected test zones where environmental factors and infrastructure meet certain conditions. These initial deployments will rely on drivers getting the vehicles to and from the highways, and seeing that the system can be safely engaged once on the highway. This application has the potential to decrease the total cost of ownership (TCO) by a further 9%.

It is anticipated that around 2030 these pilots will gradually scale up to widespread deployments of autonomous trucks with no drivers, a change that has the potential to reduce TCO by 45%.

Deloitte anticipates that automated trucking will not have a single launch date.[29] It is likely that instead, as the systems of AV companies mature and they are able to expand their logistical capabilities, incremental pilot schemes will gradually lead to deployments in supported geographic areas. A complex interplay between technological, economic and regulatory incentives and limitations, as well as companies' readiness to reassess well-established operations and footprint, will drive the pace at which this occurs.

To help answer the "Where?" question, Deloitte has developed a solution for scenario planning, the Self-Driving Truck Adoption Rollout Method,[30] which aims to capture data about this dynamic interplay of factors and use it to forecast the growth in the adoption of automated trucking in the US over the next 20 years. According to this study, Stage 1 will run from 2020 to 2025 and will see autonomous vehicles being used predominantly in the Southwest; Stage 2 will include expansion into the Midwest and Southeast, from 2025 to 2030; and from 2030, deployments will expand to all other parts of the country. We foresee a similar pace for the process of adoption of automated trucking in other areas of the world, such as the EU and China, and that it will be one that is also characterized by a number of phases.

FIGURE 15 **Deployment road map for autonomous trucks**



6 A range of problems to solve

Unlocking the full potential of driverless trucks will rely on progress across a number of sectors

A number of major commercial challenges need to be faced in the process of enabling the transformation of the trucking industry from one that relies on traditional logistics operations to one that relies on automated trucking.

Firstly, the business case for fully autonomous trucks is still unproven. Companies continue to invest heavily into AV development, and many start-ups have already folded, claiming that autonomous technology currently offers a poor return on investment.[31]

Technological developments aside, policymakers are continuing to learn about AVs in order to anticipate how to govern them in future – but the pace of sketching out future regulation is likely to lag behind that of development. How will regulations support this transformation without creating extra burdens in the industry? Truck OEMs and software developers will need the full support of government bodies in order to launch commercial services at scale.

The prospect of autonomous trucking suggests a diverse range of challenges:

FIGURE 16 **Challenges in the development of autonomous trucking**

	Current	Future
Cost	Technical performance of the fleet, managing a diversified fleet, transport, vehicle/route planning	Technology and manufacturing are expected to be the biggest items of expenditure
Data and cyber security	Availability of qualified professional drivers, drivers' attitude to work, driver training	Implementation of certified safety measures against hacking threats
Safety and liability	Hazardous material transportation, impending collision warning, vehicle and driver security	In the event of an accident, the vehicle manufacturer and technology provider will be liable (liability is still being debated)
Infrastructure investment	Single portal to view, manage and control the entire fleet, 24/7 connectivity, fuel station and parking spots, toll systems	Requires a large communication network range to enable vehicle-to-vehicle and vehicle-to-infrastructure communications
Government support	Delivery time management, maintenance scheduling, time of delivery, customer satisfaction, hours of service	Region-wide mandates are required for a standardized legal framework for the manufacturing and operation of autonomous vehicles
Acceptance	Fleet acceptance: service cost, fuel savings, empty runs, fuel emissions	Social acceptance: continued consumer education and training will be crucial

Another important area to evaluate will be the implications of automation on the workforce. Although driver shortage is a pressing global issue for the trucking industry, it is important to understand that long haul drivers are paid more than last-mile delivery drivers. It is forecasted that in the US, around 274,000 drivers will be affected by this seismic shift in technology, and it is critical that all stakeholders find a working model for long-haulage drivers,[32] not only to understand the likely shift in the demand for qualified drivers, but also the changing skills requirement in shifting from driver to engineer operator.

7 The need for new regulatory frameworks

Legislative change will be critical in moving autonomous trucking towards market-ready solutions

Trucking is already subject to considerable regulation in developed markets, and introducing new regulations, frameworks and other policies always involves a lengthy process that impacts multiple stakeholders, including those at various levels of government (local, national and international). The fact that so many different agencies have a stake in ensuring the safe operation of autonomous trucks creates tension, as well as differing perspectives on the best way to safely deploy them.

Regulatory changes and new frameworks governing the function, deployment and operation of automated driving systems will be a critical factor in the commercial adoption of autonomous trucks.

7.1 Global legislative initiatives for testing AVs

Regulatory changes and new frameworks governing the function, deployment and operation of automated driving systems will be a critical factor in the commercial adoption of autonomous trucks.

Pilots that study, trial and refine new policies will be crucial for facilitating the deployment of autonomous vehicles in all applications, including trucking. Insurance providers, automotive companies, government and societal stakeholders must collaborate for developing these frameworks.

China

In 2018, China released a set of national guidelines for AV testing that included a requirement that they first be carried out in non-public zones. Road testing is only permitted on designated streets, and with a driver present to take control of the vehicle if necessary. Autonomous driving has become a priority for China, both to aid its ambitious industrial policies and to establish itself on a technological par with Western countries.

North America

There is no comprehensive federal policy in place for AV testing and states have enacted their own legislations for testing and deployment of on-the-road vehicles.

– The US Congress is in the process of drafting AV legislation with a stronger focus on safety after in 2018, both the Safely Ensuring Lives Future Deployment and Research in Vehicle Evolution Act (SELF DRIVE) and the American Vision for Safer Transportation Through Advancement of Revolutionary Technologies Act (AV START) failed to pass through the Senate.

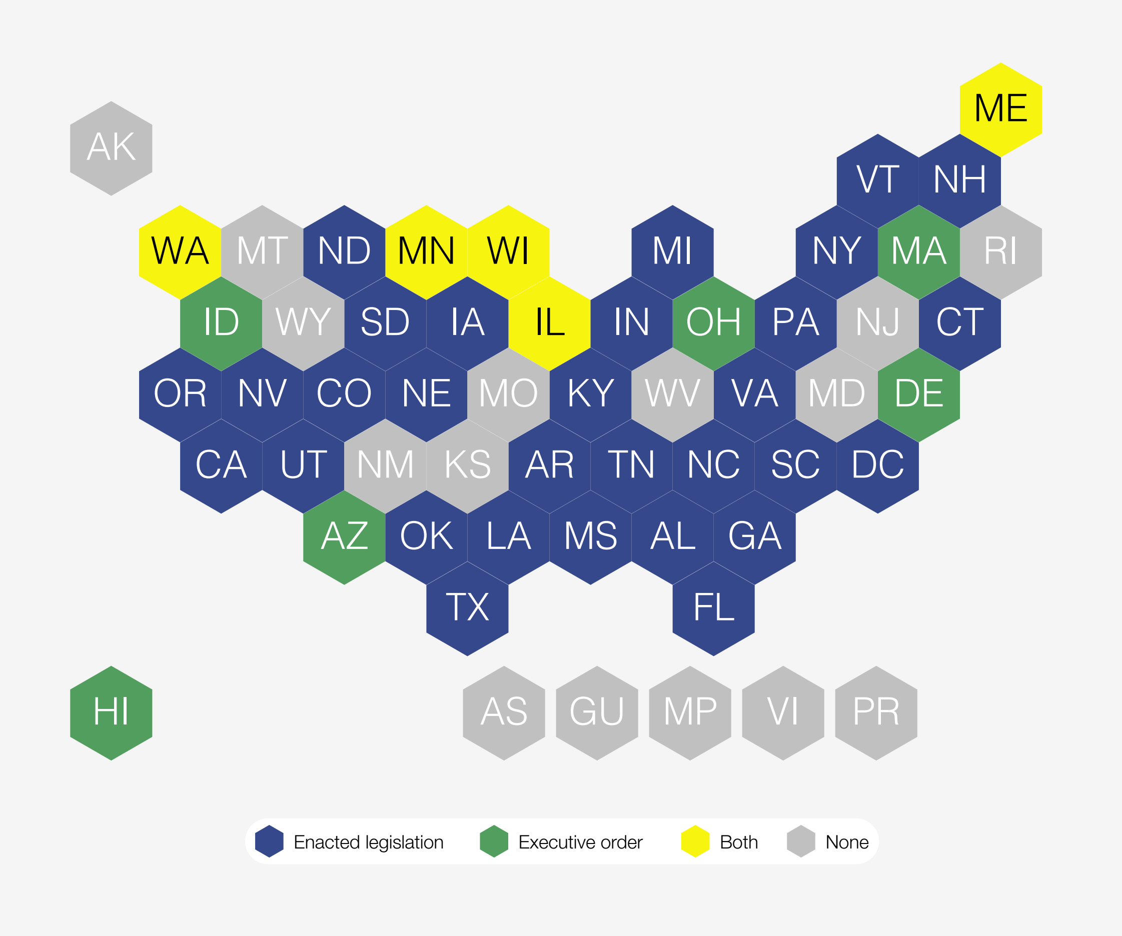
– The US Department of Transportation is currently seeking opinion from industry stakeholders on recently announced plans to introduce a “comprehensive framework” for autonomous vehicles, and amend existing Federal Motor Vehicle Safety Standards (FMVSS).

– So far, 41 US states and the District of Columbia have enacted laws or issued executive orders that relate to autonomous vehicles.[33]

– Each state has different permit requirements for licensing autonomous vehicles. For example, Tennessee does not require any operator in the vehicle during the pilot, whereas an operator is mandatory in Michigan, and California has created a graduated licensing system to allow AV developers to move forwards with driverless operation.

– Texas is a major on-road testing location for several AV companies; in addition, Daimler has started tests of autonomous trucking in Virginia.

FIGURE 17 **States with autonomous vehicles enacted legislation and executive orders**



Asia Pacific and Oceania (APAC)

Japan, South Korea and Singapore are undertaking trials in autonomous technology development in the APAC and Oceania region.

The Singapore Autonomous Vehicle Initiative was set up by the Land Transport Authority for the testing of automated vehicles on public roads.

Japan has made amendments to the Road Traffic Act to allow Level 3 vehicles on public roads in 2020.

Europe

The testing of AV technology has been taking place in European countries under ad-hoc legal permits, so there is a growing need to develop a harmonized standard that applies across all member states of the EU.

In Germany, the UK, France, Italy and Spain AV testing permits require a driver to be present during testing, whereas in the Netherlands and Sweden it does not require the driver, provided approval is granted by the local authority.

The UK has implemented a voluntary code of practice for AV trials that provides guidance to developers as to how to operate autonomous vehicles on UK roads in compliance with UK law.

Germany has introduced regulations that allow for use of automated lane-keeping systems (ALKS) (SAE L3) and plans to release a regulatory framework in 2021 to allow for Level 4 vehicle deployment.

France released a roadmap for AV technology testing in 2014, a framework which defines pilot zones and authorizes on-road testing for schemes using both partial and high-level AV. The country has established a plan (begun in 2020) to incorporate supervised AVs into public transport, and plans to place Level 4 AVs on public roads by 2022.

Companies in Sweden are allowed to test highly automated vehicles on public roads in restricted areas, provided that the Swedish Transport Agency has granted them special permission to do so. The government permits vehicles without a human inside the vehicle, but an operator must be able to operate the vehicle remotely. Both Volvo and Einride have been testing driverless AVs in Sweden.

Since 2015, the Netherlands has been enabling supervised tests on AVs on public roads. In 2019, with the prior approval of the Minister of Infrastructure and Water Management, the Netherlands Vehicle Authority, the police, the road authorities and the Institute for Road Safety Research (SWOV), the country allowed the testing of unmanned autonomous trials on public roads for a limited period of time.

In 2018, Italy released a framework allowing for public road-testing of AVs. Stipulations included that all experiments must be carried out "under conditions of absolute safety", that findings be shared with the government, and that during testing a driver be present in each vehicle.

Spain is currently working on creating a legal framework for AV. The Dirección General de Tráfico recently announced a roadmap proposal described as a "strategic plan for the vehicle of the 21st century", and is currently collaborating with Mobileye on a project that will deploy 5,000 AV vehicles in Barcelona, turning the city into a full-scale test site.

More information on global AV policy approaches can be found in the Forum's recent publication *Creating Safe Autonomous Vehicle Policy*.

7.2 Regulatory gaps that need to be addressed

Policy pilots will assist governments and authorities in creating and refining policies that will help enable stakeholders to benefit from AV technologies. The Forum has identified a range of areas that need to be addressed in the form of policy over the coming decade:

Driver

There is an opportunity to revisit the number of hours a driver can work (Driver Hours or Hours of Service) when operating trucks at Level 3 or above, to help them log more consecutive hours while driving in autonomous mode, time during which the driver will likely experience less cognitive load, even potentially resting during periods when the technology takes control.

A framework is needed to outline the level of driver involvement (hands on/hands off/sleeping) above trucks operating at Level 3 or above.

Safety

By 2025, companies will be required to install advanced safety systems (involving sensors, cameras, electronic controls and stabilizing technology) in AV trucks in some markets, to encourage the safe deployment of this kind of vehicle on public roads.

Before drafting policies, governments need to determine the conditions and locations that allow for the safe operation of autonomous trucks (weather conditions, particular stretches of highway, not within city limits, etc.).

Cyber security

Cyber security regulations will be adapted to the trucking industry; agile policies will be key as hackers constantly find new ways to breach security.

A standardized cyber security approach may not be optimal as particular vulnerabilities could become a security risk across the industry.

Communication networks

Companies will have to be mandated to install all heavy-duty trucks with vehicle-to-vehicle communication technology, to relay information relating to speed, direction and braking; current proposals have dedicated short-range communications (DSRC) as the technology of choice.

The development of 5G communication networks will be crucial in connecting the entire ecosystem at speeds fast enough to unlock the full potential of autonomous vehicles.

Liability

Insurers, system developers, government and societal stakeholders need to collaborate to develop a liability framework that is both consistent and appropriately considers shifts in risk and culpability.

Shifting liability from the driver to the automated driving system could be a related outcome of the development of AV driving technology in trucks.

Conclusion

Although autonomous trucking still faces challenges on many fronts, such as technology, governance and commercial return, many people think that the industry will present the first viable business case for the application of this emerging technology. It not only offers significant benefits to the environment but also an enhanced quality of life for drivers.

To enable the industry to more quickly achieve the first viable business case, we should focus carefully on a range of stakeholder problems: industry wants interoperability and clear regulations; society wants to better understand the technology and to enjoy its benefits; regulators want to be part of the solution without putting anyone in danger, while facilitating the deployment of a potentially beneficial technology.

This new era of transport will feature many unknowns, so public-private cooperation remains crucial in the piloting and development of new governance solutions that will enable a safer and more efficient transportation ecosystem.

Contributors

The World Economic Forum's **Platform for Shaping the Future of Mobility** is leading a portfolio of research projects aimed at empowering regulators to develop successful AV policies and improve the safety of pilot programmes relating to AV technologies.

With the support of our research fellows, and partners at Ford Otosan, this project has engaged leaders from private companies, governments, civil society organizations and academia, enabling them to understand AV policy, identify challenges and define principles that can guide future policy solutions.

Please note that the opinions expressed in this report may not correspond with the opinions of all members and organizations involved in the project.

Lead authors

Tim Dawkins
Lead, Automotive and Autonomous Mobility, World Economic Forum

Canalp Gündoğdu
Smart Mobility Manager, Ford Otosan
Automotive and Autonomous Mobility Fellow, World Economic Forum

Endnotes

1. "How big is the logistics industry?", *Freightwaves,* 11 January 2020, https://www.freightwaves.com/news/how-big-is-the-logistics-industry
2. "Global Freight Trucking Industry", *Reportlinker,* September 2020, https://www.reportlinker.com/p05960941/Global-Freight-Trucking-Industry.html?utm_source=GNW
3. "Trucking Moved 11.84 Billion Tons of Freight in 2019", *American Trucking Associations,* 13 July 2020, https://www.trucking.org/news-insights/trucking-moved-1184-billion-tons-freight-2019
4. "Total revenue of the trucking industry in the United States from 2014 to 2019", *Statista,* 3 August 2021, https://www.statista.com/statistics/922817/trucking-industry-united-states-total-revenue/#:~:text=U.S.%20trucking%20
5. "Truck classifications by gross vehicle weight", *Camden, Matthew C.*, September 2017, https://www.researchgate.net/figure/Truck-classifications-by-gross-vehicle-weight_fig2_323492305
6. "An Analysis of the Operational Costs of Trucking: 2019 Update", *American Transportation Research Institute,* November 2019, https://aktrucks.org/wp-content/uploads/2020/01/doc01315520200106124920.pdf
7. "Number of Truckers at All-Time High", *United States Census Bureau,* 6 June 2019, https://www.census.gov/library/stories/2019/06/america-keeps-on-trucking.html
8. "Truck Driver Shortage Analysis 2019", *American Trucking Associations,* July 2019, https://www.trucking.org/sites/default/files/2020-01/ATAs%20Driver%20Shortage%20Report%202019%20with%20cover.pdf
9. "How safe is 'safe enough' to put driverless cars on the nation's roadways?", *The Washington Post,* 10 December 2017, https://www.washingtonpost.com/local/trafficandcommuting/how-safe-is-safe-enough-to-put-driverless-cars-on-the-nations-roadways/2017/12/10/9a1aa348-d519-11e7-b62d-d9345ced896d_story.html
10. "US Transportation Sector Greenhouse Gas Emissions 1990-2015", *United States Environmental Protection Agency,* July 2017 https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100S7NK.pdf
11. "The Environmental Impacts of Transportation"*, Rodrigue, Dr. Jean-Paul,* April 2016, https://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html
12. "The era of digitized trucking: Charting your transformation to a new business model" , *PwC,* 13 September 2018, https://www.strategyand.pwc.com/gx/en/insights/2018/digitized-trucking.html
13. Ibid.
14. "The world's truck manufacturers – 2020 edition", *Automotive World,* 7 May 2020, https://www.automotiveworld.com/research/data/the-worlds-truck-manufacturers-2020-edition/
15. "Navlungo – Home", *Navlungo,* 2021, https://navlungo.com/
16. "Transfix – Home", *Transfix,* 2021, https://transfix.io/
17. "TuSimple plans autonomous truck network backed by UPS", *Venturebeat*, 1 July 2021, https://venturebeat.com/2020/07/01/tusimple-plans-autonomous-truck-network-backed-by-ups/
18. "Amazon is hauling cargo in self-driving trucks developed by Embark", *CNBC,* 30 January 2019, https://www.cnbc.com/2019/01/30/amazon-is-hauling-cargo-in-self-driving-trucks-developed-by-embark.html
19. "The world's truck manufacturers – 2020 edition", *Automotive World,* 7 May 2020, https://www.automotiveworld.com/research/data/the-worlds-truck-manufacturers-2020-edition/
20. "Bosch invests in Trunk for autonomous trucking solutions", *Autocar Professional,* 30 September 2019, https://www.autocarpro.in/news-international/bosch-invests-in-trunk-for-autonomous-trucking-solutions-44222
21. "Waymo Forges Robot Truck Alliance With Daimler", *Forbes*, 27 October 2020, https://www.forbes.com/sites/alanohnsman/2020/10/27/waymo-forges-robot-truck-alliance-with-daimler/?sh=6276b7625ae2
22. "Volkswagen's Truck Unit Ties Up With TuSimple On Robot Big Rigs", *Forbes,* 23 September 2020, https://www.forbes.com/sites/alanohnsman/2020/09/23/volkswagens-truck-unit-ties-up-with-tusimple-on-robot-big-rigs/?sh=1087a95b7705
23. "Will Truck Convoying Be The First Viable Commercial Application For AV Technology?", *Forbes,* 21 March 2020, https://www.forbes.com/sites/rahulrazdan/2020/03/21/will-truck-convoying-be-the-first-viable-commercial-application-for-av-technology-/?sh=5e88a3a41454
24. "Distraction or disruption? Autonomous trucks gain ground in US logistics", *McKinsey & Co.,* 10 December 2018, https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/distraction-or-disruption-autonomous-trucks-gain-ground-in-us-logistics
25. "Truck Platooning Roadmap", *European Automobile Manufacturers Association,* 2017, https://www.acea.be/uploads/publications/Platooning_roadmap.pdf
26. "Distraction or disruption? Autonomous trucks gain ground in US logistics", *McKinsey & Co.,* 10 December 2018, https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/distraction-or-disruption-autonomous-trucks-gain-ground-in-us-logistics

27. “Where Does Auto-Follower Platooning Fit Within The Driverless Truck Ecosystem?”, *Forbes,* 30 August 2019, https://www.forbes.com/sites/richardbishop1/2019/08/30/where-does-auto-follower-platooning-fit-within-the-driverless-truck-ecosystem/?sh=633d6ebc3c0c
28. “Ford Otosan - Home”, *Ford Otosan,* 2021, https://www.fordotosan.com.tr/en
29. “Trucking Is Leading The Race To Commercialize AV Technology”, *Forbes,* 15 September 2020, https://www.forbes.com/sites/scottcorwin/2020/09/15/trucking-is-leading-the-race-to-commercialize-av-technology/?sh=171eeaeb32c9
30. Ibid.
31. “The Poor ROI of Autonomy”, *Seltz-Axmacher, Stefan,* 22 April 2020, https://medium.com/starsky-robotics-blog/the-poor-roi-of-autonomy-f5d6f4f2dd14
32. “Driverless? Autonomous Trucks and the Future of the American Trucker”, *Viscelli, Steve,* September 2018, http://driverlessreport.org/files/driverless.pdf
33. “Self-Driving Vehicles Enacted Legislation”, *National Conference of State Legislatures*, 18 February 2020, https://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org