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# New Technology and Automation in Freight Transport and Handling Systems

## Future of Mobility: Evidence Review

Foresight, Government Office for Science

# New Technology and Automation in Freight Transport and Handling Systems

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**This document is not a statement of government policy.**

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# 1. Contents

# 2. Executive summary

This report presents a state-of-the-art review of new technologies and automation in freight transport and handling. The review identifies:

- key emerging technologies, how are they being applied in the UK, and examples of (international) best practice
- the drivers of, and constraints on, innovation in the UK freight sector
- implications for policies and research

## a. Key technologies

With respect to **long-haul road transportation**, the strongest prospects in the short to medium term relate to platooning[1] of heavy goods vehicles (HGVs). The technology is already mature, and the next step will be to develop, through trials, the appropriate regulatory frameworks and operating practices to enable the safe platooning of HGVs on public highways. Over the longer term, there is potential for autonomous electric and connected vehicles to be utilised in the freight sector.

In relation to long-haul rail transportation, on the European continent, high-speed rail lines are utilised already as 'rolling motorways' through which freight containers are transported for the longest part of the journey. Various **transhipment systems** have been developed to automate the transfer of cargo containers between road and rail (e.g. CargoBeamer, the Lohr Railway System and InnovaTrain). Such systems could be readily deployed on new sections of the UK rail network (i.e. High Speed lines 1 and 2; HS1 and HS2), since these will meet the required design standards.

Emerging solutions for **last-mile deliveries** include autonomous vehicles (AVs), drones and 3D printing. These can be combined in 'urban freight systems' with local cross-docking centres for receiving and collecting goods: e.g. consolidation centres, pick-up points and pack stations. With the establishment of the necessary regulatory frameworks, there is potential for such innovative solutions to reduce road freight movements in urban areas. Figure 1 summarises some innovative technologies, splitting them by where they operate, e.g. air or road. As transport is a system, changes in one part will also impact other modes.

[1] 'Platooning' is the grouping of vehicles in operation on a highway in such a way that their control systems are temporarily linked, which enables the space between the vehicles to be reduced. In turn, greater proximity results in more efficient use of roadspace and increased energy efficiency for second and subsequent vehicles in a platoon. The lead vehicle also has an aerodynamic advantage, and lower fuel consumption. More generally it refers both to the connection of the vehicles through a data link, but also limited or partial automation for following vehicles as the control systems are linked.

## b. Drivers and constraints on innovation

As well as being a necessary component of an internationally-leading economy fit for the information age, the provision of nationwide superfast/gigabit broadband and high-speed mobile networks will also be fundamental to stimulating innovation in the freight sector. Such high-capacity data transmission networks may help unlock the potential for:

- increased capacity to transmit logistics data between freight providers (and to customers), to improve efficiency in freight operations
- the operation of automated drones for last-mile deliveries

Views differ as to whether future self-driving freight vehicles will need to be connected and if so how. For safety reasons, some operation without active real time remote data feeds, is likely to have to be designed into systems. Will vehicle-to-vehicle, vehicle-to-infrastructure or vehicle-to-cloud technologies be necessary? If such connectivity becomes necessary, then any such connections will also need to ensure the safety of the vehicle and its data.

However, compelling and reliable evidence of supply chain efficiency gains and cost reductions is necessary to incentivise private sector stakeholders to invest in these new technologies.

Conversely, the review points towards a number of factors that could stifle innovation in the freight sector, including:

- if the autonomous operation model pursued requires complementary infrastructure, then this will need to be in place. However, this is unnecessary for many current operating models
- a perception of limited added value and comparatively poor economies of scale associated with new technologies, which are likely to require high capital investments in the early development stages
- a lack of compelling evidence that new technologies are safe, reliable, cyber secure and offer efficiency gains and cost savings
- a collective resistance to change operating practices among institutions and the labour force, which may arise in part from an ongoing social norm that places greater trust in human control than machine control

## c. Implications for policy and research

At a high level, the review's findings imply that an integrated package of measures to support innovation in freight handling and movement should include the following:

1. Continued investment in nationwide high-speed, high-capacity data transmission networks (both fibre-optic and mobile).
2. Ensuring that legislative and regulatory frameworks are adapted to enable the use of AVs on the public highway network. This includes giving due consideration

to standards for vehicles, roadside infrastructure and the regulation of AV operation on public highways.

3. Ensuring that the future rail freight strategy allows for the potential deployment of ‘rolling motorways’ on new sections of the rail network, along with complementary transhipment points[2], as is happening on the European continent.

4. Developing a strategic plan to support the private sector to adopt and develop new systems of freight handling and movement, including:

   (a) providing financial support for research and development programmes, with trials objectively and fully evaluated (to generate compelling evidence of efficacy relevant for knowledge transfer the sector); and

   (b) training programmes to increase workforce capacity regarding the adoption of new operating practices.

In addition, consideration might be given to calls (for example, by the Institute for Public Policy Research (Lawrence et al., 2017) for the establishment of a ‘National Robotics and Artificial Intelligence Ethics Authority’ to advise on the ethics of automation. The authority’s potential remit could include:

- giving consideration to human safety in proximity to autonomous technologies
- examining liability issues in cases where autonomous technologies fail
- advising on socially equitable strategies to deal with circumstances where human labour is replaced by automated technology

Finally, it is noted that further primary research in the form of an in-depth analysis of the UK supply chain (considering different sectors, e.g. automotive, food, coal) is required to identify the prospects for applying different automated freight systems. Such an analysis could be carried out at regional and national levels, giving consideration to the major freight corridors across the UK.

[2] A transhipment point is a place located between origin and final destination where goods or containers are in some way transferred from vehicle to vehicle, or vehicle to temporary storage facility. Reasons for transhipment might be changing of the means of transport during the journey, or consolidation/deconsolidation (e.g. combining small shipments into a large shipment or dividing the large shipment at the end of a ‘trunk’ haul).

**Application across the supply chain and benefits**

| Key Tech | Air | Road | Maritime/port | Railways | Warehousing | Other |
|---|---|---|---|---|---|---|
| Autonomous vehicles (AVs)<br>Platooning | | Improved safety<br>Improved driver's working time<br>Reduction energy and fuel consumption<br>Reduced congestion and increased road capacity | | | | |
| Drones | Reduced congestion | | | | Cost savings<br>Greater efficiency | |
| 3D printing | | | | | | Reduced congestion |
| Agile port and efficient maritime terminal | | | Greater efficiency of freight terminals | | | |
| Self driving or remote control units and stacking equipment | | | Greater efficiency of freight terminals | Greater efficiency of freight terminals | Greater efficiency of freight terminals | |
| Timetable advisory system | | | | Energy savings of 3–5% | | |
| Freight collaborative DM system | | | | Greater efficiency of freight terminals | | |
| Mobile consisting applications | | | | Greater efficiency of freight terminals | | |
| Driverless E-trains | | | | Reduced staffing costs | | |
| Digital signalling | | | | Increased network capacity | | |
| 'Rolling motorways' and automated Road/Rail Transshipment Systems | | | | Modal shift from road to rail | | |

Long haulage  Last mile deliveries  Inventory management

**Figure 1: Key technologies identified across the supply chain**

# 3. Introduction

An efficient freight transport system is essential to the economy and to ensure a high quality of life. Intelligent transportation systems aim to increase the use of existing transportation systems, capacity from the existing physical infrastructure, safety and security, while at the same time decreasing the negative environmental impacts of freight transport (Ranaiefar, 2012). Innovative solutions may support operators in the organisation of freight management and handling activities at freight terminals and, in particular, may promote intermodal[3] transport by reducing handling times and costs at terminals (Gattuso and Pellicanò, 2014). Automated guided transport systems and vehicles for commercial purposes were introduced in the early 1950s in the USA and approximately 10 years later in Europe, driven by the mechanisation of production, with the aim of optimising flows of materials and reducing labour needs. Initial applications of automation were in production and warehousing contexts (Flämig, 2016), but to date, automated freight transport systems are not used in public open space, as they require a specific and dedicated infrastructure and regulations.

Neuweiler and Riedel (2017) found that there is a gap in research related to identifying competitive advantages, with autonomous driving entering the market. In terms of 'technology', there has been great effort in investigating new technologies for transport systems, and notable progress has occurred in recent years. However, there has been limited investigation into the microeconomic and macroeconomic benefits and costs of these developments, and more research is needed (Flämig, 2016).

The present report analyses, in an accessible way, the potential for new forms of freight transport (i.e. automated freight transport systems) to replace or integrate with current transport systems in the UK. It provides a state-of-the-art study with an overview of past, current and future developments in automated freight transport systems. Technology available now or in the short- and mid-term future is considered. The review was commissioned by the Government Office for Science as a contribution to the *Foresight Future of Mobility* project, which aims to explore opportunities and implications regarding the transport system for the period up to 2040.

This report also provides a literature review and state-of-the-art summary of different innovative systems for freight transport and logistics (see Section 5). It analyses different applications to the supply chain and different transport modes, as well as the advantages and disadvantages of the reviewed automated and innovative systems. The literature review section ends with a focus on innovative solutions for last-mile deliveries. Section 6 identifies and defines business models for different automated systems, with a particular focus on road transport and platooning, which

[3] Intermodal transport implies that more than one mode of transport (e.g., rail, ship, and truck) is used to transport goods from origin to destination, avoiding any handling of the freight itself when changing modes. The main reasons for inter-modality are to reduce direct cargo handling through the use of standardised containers, improved security, reduced damage and loss, reduced overall delivery times and reduced costs.

emerged as an important topic due to upcoming technology development and the ongoing process of defining regulations. Following this, an analysis of the stakeholders involved and their needs is provided (Section 7). Section 8 analyses the enablers of, and barriers to, the implementation of automated systems for freight. Section 7 analyses the implications of introducing automated systems for freight in relation to employment in the sector, for logistics service providers and for the environment. Section 8 identifies specific relevance for the government in its role as the potential promoter and fosterer of new technologies to improve the UK's competitiveness in the sector, reduce negative externalities[4] related to freight transport and logistics, and support the UK economy's growth and development. Finally, the limitations of the study, some key issues that policymakers may wish to consider, and identifying future research topics to address identified gaps, are all considered.

# 4. Methodology[5]

The review was conducted through two different and parallel approaches:

- consulting a pool of experts with a view to identifying relevant work published worldwide on the review topics, including academic papers, reports, trials and experiences, and any other evidence on the topic

- searching relevant documents through online web search engines, such as Google and Google scholar

For each new technology, consideration was given to the state of technological development and its impacts to date, and its applicability to different operating contexts (defined in relation to modes of transport and location in the supply chain). Candidate source documents were searched, selected and prioritised for inclusion through a two-step filtering and ranking process, which first considered the relevance and transferability of the evidence, then a further rating linked to the perceived importance of the source.

The sources and their scores were recorded in a database (see Database in Annex). Finally, the documents were identified for inclusion in the review, depending on their rank scores against the defined criteria.

[4] Externalities, or 'externalised costs' are those costs which arise from an economic activity which are not met by either the producer of the goods or services or the consumer of them. Hence, they are 'externalised' onto the wider economy, society and environment. Classic examples are: air pollution, with the costs being suffered by individuals in terms of poor health or picked up by public health systems in addressing poor health; congestion, with the costs of delay increasing the transport cost element in consumer prices; and climate change, where the main costs are likely to be met by future generations.

[5] A more detailed document is included in Appendix A.

# 5. Literature review

This section focuses on the different applications of automation in the freight transport and logistics sector. Different technologies, together with different topics, are analysed, along with the benefits and limitations of innovative solutions.

The literature review begins by introducing automated loading systems at ports and depots, and remote controlled units and stacking equipment. It then moves on to road transport, introducing automated and potentially connected technology for trucks (**autonomous vehicles** – AVs) and platooning[6] (connectivity combined with limited/ partial automation), and identifies the benefits and limitations of their application. The review analyses automated railway systems, and also focuses on air transport and drones. It concludes with automated systems and new technologies for last-mile deliveries in an urban environment (e.g. AVs, drones and 3D printing).

## a. Automated loading systems at ports and depots

A container port represents a breakpoint in the supply chain (Franke, 2008). Being an intermodal[7] transhipment point[8], it is subject to differences in arrival and departure time, with a lack of information that often causes lead time inefficiencies. Automation in a container terminal can overcome issues due to spatial limits. According to Tavasszy (2016), a container terminal's efficiency can be improved by automation: if the order of truck arrivals at a terminal is well known beforehand, yard planning can be more efficient. For this reason, **port terminals** need to be characterised by an **efficient marine terminal** part-ashore (Franke, 2008), and an **intermodal interface centre** inland. In this ideal model of the **Agile Port System**, the efficient marine terminal and intermodal interface centre are connected by a dedicated railway line (Franke, 2008). The core idea of the Agile Port System is as follows:

- handle as many containers as possible between vessels and trains, avoiding storage in the terminal
- transport containers immediately between terminal and intermodal interface centre by train
- sort containers between trains according to their final destination
- load and unload trucks which serve the nearby area at the intermodal interface centre

[6] For full definition see Footnote 1. 'Platooning' is the grouping of vehicles on a highway (usually with data links) so that their control systems are temporarily linked. This connectivity offers limited automation to the following vehicles in the platoon.
[7] See Footnote 2 for a definition of 'transhipment point'.
[8] See Footnote 3 for a definition of 'intermodality'.

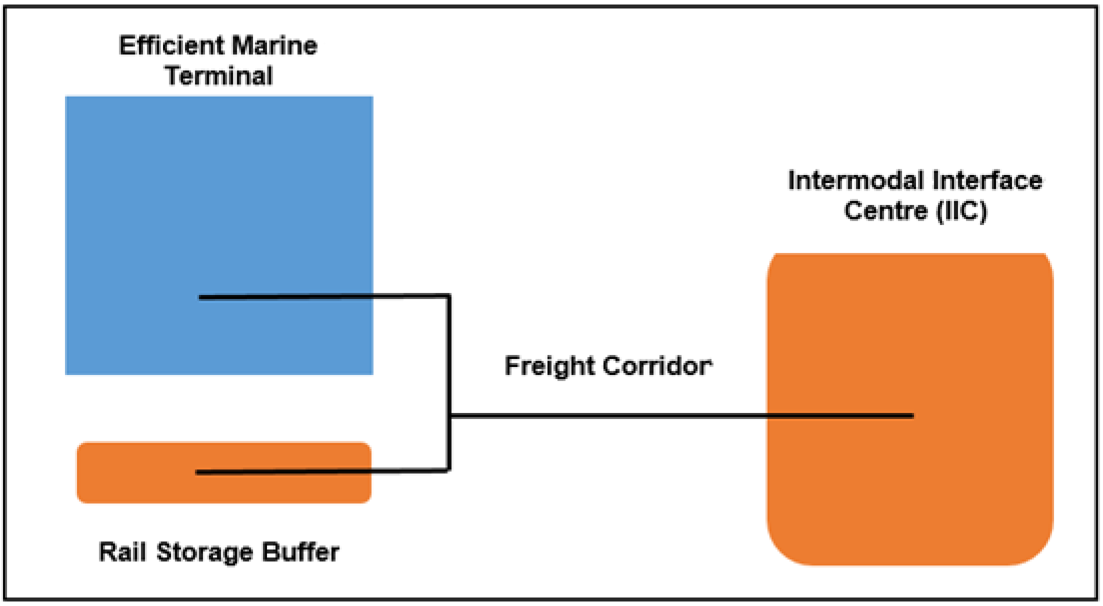


**Figure 2: The Agile Port concept**

The Agile Port concept (Figure 2) considers a combination of improved semi-automated equipment that allows transhipment of containers between vessel and train and vice versa directly at the quay, without a loss in performance. In fact, load units may be stored close to the customer, instead of at the port terminal (Franke, 2008). The Port of Hamburg represents a good example, where Noell[9] improved the original efficient marine terminal concept by elaborating the 'Mega Hub' concept, through which 360 boxes could be transhipped between trains in 100 minutes.

A reduction in machinery and labour costs is the main benefit of the efficient marine terminal, due to the redundancy of yard transfer vehicles. The system considers a combination of improved semi-automated, ship-to-shore cranes; semi-automated, cantilevered and rail-mounted gantry cranes; and a box mover based on rail-mounted, automated shuttle cars driven by linear motor technology (Figure 3).

[9] For further details please see the following patent listing: https://patents.google.com/patent/US6778631B2/en

**Figure 3: Intermodal ship-to-rail transfer of containerised cargos, port in Long Beach, California[10]**

**Source: https://commons.wikimedia.org/wiki/File:Intermodal_ship-to-rail_transfer.JPG**

A number of studies have examined the automation of **container-carrying vehicles** and **cranes** at ports. Moghadam (2006) conducted an economic study on the effect of automation and semi-automation on loading, discharging and stacking processes in terminals using Quayside Cranes, Straddle Carriers, Rubber Tyred Gantry cranes and Rail Mounted Gantry cranes. The automated features examined were those on 'post-Panamax' cranes.[11]

Moghadam found that if such devices were added to conventional quayside cranes, container waiting times in the terminal were reduced; however, this should be offset against the times where automated berths were unproductive (Moghadam, 2006). Automation reduces the turnaround time for ships in port, and thus would produce benefits for shipping companies. Moghadam suggests that the cost of investing in automatic devices would be compensated for within months of operation; he further notes the safety improvements arising from automatic devices, but considers them hard to quantify monetarily. Automated rail mounted gantry systems were found to be cheaper per container than semi-automatic, rubber-tyred gantry and straddle-carrier systems.

Široký (2011) examines the benefits of **automated guided vehicles** (AGVs) and **automated stacking cranes (ASCs)** at ports. The study consists mainly of summaries of the automated devices' technical characteristics, and does not identify the systems' drawbacks or weaknesses. However, the study is effective in

[10] Yard hauler is parked adjacent to train; cargo is transferred to train by a rail-mounted gantry crane.
[11] A post-Panamax crane is able to load and unload containers from a post-Panamax cargo ship. Post-Panamax vessels are too wide to pass through the Panama Canal, meaning vessels about 18-containers wide.

highlighting some of these devices' strengths and technical capacities. Široký states that AGVs can convey freight between the quay and the stack yard.

AGVs have a number of strengths and advantages:

- all wheels rotate independently, allowing precision loading and unloading
- they are able to convey containers of varying lengths
- they work to schedule at high-speed, almost silently
- they can overtake each other
- they can refuel automatically (although they can also take on enough fuel to work for several days without refuelling)
- they can move safely, due to laser detectors that register obstacles in their paths

In addition some AGVs feature lifts, which can raise and lower loads. Lift AGVs can decouple transport and storage processes, can further increase efficiency and reduce the size of the fleet that is necessary.

ASCs also boast many strengths. They:

- can stack containers between one and five layers deep
- can move at speeds of up to 21kmh on tracks
- contain anti-collision precautions
- can save space
- can work in extreme conditions, including wind speeds of up to 10 on the Beaufort Scale
- can position loads accurately

Together, AGVs and ASCs can provide automated solutions from quayside to stack yard. The software running AGVs and ASCs can be integrated with other terminal systems.

**Information technology** (IT) can be used to assess the effectiveness of automation. Port container terminals vary according to some key aspects (type of water access, maximum ship size, financial constraints, etc.). However, they need to be compared to one another to evaluate efficiency and competitiveness (Wiśniki et al., 2017): specifically, in order to understand what levels of automation are most cost-effective. Thus, a tool which can take account of multiple criteria is useful.

**Data envelope analysis (DEA)** has been proposed as applicable for this purpose by Wiśniki et al. (2017), who compared nine European port container terminals with varying levels of automation. The DEA method allows us to identify which features of a port container terminal are key to its efficiency. However, one limitation of this method is that the greater the number of characteristics of a terminal are considered, the greater the number of ports are required for comparison. The analysis suggests that increasing levels of technology in the less efficient terminals would increase efficiency – by up to 219%, in the case of one port. However, Wiśniki et al. conclude that efficiency is not necessarily dependent on high levels of automation in terminals. DEA mathematical programming was able to compare and assess different terminals, even though they differed from each other in multiple respects.

Mechanisation and automation are also improving the efficiency of transporting freight by train in ports via **marshalling yards**, where trains are split up for different destinations (Zářecký et al., 2008). In marshalling yards, individual wagons are separated and often moved to new target tracks via a downward gradient. However, manual work in a live marshalling environment can be dangerous, necessitating constant awareness of multiple moving wagons. Here, automated systems can reduce the need for a manual work element. By 2008, IT was being used to control points in marshalling yards, control signals to drivers, relay information on the speed of vehicles, assess the position of wagons and regulate the speed of wagons as gravity takes them towards destination tracks. Such systems provide safety functions, including helping to regulate the opening and closing of gates to the yards, ensuring safe coupling to equipment, and controlling signals that indicate a driver can continue. Thus Zářecký et al.'s (2008) main emphasis is on the safety improvements available through automation.

The same can be said for **automated docking**. Distribution centres could become more efficient if the order of truck arrivals is known beforehand. In general, automated warehouses are successfully established worldwide, and there are different automated tools and systems to support employees at a depot. Probably the most common tools are voice-directed or light-directed picking tools, which have not changed much over the years. Employees recognise that they can work faster and more accurately and, according to Trebilcock (2011), logistics operators do not aim to eliminate the human component; rather, they want to support employees to reach their potential by eliminating walking, reading, waiting or any other extraneous process in order to improve overall performance. Furthermore, companies decide to have automated depots to create a safer and more ergonomic work environment, especially if an ageing workforce is considered. In fact, European regulations are looking increasingly at reducing the weight that workers can move at any one time, or during a shift (this is also becoming a concern for some facilities in the USA). However, labour is not the only reason for automation. Automated depots are more flexible and can be 'reprogrammed' by considering new customers' needs. Automation is also justified by considering a holistic view of the supply chain, which considers coordination with what happens in retail outlets in order to reduce operating costs.

In the **UK environment**, probably the largest automated port is London Gateway (Wainwright, 2015). Twice the size of the City of London, the Gateway hosts the world's largest cranes. Its development is ongoing, but following completion it will be able to unload six cargos at once. DP World, a world leader in global trade enablement, declared that the port will allow the reduction of 2,000 HGVs on the roads every day, with a significant impact on the environment and economy.

In particular, the Gateway reduced its carbon emissions by 28% per Twenty-foot Equivalent Unit (TEU)[12] in 2016. The reduction was related to high automation to handle the high number of containers (e.g. increased efficiencies and economies of scale), the introduction of hybrid-electric shuttle carriers to the port's operations, the optimisation of energy usage, and reduced energy consumption in buildings (DP World, 2017). Fully automated cranes on rails manage the stacks, but notably the ship-to-shore quay cranes themselves are not automated, but manually operated. Truck collection is also fully automated (i.e. vehicles arrive, are scanned and then loaded to the bay), with a turnaround time under 30 minutes. Being highly automated, London Gateway is not influenced by the weather in terms of operational efficiency, and can operate when Felixstowe and Southampton have to close due to poor conditions. This makes it more competitive than the other ports in the UK. However, despite the strong advantages provided by automation, the port is not performing as expected due to supply chain managers' unwillingness to change their operational behaviour.[13] This is limiting its ability to reach critical mass (e.g. 300,000 containers were handled during the first year of operation in 2015, rather than the projected 3.5 million).

According to Moody (2016) the limited number of ports causes inefficient queuing of container ships outside the port, which in turn creates inland freight congestion issues.[14] In addition, there are many issues related to large container ships' loading and unloading operations, which take a long time. Furthermore, fixed scheduling systems cause queues of lorries, which are loaded and checked slowly, which slows down the process.

Another important area of development for maritime shipping is autonomous shipping, with autonomous vessels that are equipped with detectors, sensors, high-resolution cameras, advanced satellite communication systems, no crew members on board, remotely human monitored and controlled from a shore operating centre. Based on the autonomous shipping concept first introduced in the 1980s by Rolf Schönknecht (1983), Rolls-Royce is collaborating with universities, designers and manufacturers to explore the economic, social, legal, regulatory and technological issues of autonomous shipping within the Advanced Autonomous Waterborne Applications – AAWA project. Rolls-Royce (2016) expects remotely-operated local vessels to be the first stage and in operation by 2020, with remote-controlled unmanned coastal vessels by 2025, remote controlled unmanned ocean-going ships by 2030, and autonomous unmanned ocean-going ships by 2035. While most of the automation is introduced for container cargo, automated vessels might be connected to different investments in automated terminals for some of the bulk traffic.

[12] The twenty-foot equivalent unit (TEU) is an international recognised unit of cargo capacity, usually used to describe the capacity of container ships and container terminals. It is based on the volume of an intermodal container that is 20 feet in length (6.1 m). It is a standard-sized metal box that can be easily transferred between different modes of transportation, such as ships, trains and trucks.

[13] If supply-chain managers are happy with their operational and strategic plan, they are unwilling to change it as this might mean incurring longer times and higher costs, with a strong impact on supply-chain competitiveness.

[14] Container ships must wait to be allowed in port for loading and unloading operations. This generates correlated inland congestion, due to the time that trucks need to wait for their containers to be delivered and loaded to or unloaded from the vessels.

However, despite the high benefits in terms of crew cost reduction, there are major concerns about safety in navigation and liability for autonomous vessels sailing in the open sea, due to weather conditions.

## b. Self-driving or remote-controlled units and stacking equipment

Self-driving units can be used on private premises. For example, automated vehicles can be used at a container terminal to move containers between the quay cranes and stacking area, with the aim of shortening routes, reducing empty trips and achieving optimal utilisation of all resources (Flämig, 2016). They also can be used in cargo hubs, where several trucks load or unload their cargo. The services are usually planned per single truck, while the terminal's facilities and resources (crew, cranes and space) are shared to a large degree by the clients, their trucks and cargo. Truck arrival times at a loading and unloading dock are usually uncertain: they can vary between seconds and hours, depending on unexpected issues along the supply chain that generate delays. For this reason, predicting the exact order of truck arrivals at a terminal is difficult or impossible, making it challenging to plan the stacks on the container yard because ideally they should be aligned for the order of servicing.

For example, if truck A comes before truck B, container A should be on top of B, not the other way around. Truck platooning may reduce the yard planning problem significantly at terminals, because the order of trucks is fixed and known with platooning. This implies that the number of repositioning moves with containers due to modal shift[15] at a container terminal can be reduced. Estimating the benefit then relies on assumptions of how many moves will be saved, and at what cost per move (Tavasszy, 2016).

If we consider the case of a terminal with 35–50 million TEU a year, of which 40–80% are moved by road transport, then automation could result in two to three fewer repositioning moves of containers within the terminal 'stacks' on average per container. As each container repositioning move has an individual cost of about €30-40, then the total savings at the terminal per year would be very significant[16]:

- in the optimistic case that all trucks arrive at terminals in platoons, so the stacking of containers is fully optimised, the cost reduction would be between €1 and €4 billion a year
- in an initially more likely scenario that just 10–20% of trucks arrive in platoons, the savings amount to €100 to €800 million a year. (Tavasszy, 2016)

[15] Modal shift means transfer a load unit from one mode to another one with the aim of reducing costs for the operators, or to achieve policy objectives e.g. reduce road congestion. Indeed, it usually refers to the shift from road transport to another mode, as the former is usually the most congested mode.
[16] According to Tavasszy (2016), given the uncertainties in these variables it is easiest to work with plausible ranges of numbers.

## c. Freight transport of the future

This section reviews automated systems for road transport and last-mile deliveries. AVs, platooning of vehicles for the long haul, as well as new solutions for last-mile deliveries are considered.

### Autonomous vehicles for road transport

Probably the first example of the use of automated trucks was at one of the world's largest iron-ore mines in Australia in the 1990s, which aimed to overcome difficulties in staffing due to dangerous shift work in the outback and demanding logistical requirements in terms of personnel planning and staff transfer (Flämig, 2016).

Numerous pilots on automated and electric transport systems have been carried out since the mid-1990s: e.g. the European projects Chauffeur I and II, Safe Road Trains for the Environment (SARTRE), Cooperative Mobility Solution for Supervised Platooning (COMPANION), the Californian PATH Program, the German KONVOI-Projekt and the Japanese ITS Project by the New Energy and Industrial Technology Development Organization, NEDO. These projects involved multiple trucks or a convoy of lead trucks and following passenger cars that were driven at up to 90km/h, with a minimum gap of 4m (Flämig, 2016).

Compared with other modes of transport such as aviation and rail, automation for road transport has been less adopted to date, primarily due to the development level of the technology for road environments, which are much more complex than the segregated rail and air systems involved. As automation technology continues to develop it will be important to ensure that the complex regulatory and legal regime keeps up with the evolving questions and challenges this technology poses for users, goods and society.

Nonetheless, AV technology potentially has significant impacts in terms of safety improvements, fuel consumption reduction and consequently cost reduction, as well as increased efficiency and flexibility: for example, due to the reduced effect of driver absence from work. According to Guerra (2015), the acceptance and adoption of AV trucks is likely to be higher than AV cars, despite high commercial prices. According to Neuweiler and Riedel (2017) (Table 1), there is a lack of research on autonomous trucks: only few published articles examine barriers and advantages. They identified opportunities for the logistics market, which have been recognised by several authors.

**Table 1: Summary of main opportunities identified in the review by Neuweiler and Riedel (2017)**

| Opportunity | Sources |
|---|---|
| Increased safety | Roland Berger (2015, 2016); Bagloee et al. (2016); DHL (b) (2014); McKinsey Global Institute (2013) |
| Decreased transportation costs | Roland Berger (2015, 2016), Hars (2015); Viereckl et al. (2015) |
| Decreased fuel consumption | Roland Berger (2016); Viereckl et al. (2015); McKinsey Global Institute (2013) |
| Environment and emission | Bagloee et al. (2016); DHL (b) (2014) |
| Improved truck utilisation | Roland Berger (2016); Viereckl et al. (2015); DHL (b) (2014) |
| Better road utilisation | Roland Berger (2016); Bagloee et al. (2016); Viereckl et al. (2015). |
| Better driver utilisation | Roland Berger (2016); McKinsey Global Institute (2013) |

**Source: Neuweiler and Riedel (2017), Table 1**

Combining connectivity with automation (be that limited or full), **platooning** is one of the most promising functions of automated vehicle technology for freight. According to COMPANION (2016): "*platooning means grouping vehicles into platoons to gain advantages compared to individually driving trucks*". In this way, the distance between vehicles decreases by allowing them to accelerate or brake simultaneously. According to SARTRE (Chan, 2014), platooned vehicles are connected through smart technology that allows them to travel together with automated control. This results in safety, efficiency, congestion and emission-level improvements. Such benefits are facilitated by vehicle-to-vehicle (V2V) communication, which allows the formation and maintenance of a close-headway formation (i.e. reduced distance) between vehicles, by keeping them under coordinated control both longitudinally and laterally (Besselink et al., 2016). 'Longitudinal' control refers to the distance between the vehicles, whilst 'lateral' control refers to the position of a vehicle within a lane on a highway[17].

However, as Tavasszy (2016) notes, truck platooning technology has not been fully defined yet – it is still at the demonstration and pilot stage. Different aspects related to technology, logistics, regulatory and business need greater definition. Moreover, advances in research and development from the technology side have not been matched by investigations into, and quantification of, the potential benefits for road

[17] The lateral position should normally be fairly central to minimise the risks of collisions with vehicles in other lanes, but very precise and standardised positioning within a lane would result in fast wearing of a particular alignment, so it is likely that platooning systems will vary the running position to spread this wearing effect across a wider band of the lane.

users, logistics companies and the environment. Similarly the potential impact of truck platooning on both rail and sea freight is another unknown, which may change its desirability.

Figure 4 shows a taxonomy and definitions for automated driving provided by the Society of Automotive Engineers International's J3016 report[18] in January 2014. The report's six levels of driving automation span from none (Level 0) to full (Level 5).

Traffic congestion reduction, fuel consumption improvement and increased capacity by vehicle throughput are the benefits identified from platooning. Early-generation platooning technology requires the driver to be responsible for steering, implying Level 1 automation. Platooning testing is proceeding for Level 2 automation, where both longitudinal and lateral control are managed by the automated system.

As mentioned previously, in Europe, truck-platooning efforts began in the 1990s with Chauffeur, followed by Chauffeur II, and in the 2000s by the SARTRE project (Shladover, 2012). In 2016, an experiment was carried out featuring six convoys of truck platoons belonging to different European trucking brands, originating from various factories in Sweden and Germany and arriving in Rotterdam. During the 2000s, Japan also began to support truck platooning studies under the Energy ITS program. In the same period, similar research was supported by the US Department of Transportation and US Army to confirm technical feasibility and fuel economy benefits (ATA Technology and Maintenance Council, 2015).

The Ministry of Transport of Singapore and PSA Corporation signed agreements with Scania and Toyota to design, develop and test-bed an autonomous truck platooning system for Singapore's port. It is a two-step truck platooning trial developed from January 2017 to December 2019, in which trucks transport containers from one port terminal to another (Ministry of Transport of Singapore, 2017).

Most major truck manufacturers have already begun, and will continue, platooning tests in cooperation with government agencies all over the world, claiming that trucks equipped with platooning technology will come on the market by 2020. Trucks equipped with radar and V2V systems may form, join or leave a platoon on the highway. The systems do not require changes in signage and lane markings, but do require changes to spacing requirements. However, even though the technology will permit 'cutting in' by other vehicles, long lines of platooning trucks may create some difficulties for the operation of other vehicles in traffic. For the USA, states that have 'following too closely' statutes in force should review and amend these, as they might create an impediment to platooning operations. Other regulations necessary to ease the operations in traffic, such as designated lanes, might also be considered. Although the current UK truck platooning trials can occur without legislative change.

[18] The document is titled: "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems J3016_201401". It describes the full range of levels of driving automation and related terms and definitions.

| Level | Name | Narrative Definition | The Dynamic Driving Task: Sustained lateral and longitudinal vehicle motion control[19] | The Dynamic Driving Task: Object and Event Detection and Response | Fallback performance of Dynamic Driving Task | (Operational Design Domain) |
|---|---|---|---|---|---|---|
| **Driver performs part or all of the DDT** | | | | | | |
| 0 | No Driving Automation | The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*. | Driver | Driver | Driver | n/a |
| 1 | Driver Assistance | The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation | Driver and System | Driver | Driver | Limited |
| 2 | Partial Driving automation | The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes | System | Driver | Driver | Limited |
| **ADS("System") performs the entire DDT (while engaged)** | | | System | System | Fallback-ready user(becomes the driver during feedback) | Limited |
| 3 | Conditional Driving Automation | The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately. | | | | |
| 4 | High Driving Automation | The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*. | System | System | System | Limited |
| 5 | Full Driving Automation | The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*. | System | System | System | Unlimited |

**Figure 4: Levels of Automation**

**Source: Society of Automotive Engineers International (SAE). Reproduced Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_201806 (2018).**

[19] In earlier SAE versions, this table was sometimes simplified: Sustained lateral and longitudinal vehicle motion control was simplified to steering, accelerating and braking. Object and Event Detection and Response was simplified to Monitoring of driver environment. Operational Design Domain referred to which driving modes the system works for.

The benefits achievable through AV trucks are as follows.

**Safety improvement**. AVs are designed to drive safely, respecting regulations and laws, thus reducing the number of risks and crashes. The US National Highway Traffic Safety Administration (2016) estimates that V2V and vehicle-to-infrastructure (V2I) technologies could avoid or mitigate the severity of crash outcomes up to 80%, looking at 20 years after their implementation. In 2014 there were 3,903 fatalities in the USA resulting from large truck-involved crashes (Short and Murray, 2016). Of those fatalities, 17% were the occupants of large trucks, 73% were the occupants of other vehicles and 10% were non-occupants. As noted by the Department for Transport (2015), 94% of the road deaths and injuries in the UK are due to human error, and the portion of these involving HGVs could be avoided if fully-automated trucks are used. The reduction in collisions implies lower overall insurance claims and premiums – a benefit potentially rising to 90% lower than currently, when automation is widespread (Celent, 2012). However, the level of information provided during the trials by track testing may not provide enough evidence for an insurance company to provide cover. In this case, self-insurance either by the vehicle operator or another trial stakeholder would be required (Ricardo, 2014).

**Improved drivers' working time**. Drivers may be able to execute other tasks beside their driving task (Tavasszy, 2016), such as processing documentation or assisting customers. In general, it can be said that automated systems can increase the productivity of single truck–driver combinations (Tavasszy, 2016). The European directive allows a consecutive driving time of 4.5 hours, which can be repeated after a short break. This driving time constraint limits the action radius of a single truck–driver combination to about 720km, travelling at an average speed of 80km/h. If a delivery needs to be made within one day in Europe beyond this distance, at least two drivers need to be on board the truck (Figure 4). The study carried out by Tavasszy (2016) considers that "the second truck's driver's time is not counted fully, together they can increase their range of travel. If the work time of the second driver would only count for 50% and the two would change leading positions after 3 hours, they could increase their daily travel range each to 960km" (Figure 5).

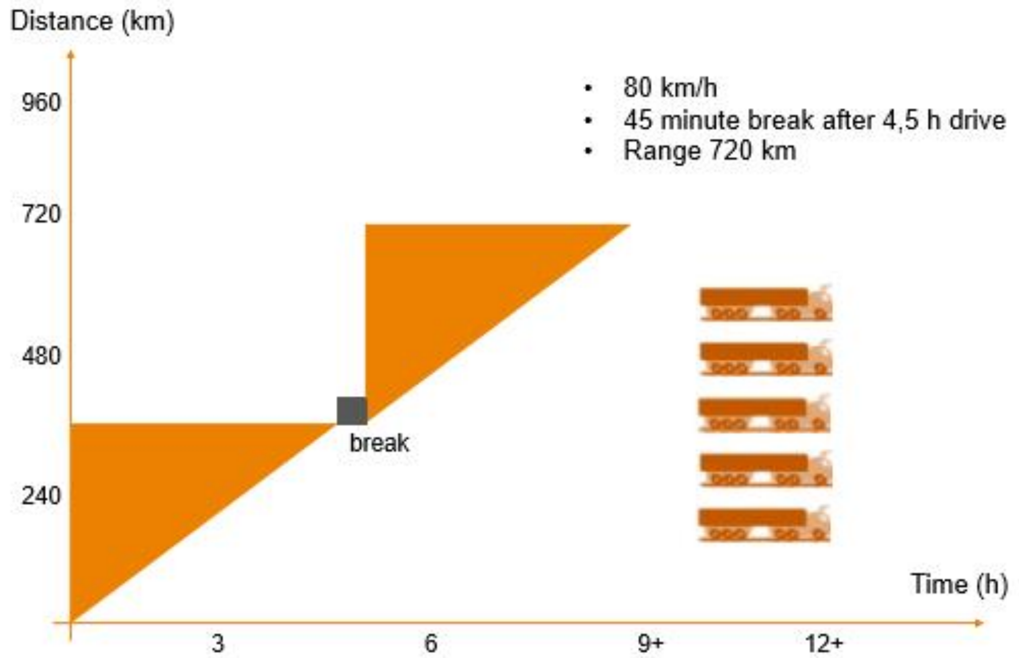


**Figure 4: Time–distance graph for single driver trucks with current European driving time directive.**

**Source: Tavasszy (2016), Figure 1; reproduced with permission.**

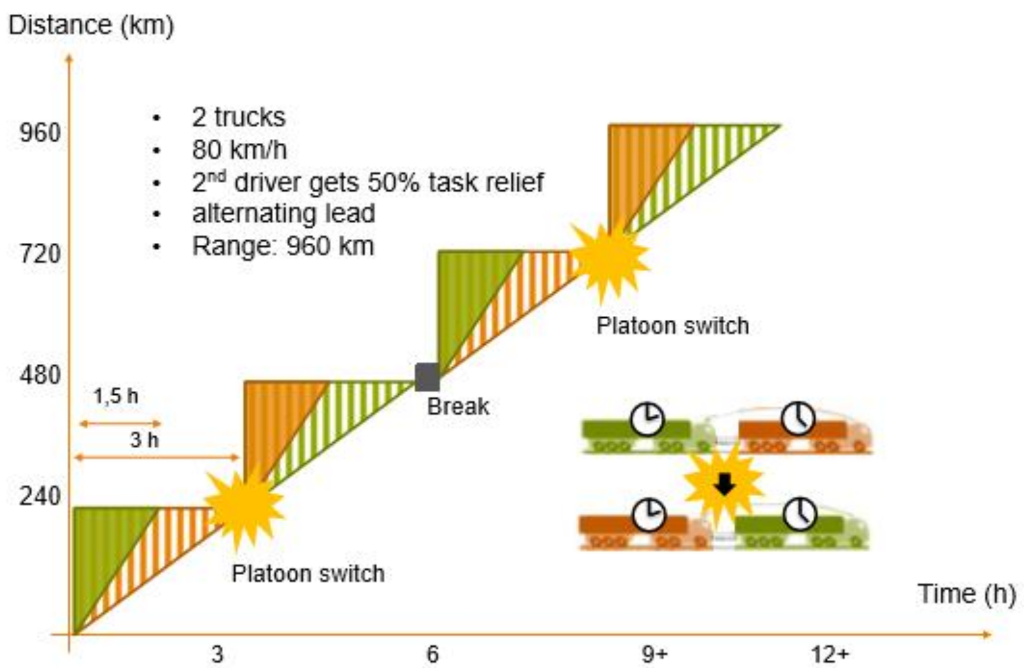


**Figure 5: Time–distance graph for adapted driving time directive and platooning**

**Source: Tavasszy (2016), Figure 2, reproduced with permission**

In terms of economic benefits, Tavasszy (2016) estimated that on average, €8.8 billion a year could be saved through truck platooning. Moreover, driver salaries are a large share of direct costs. If automated trucks are used, drivers can perform other tasks during the journey, so the operating costs associated with them can be reduced. Wadud (2017) reports that this reduction in salary costs can be 60%, with the residual cost being for loading and unloading operations at the origin and destination.

**Energy and fuel consumption reduction**. AV technology allows more efficient driving and reduction in fuel consumption, which has been well documented. Especially with platooning, a reduction in travel time and fuel consumption is achievable by enabling higher effective speeds and lowering air resistance (Scribner, 2016), which benefits second and further following trucks. The potential overall savings in fuel costs for Europe have been estimated at between €400 million and €6 billion a year, with an average value of €1.9 billion a year (Tavasszy, 2016). However, the actual rate of fuel savings is still uncertain, and depends on the interaction of a platoon with other road users (Bakermans, 2016).

Tsugawa et al. (2016) simulated an automated truck platooning system of three trucks with a constant speed of 80km/h. The trucks were unloaded. The measurements indicated that with a 10m gap there was a 13% energy saving, and 18% when the gap was 4.7m.

The experiment was repeated with the trucks loaded. In this case, the fuel saving was 8% for the 10m gap, and 15% for the 4.7m gap (Table 2).

**Table 2: Reduction of fuel consumption based on theory, simulation and test for 14-ton and 28-ton trucks**

| Fuel consumption | Theoretical | Simulation by Daimler | Measurement by Daimler | Simulation with PELOPS by KONVOI[20] |
|---|---|---|---|---|
| First vehicle | 2.17% (14T)<br>1.64% (28T) | 2% (28T) | 6% (14T) | 2% (14T) |
| Second vehicle | 38.1% (14T)<br>28.8% (28T) | 19% (28T) | 21% (28T) | 11% (28T) |

**Source: Tsugawa et al. (2016), Table III**

Figure 6 shows a computational fluid dynamics simulation of two trucks, which indicates that the air pressure is low with a short gap in the platoon, and increases as the gap between the vehicles increases. The reduced air drag results in lowered implied fuel consumption, which has been quantified as at least 5%.

[20] Results are based on a simulation study that was performed in the KONVOI (Development and Examination of the application of electronically coupled truck convoys on highways) project using the software PELOPS (Program for the development of longitudinal traffic processes in system relevant environment), which takes into account the three relevant elements of traffic— route/environment, driver and vehicle—and their interaction. (Please refer to Tsugawa et al. (2016) for more details).

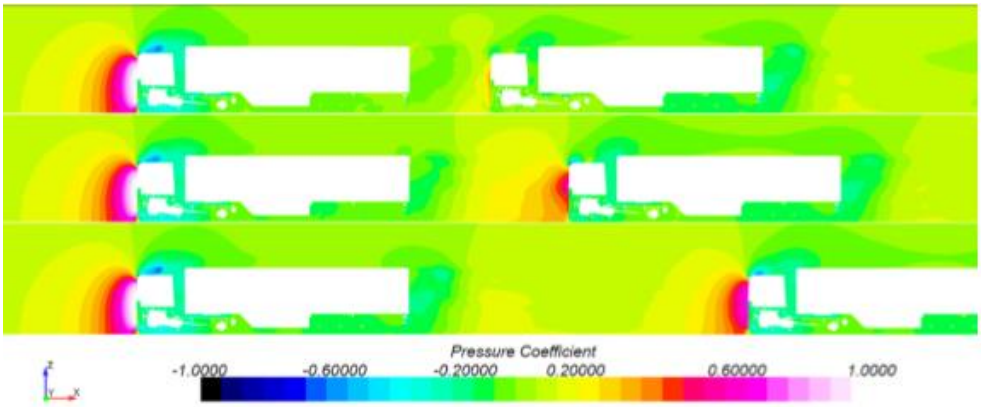


**Figure 6: Simulation of air pressure for two trucks for different inter-vehicle distances**

**Source: COMPANION (2016), Figure 6**

**Reduction of congestion and increased road capacity**. The freight industry faces significant but potentially avoidable additional costs every year due to congestion (Torrey IV, 2016). Estimates for all UK road users recently placed the lost time cost at nearly £40 billion for 2017, with the UK performing as the 10th most congested country out of 38 surveyed (Inrix, 2018).

As well as the monetised cost of wasted time, fuel consumption is higher in unstable traffic flows compared with free-flow driving conditions. AV technology will allow fleets of AV trucks to travel more efficiently under different traffic conditions. V2V and V2I technology will enable communication between trucks and other road system components (i.e. vehicles and infrastructure), allowing mitigation of ‘stop–start’, increasing travel speed and improving overall travel conditions, so creating benefits beyond the freight sector.

Reduced congestion due to AV trucks is likely to be a practical application first on the motorways, as automation is more likely to be introduced in the short term within such a relatively controlled environment (Ginsburg and Uygur, 2017). In a study carried out in the USA, more than 75% of HGV drivers in Illinois reported problems finding safe parking, and 58% contravene parking regulations three to four times per week (Oberhart and Perry, 2017). This problem can be mitigated after the introduction of connected vehicles and AVs for freight, even though further study is still needed to understand and quantify the effect, as no amount of technology can reveal nearby parking opportunities if none are actually available. However, the parking requirement may go down due to the application of more efficient technologies, just-in-time arrival could be more precise with managed traffic flows, and there may be reduced needs for driver layover due to maximum driving hours regulations.

In addition, identifying locations for warehousing can be influenced by connected vehicle and AV applications. This could change truck volumes on roads, but as in the case of parking, the importance of this effect is difficult to estimate. For this reason, private party stakeholders of freight (e.g. logistics companies, third-party logistics and large shippers) should be involved in the planning process (Ginsburg and Uygur, 2017).

Despite the high potential benefits from autonomous trucks and platooning, their applicability to the **UK context** might be not possible or convenient. As suggested above, UK motorways are among the most congested in Europe, and this technology might not work very well if private cars continually require platoons to break and reform. Therefore, while the benefits for the UK have been theoretically identified (e.g. reduced fuel consumption, improved logistics schedule due to reduced time delays, improved safety due to accident reduction, likely $CO_2$ reduction, reduced congestion[21] – all these benefits generate an overall cost reduction) (Ricardo et al., 2014), road trials are needed to test the responsiveness of the system when integrated within the whole transport system.

To this end, the Department for Transport and Highways England have commissioned the first real-world operational trial of platooning on UK roads (TRL, 2017), planned for 2018. The real-world trial will identify if potential benefits can be realised in practice, and therefore if the UK environment is suitable for this technology.

Successful implementation of platooning on UK motorways will be more possible if the road infrastructure is adapted to host automated transport systems. This challenge might be variously addressed by equipping motorways and roads with specific sensors (instrumented highway), or defining dedicated lanes for AVs and platooning, in order to limit the interaction with other types of traffic.

### Automation for railway systems

The European Union (EU) has sought to support such innovations via multiple research and development projects. The following enhancements to the EU rail freight system were identified as priorities by the Capacity4Rail (2018) project (Nedall 2017; Ricci 2017):

- deployment of wagons that can tolerate axle loads of up to 30 tonnes, with higher and wider gauges (to handle larger containers), lower floor heights (to facilitate container transfer), electro-pneumatic brakes and automatic couplers
- deployment of (driverless) electric locomotives that are capable of longer configurations (up to 2,000m), and heavier trains – e.g. providing 400kNs of traction effort and capable of handling 25-tonne axle loads
- wider deployment of transhipment terminals that enable the efficient (roll-on, roll-off) transfer of containers between road and rail
- completion of the European Rail Traffic Management System (ERTMS) digital signalling system

[21] Reduced congestion might be achieved if existing infrastructures are used efficiently. Platooning can ensure better use of road space, related to the reduced gap between vehicles.

Currently, two new projects are in progress under the Horizon 2020 programme, although neither project has reported findings to date. The Automated Rail Cargo Consortium (European Commission 2017a) project is examining three areas:

1. the use of automated freight trains

2. the application of automated processes at transhipment nodes

3. timetable planning.

The Smart Automation of Rail Transport (SMART) project is researching technology to deliver obstacle detection and automatic, 'forward-looking' braking systems that offer short-distance wagon recognition for shunting onto buffers (using thermal cameras, image intensifiers and laser scanners). The SMART project is also aiming to develop a real-time marshalling yard management system (European Commission 2017b).

Wiegmens et al. (2007) examined barriers to the adoption of new technologies in the context of rail freight transhipment terminals. They identified that costs of new technology are often prohibitive; that efficiency gains are often not perceived to be sufficient to justify investment; and that efficiency gains may not be accrued to terminal operators, hence reducing their incentive to invest. Moreover, the transhipment market was perceived to be relatively 'stable', and this is argued to be a barrier to innovation, for example through technology 'lock-in' (institutional resistance to change), at least relative to unstable market contexts, where innovations tend to be adopted more quickly.

The Department for Transport (2016a) published a strategy for rail freight in 2016, which highlighted three technical innovations that have been taken forward in the UK market through the Freight Technologies Group: Network Rail and the freight operators:

1. Timetable Advisory System (SNC-Lavalin, 2017) – this equips train drivers with software, hosted on tablets, to track train progress against the timetable. The aim of the system is to improve driving efficiency. Simulations predicted energy savings of between 5% (Rail Safety and Standards Board, 2010) and 8% (Davies, 2014).

2. Freight Collaborative Decision Making system – this offers real-time information boards at freight terminals, indicating the arrival times of freight services, to improve decision-making and operational efficiency.

3. Mobile Consisting Application – before a loaded freight train departs, it is necessary to log the 'consist' of the train (i.e. the nature of the carriages forming the train) with Network Rail. This previously involved manually faxing a written note to Network Rail for input by a data entry clerk. The Mobile Consisting Application enables consist data to be transmitted directly from freight terminals via software loaded onto a tablet device.

Alongside these innovations, digital signalling (as offered by the ERTMS) is being strategically deployed at pinch points on the network (currently available on the Thameslink and Crossrail routes) to unlock rail freight capacity, and hence increase the competitiveness of rail freight operations relative to road haulage. The ERTMS is being developed to harmonise train control systems across EU borders. This simplifies the signalling equipment requirements for cross-border rolling stock, leading to cost savings, and offers up to 40% more network capacity (through the deployment of continuous communication systems, which enable reduced running headways) (European Rail Traffic Management System, 2014).

The Rail Freight Strategy (Department for Transport, 2016a) was accompanied by ‘Future potential for modal shift in the rail freight market’, a review conducted by Arup (2016). This identified opportunities for innovation in locomotive technology, noting that network electrification offers fuel and emissions savings. The alternative, shorter-term option is to establish ‘handover’ connections to electrified networks, where wagons can be switched to diesel haulage for the last mile. Further research is recommended by Arup (2016) into what are considered to be ‘disruptive future technologies’, including alternative fuel sources (liquid nitrogen gas or hydrogen) and driverless locomotives.

There is additional potential to utilise the new (and hence modern) specification UK rail lines (HS1 and 2) as ‘rolling motorways’, whereby HGV containers are transported via rail for the longest section of the journey – for example, maximising network utilisation at night. A number of (part-automated) systems have been deployed already across the European continent to facilitate the efficient transfer of containers between HGVs and train wagons (Arup, 2016). These include:

- CargoBeamer (2017) – a modular transhipment terminal system. Containers are transferred from trucks onto CargoBeamer pallets, which are then automatically (horizontally) loaded and unloaded onto CargoBeamer wagon trains (via ‘side arms’ which slide under and engage with the pallets). Up to 36 semi-trailers can be loaded in 15 minutes. Modules are pre-cast in concrete, enabling quick and easy installation of new transhipment terminals.

- The Lohr Railway System (2017) – currently deployed between Chambéry and Turin, and Luxembourg and Perpignan, which is being rolled out more widely, including at the Channel Tunnel rail link. Low floor wagons ‘swivel’ at transhipment points, enabling containers to be driven on to and engaged with the wagon (via a roll-on, roll-off configuration). Vertical loading and unloading of containers via cranes is also possible.

- The InnovaTrain (2017) suite of systems – which is deployed in parts of Switzerland. This consists of a ‘ContainerMover’ system mounted to the truck chassis, enabling (driver-operated) lifting and horizontal transfer of containers between trucks and train wagons. A second ContainerStation system enables containers to be removed from wagons and stored at yards, yielding truck loading and unloading times of under 2 minutes.

### Automation for air transport

Since the early 20th century, stabilisation systems and autopilot functions have been adopted for aircraft. Drones appeared for the first time in military, police and firefighting applications. Unmanned aerial systems and vehicles are also used in civil applications, for example to inspect remote areas after storms or fires, in film productions and industrial inspections. Recently, some pilot studies have been carried out to explore the potential application of drones to transport goods in urban areas (for more information about drone applications for last-mile deliveries, see Section 3.3.4) (Flämig, 2016). Another potential application of drones is the transport of lightweight, high-value goods point-to-point, such as blood samples being transported between hospitals, or in remote regions. In Rwanda drones are already being used to deliver life-saving medicine to rural areas (McVeigh, 2018).

Drones also can be used for handling tasks in a warehouse. This is happening in the USA, where they replace humans on foot or operate fork-lift trucks and mechanical lifts. Drones were found to be operationally cheaper and more accurate, because they help to reduce the number of human errors with inventory (e.g. misplaced items and faulty inventory records in the warehouse). Argon Consulting argues that two drones can carry out the work of 100 humans (i.e. in terms of handling, picking and order preparation) over the same time period with an accuracy close to 100%, with warehousing and logistics cost savings (Jackson, 2017). A more advanced technology has been launched by the French firm, Hardis Group, which uses an inventory-scanning drone (i.e. EyeSee). EyesSee is fully automated and easy to use, with no installation, no infrastructure adaptation and no driver.

These developments are both recent. To date, independent analyses of efficacy were not found in the literature, but the potential for cost reductions and competitive advantage for those who adopt them seems high. The investment capital requirements are also high and can be uncertain: media reports in February 2018 indicated that the online grocery retailer Ocado recently had to obtain an additional £150 million in shareholder investment to enhance functioning of its robotised warehousing (Wood, 2018).

However, the significant potential impact on the currently growing employment sector of warehousing should be noted. Political strife may not be a barrier to adoption in newly-opened warehouses, as no humans will be obviously replaced. However, the cumulative effects of automation across the sector, and indeed the economy, may grow to become a significant topic of political debate, and potentially a barrier to adoption.

### Innovative solutions for last-mile deliveries

As well as being fundamental to the economy, the transport sector imposes significant costs on society in the form of traffic congestion, road collisions and health and environmental impacts (Korzhenevych et al., 2014). These impacts are more concentrated in urban areas, due to high density of activity. They are also more significant due to the high density of people, resulting in high exposure. Freight transportation, mostly using diesel vehicles of medium and large dimensions, plays an important role in the ‘urban transport problem’.

Different solutions have been developed in recent years to reduce negative externalities related to these increasing freight flows in urban areas. In terms of emerging solutions, there has been enthusiasm among commentators that shared-resource economic models can both create new commercial opportunities, and address transport policy problems. Korzhenevych et al. (2014) identified that stakeholder collaboration through sharing can be an important tool for making the urban freight transport system more efficient and effective. Collaborative strategies are commonly used in the field of supply-chain management (Montoya-Torres et al., 2016). Collaboration requires information sharing, and therefore confidence and trust, between the actors involved in the process.

However, in terms of new technologies and automated systems, the literature offers a smaller volume of material on last-mile deliveries and urban goods distribution rather than port-related initiatives, rail transport and long-distance haulage. The main findings of this evidence review are presented on the next sections.

**AVs.** Emerging solutions for last-mile deliveries draw on the innovative technologies that have mostly been introduced above. As in the case of longer supply-chain links, AVs are proposed to make last-mile deliveries. AVs for the last mile offer more routing flexibility in a complex network environment (Priemus et al., 2005). According to Alessandrini et al. (2015), the potential applications of AVs for urban freight movement relate to:

- just-in-time restocking of shops from remote warehouses;
- drop-off points for last-mile deliveries at houses or small offices; and
- waste collection and transportation.

A noteworthy application of AV systems for urban freight transport is represented by a ‘light duty automated transport vehicle’: a physically connected vehicle train consisting of a single automated ‘driver’ module (in fact, driverless), and a number of standardised, interchangeable cargo modules which can be adapted and shaped depending on the specific tasks and requirements. Figure 7 represents the concept of a multi-trailer freight train.

**Figure 7: Representation of an automated multi-trailer vehicle for last-mile deliveries**

**Source: Alessandrini et al. (2015), Figure 6**

An example of the modular approach is the Cargo Hopper System in Utrecht, powered by a solar and battery-electric motor and comprising three containers which can be loaded on or off the undercarriages by a forklift. However, this system is human-driven, not automated.

Alessandrini et al. (2015) suggest that this type of solution is likely to be applicable to support last-mile deliveries performed through an urban consolidation centre. In this case, goods are consolidated by destination and collected in modules, which are accessible by customers who want to take their shipments through secured access: e.g. credit card, smartcard or near-field communication (NFC) devices. This integrated solution can result in reduced emissions from last-mile deliveries, due to both the nature of the electric automated vehicles and the efficiencies brought by urban consolidation centres. Operating cost reductions (e.g. driver labour cost avoided),[22] safety improvements and reduced loading bay needs are achievable with this system.

Other emerging solutions are considered within the European Freight Urban Robotic vehicle (FURBOT) project. Cepolina (2014) proposes a mobile packstation which, unlike the Amazon locker system[23], does not have a fixed position as a solution for urban deliveries. DHL Parcel Germany runs the Packstation service, which allows customers to self-collect parcels, 24 hours a day, seven days a week. FURBOT integrates the Packstation into the Urban Consolidation Centre concept. The goods are unloaded in the location where they are required through the mobile packstation in a timely manner (Figure 8).


**Figure 8: FURBOT and the mobile Packstation concept[24]**

**Source: Cepolina (2014), Figure 4**

[22] Every year, the Transportation Institute at Texas A&M University produces the Urban Mobility Report, which shows statistics for the annual costs of congestion in the USA. The report considers three main cost components for congestion delays: (1) the value of time for personal travel (estimated at $16 per hour); (2) the value of additional driver time and other operating costs for large trucks (estimated at $88 per hour); and (3) the cost of excess fuel consumption (based on prevailing prices for petrol and diesel). Source: Anderson et al. (2014).
[23] Amazon Lockers are self-service kiosks where customers can collect or return their Amazon parcels at a time convenient for them.
[24] LBL – Less than full Box Load, UDC – Urban Distribution Centre (also called Urban Consolidation Centre)

The vehicle proposed by the FURBOT project (Figure 10) integrates a mobile robot, a van and a forklift. Driving assistance is provided to the driver for emergency braking, obstacle avoidance, parking assistance, itinerary assistance and adaptive speed control (FURBOT, 2014). It is claimed that these characteristics would enable FURBOT to operate in city-centre locations which have access restrictions for traditional vehicles (Molfino et al., 2014). The goods lock-and-release on identification system also could resolve temporal conflicts between freight and passenger traffic in city centres (Flämig, 2016), as the Packstation is delivered in off-peak hours.

Loading and unloading operations would be automatically performed through a robotised procedure (i.e. robotised forklift), which benefits from a customised design for both vehicle and loading units (i.e. boxes). This makes the driver's tasks easier (FURBOT, 2014). The vehicle is equipped with sensors providing information about the internal state of the vehicle and the environment outside. Conflicts with other road users are avoided, and congestion is reduced, thanks to the use of specific loading and unloading bays.

**Figure 9: The FURBOT vehicle**

**Source: FURBOT**

According to Cepolina (2014), FURBOT can be used as a single transport unit, but also more effectively as a multi-agent system (i.e. fleet of vehicles).

In the UK, self-driving vehicles for passengers and goods have been tested in recent years. In terms of last-mile delivery, the Gateway project (Greenwich Automated Transport Environment) is notable. Led by TRL and funded by the UK Government and industry, the project focuses on demonstrations in Greenwich, which include the use of a zero-emission CargoPod with a carrying capacity of 128kg for last-mile deliveries in a residential area.

The CargoPod load is characterised by eight slots. When it arrives at a specific customer's stop, the corresponding slot lights up, and the customer can open the door to collect their goods, such as groceries, by pressing a button. The project involves Ocado, the online grocery retailer. Results show that the system could efficiently replace traditional delivery vehicles. Their wider adoption will depend on both the technical ability to build and operate self-driving system, and regulations ensuring their use is safe and legal, Some customers choose home delivery because they have limited lifting ability: normally, the goods are brought into the home by the delivery agent. An issue which the cargo pod does not resolve.

Another option for last-mile deliveries is proposed by Starship Technology (STARSHIP, 2018), which created an electric robot for deliveries in urban areas. A small, six-wheel robotic delivery vehicle equipped with nine cameras, GPS, radar and computer vision autonomously drives itself on the pavement to make small-size deliveries (e.g. one cube). Currently, 150 such devices have been tested in Austria, Belgium, France, Germany, the Netherlands, Spain, the UK and the USA for food deliveries (e.g. Just Eat in the UK). It autonomously travels around the city, and creates its own road maps using safer paths algorithms. When it gets a delivery order and goes to the restaurant using GPS. Then it picks the food up at the restaurant, and goes straight to the customer's home. It travels on the pavement at a 4mph speed, sharing the space with pedestrians, which may cause issues for accessibility. It is programmed for dynamic routing, so it can identify and select the safest[25] and shortest routes. The vehicles are capable of automated travel, with human oversight and assistance especially when dealing with unexpected events. The load can be accessed only through a specific app or code that allow both forwarder and receiver to open the cargo. Security is guaranteed by a control system with a visual and audible alarm. The use of motor vehicles, including delivery robots, on the footway is prohibited under Section 72 of the Highway Act 1835. This is primarily to ensure the accessibility of the footway to pedestrians, particularly those with mobility and visual impairments. The Government does not have any plans to review existing regulations on the use of the footway at this stage.

The system provides an on-demand local delivery service, so it can be used to reduce or avoid the number of failed deliveries from logistics operators, who attempt to deliver with a high uncertainty of finding the recipients at home. Failed deliveries account for 5% of total e-commerce deliveries: they cause high costs due to the increased pollution caused by HGVs (e.g. trucks) and LGVs (e.g. vans), and loss to e-commerce retailers (e.g. £183,132 for UK retailers in 2018 due to failed deliveries; Taylor, 2018). The Starship technology aims to reduce costs (e.g. on-demand service, electric robots, reduced LGVs and HGVs in urban areas), improve efficiency (e.g. reduced and more accurate delivery time) and safety of last-mile deliveries. A key challenge of this technology is social acceptance. Pedestrians have to share the pavement space with it.  It is an open question as to how they will react to this technology. Starship co-founder and CEO Ahti Heinla declared that next year the robot will be able to operate in dense pedestrian areas; there might be 1 million robots operating around the world in five years' time (Financial Times, 2018).

Urban deliveries are usually made by LGVs rather than HGVs. The UK Licence Bureau declared that commercial vehicles create 20% of traffic. Three-quarters of that traffic are vans, while the remainder are HGVs (Department for Transport, 2016b).  Van traffic is growing faster than car traffic (+12% of vans versus +4% of cars in 2014). This is probably due to increased e-commerce, which has generated a high number of small-size deliveries in urban areas, making urban goods distribution increasingly unsustainable. For this reason, new technologies might be seen a new tool to urban delivery with the aim of reducing or avoiding the number of vans, so as to make cities more sustainable.

[25] It identifies safe or unsafe zones to minimise risks for itself and others.

In general, despite the high benefits provided, some key problems occur with AVs for urban goods distribution. Kunze (2016) identified the following issues:

- the need for loading and unloading systems or devices at both ends of the last-mile transport, resulting in high costs
- low compatibility of delivery recipients at the destination location – e.g. drop boxes, commercial unloading bays, etc.
- security and safety issues if no human is present – social norms expect that goods will be accompanied by a responsible human, which may be a restraint on speed of uptake

**Drones.** Another challenging solution is proposed by Amazon, which considers the use of drones for small-size urban deliveries. Such systems have been demonstrated already in some Chinese cities (Engelking, 2015), although they are still subject to tight regulatory restriction in Europe and North America. Some applications of drones have been undertaken with medical products deliveries in developing countries, to overcome access problems caused by poor surface transport infrastructure, or to remote communities in developed countries (Haidari et al., 2016).

However, some limitations occur as a result of current drone technology capabilities. For example, the Amazon 'Prime Air' octocopter has been estimated to have a carrying capacity equal to 2.3kg and a maximum range of 16km (assuming empty, therefore lightweight, return). This limits applicability to different types of deliveries in terms of size, even though DHL (a) (2014) suggests the use of drones more within areas that are geographically difficult to access (e.g. rural areas) rather than for urban deliveries. Nevertheless, an extensive drone delivery scheme might be supported through an alliance between local retailers and wholesalers with surplus storage capacity available, to create a new network of local stockholding points – thereby deploying drones for the final leg, for which vans are least efficient.

In 2015 Amazon trialled a Prime Air drone delivery service in Cambridge, UK. The trial was open only to customers who lived close to the Amazon depot, and owning sufficient private land to allow the drone to land. The order weight limit was set at 2.6kg. The delivery took 13 minutes from website order to drone arrival. The demonstration was possible due to UK Government regulations allowing companies to experiment with autonomous aircraft that fly beyond the line-of-sight of the operator in rural and suburban areas. In the longer term, one operative might control multiple largely autonomous drones, with system sense-and-avoid technology for its autonomous capabilities (Hern, 2016).

On average, between 15 and 16 drones would be required to replace one van. D'Andrea (2014) estimated that the direct operating costs of a drone are in the order of $0.10 for a 2kg payload and 10km range, while a traditional system incurs costs around $0.60 per item to be delivered. This makes deliveries with drones feasible from a cost perspective. However, automation research – i.e. research on vehicle design, localisation and navigation and vehicle coordination – is still needed to make drone delivery practical.

The main risks to the public include:

- safety – notably the risk of malfunctioning drones crashing onto people or property, or collision with aircraft
- security – hacking of drone control systems for malicious purposes
- noise emissions
- low energetic efficiency
- impact on local ecology (e.g. on birdlife)
- lack of adequate near-ground air traffic regulation (D'Andrea, 2014; Whitlock, 2014; Kunze, 2016)

In general, Kunze (2016) argues that the adoption of urban air drone logistics on a larger scale is unlikely because they are neither energetically efficient, nor will citizens tolerate air drone noise emissions.

However, arguably even greater problems are related to both security and safety and the business model. In the UK in recent months, in addition to concerns about air proximity incidents at Heathrow Airport, there have been numerous negative media reports about the use of drones, including their illegal use for the delivery of drugs and other commodities to prison inmates, and concerns that even legitimate business use would cause intrusive overflying of private property, where the concern is as much the potential for surveillance as noise pollution.

Overall, it seems reasonable to suggest that the advantages of using drones in rural areas, due to the limited extent of current freight transport and logistics systems, combined with the reduced problems of interaction with existing activity and property in lower-density areas, will see UK market development first in this context.

**3D printers.** Last-mile deliveries are increasingly related to e-commerce and its business-to-consumer market, which generates a high level of lorry traffic in city centres. According to Iwan et al. (2016), despite the global economic crisis, online sales have shown significant growth over the last years, making the negative impacts of last-mile deliveries also more significant. Business-to-consumer last-mile deliveries are already considered the most expensive, least efficient and most polluting leg of the whole supply chain (Gevaers et al., 2014). However, in the UK, already the country with the greatest sales penetration of online retailing, the market share for e-commerce is projected to grow from 13.8% in 2015 to 17.1% by 2020 (McKinnon, 2016).

An emerging solution to reduce urban freight flows is offered by 3D printing. This allows consumers to 3D print products they have purchased in their own homes, through a process of laying down many thin layers of a material (such as plastic) in succession to make a physical object from a three-dimensional digital model. According to Taniguchi and Thompson (2014), 3D printing and other emerging technologies have the potential to reduce demand for goods movement, replacing physical distribution with digital delivery of product (McKinnon, 2016). This follows the business model pioneered by software and music download providers, whereby vendors sell reproduction licences for ‘printing’ instead of finished products. Keeney (2016) estimates that the 2020 3D global market could grow to more than $40 billion, and other analysts estimate a range from $12 billion to $490 billion for the next five to ten years, as shown in Figure 10. Keeney argues that 3D printing potentially could grow by more than 40% a year over the next five years. However, uptake to date by individual consumers has not been high, despite the fact that the price for a basic 3D printer is approximately $200 (McKinnon, 2016).

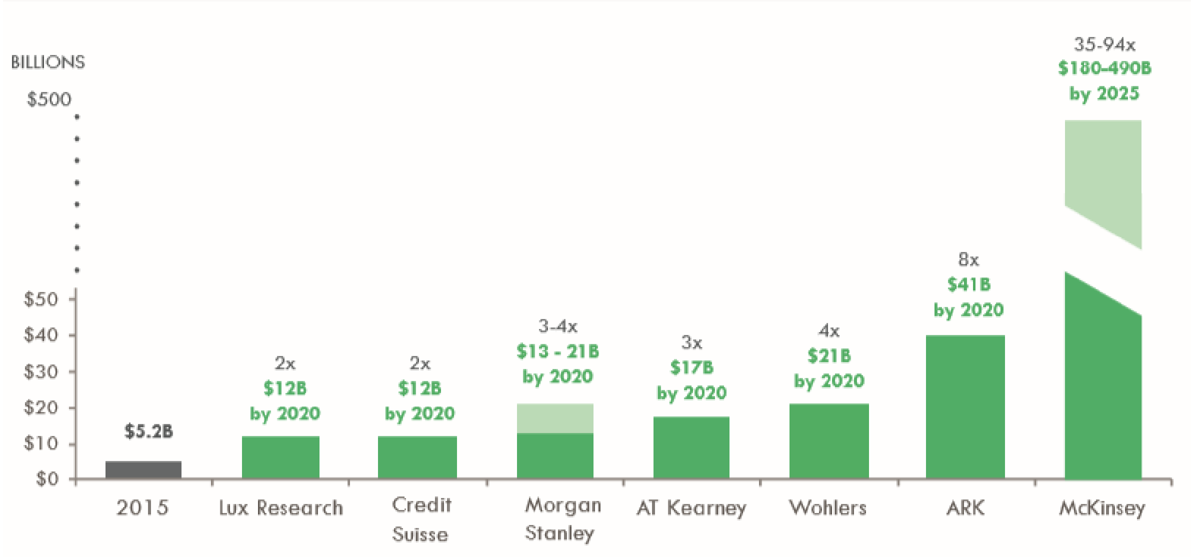


**Figure 10: 3D global market by 2020**

**Source: Keeney (2016), Figure 2. Graphic reproduced with permission of ARK Investment Management, LLC**

According to Kunze (2016), the advantages of using 3D printing include:

- the possibility to customise products;
- reduction in freight-kilometres travelled in the upstream supply chain[26], and related reduction of polluting emissions, congestion and noise;
- reduction in lead time – important in the case of urgent deliveries, for example a replacement part.

However, currently there are at least several barriers and limiters to uptake. A wide range of material types are in use, but different 3D printers are required to handle different materials e.g. plastics, metals and even food. Multi-material printers will be developed in the future, but are not available in the mid term. There are also uncertainties about the business model. While low-cost basic 3D printers might be available, consumers will expect complex, multi-material products to be available if

[26] The ‘upstream supply chain’ refers to suppliers, purchasers and production lines near the beginning of the processes linking the production of goods and services with eventual consumers.

they are to use the technology; but this will impact significantly on cost, suggesting it is unlikely that private households will own multiple 3D printers (working with different materials) in the mid-term future. Instead, local centres could pool different printers and offer the opportunity to have 3D print-on-demand products.

Nonetheless, according to Kunze (2016), the potential of the 3D printing solution is difficult to assess because it depends on the product development, production and sales strategies of producers rather than factors controlled by the logistics sector. For example, further innovations and improvements in material and printer capabilities are needed to accelerate adoption and create new applications for additive manufacturing (Keeney, 2016). Still, the technology is worthy of policy attention because of its potential to reduce upstream transport and the related negative externalities.

In general, Kunze (2016) suggested that all the above-mentioned innovative solutions for the future of last-mile deliveries can be integrated into a ‘freight urban system’ that includes local cross-docking centres for receiving and collecting goods. This solution could involve consolidation centres, pick-up points and packstations, where people can variously collect their goods themselves or receive them via larger vehicles, crowd logistics[27] solutions, drones and other sustainable delivery solutions (e.g. cargo bikes). In this environment, 3D printers can be integrated to reduce freight flows due to e-commerce and home deliveries. The overall system also could solve the problem of delivery failures that cause an increase in last-mile delivery trips.

# 6. Disruptive business models

Implementing automated freight systems can be subject to a technology push or a market pull approach. In technology push, market needs are not considered before a technology is developed and pushed onto the market. At the moment, truck platooning is based mainly on a technological push approach, as national and international authorities are facilitating truck manufacturers to bring their technology into the market. Some forecasts about market availability do indeed suggest that a ‘push’ strategy may be plausibly effective: Keeney (2017) expects autonomous trucks to be commercially available within the next five years, and international companies that are currently involved in developing autonomous truck platforms include Tesla, Waymo, Uber, Volkswagen, Volvo, PACCAR and Daimler.

However, it is not just the availability of technology that influences take-up, and there are reasons to suggest that the push strategy might not be sufficient. Conversely, a number of societal and economic benefits come from the implementation of truck platooning, such as reduction in transport costs, increased safety and decreased congestion and pollution (Bakermans, 2016). For this reason, due to the high-value

[27] Crowd logistics is beyond the scope of this technology-focused review, but involves individual actors (citizens or businesses) being incentivised to deliver consignments where they can do so for marginal cost: for example, to a house next door or in the next street which is on or very near to an intended journey route.

benefits, a market pull approach based on the needs of the stakeholders involved is also needed.

Connected automated vehicle (CAV) technologies for freight applications are likely to be early adopters of high-level automation (Shladover, 2017). However, Shladover argues that new business models for CAV deployment based on innovative public–private relationships need to be encouraged to lead vehicle–infrastructure coordination and bridge investment gaps.

A pull factor for CAV adoption is also the main value proposition highlighted within the COMPANION project: fuel consumption savings due to air drag reduction by platooning. Savings of at least 5% of fuel have been quantified. However, a deeper analysis should quantify savings by considering the total logistics costs. In Europe, fuel represents 9–32% of total costs (including personnel, administration, capital costs, taxes and insurance and other variable costs). If fuel is on average 20% of total costs, it represents an important cost, in the sense that all carrier costs are important in a highly competitive marketplace, but it is not dominant.

Indeed, in the short-term perspective, fuel saving would not be the most important factor influencing a company that might be considering using platooning. In fact, driver acceptance is held as one of the most critical factors for adoption. Driving in a platoon must be perceived as safe and comfortable: hence, among the factors influencing the success of platooning in the short term is education. Drivers need to receive objective information and proper training and support to perceive platooning as a safe system, in order to be able to accept it.

Another important factor is interoperability between platooning systems for lorries produced by different automotive manufacturers, which is essential for the viability of a platoon system. Transport companies want to be able to platoon with all their vehicles, which often are sourced from different manufacturers.

At the moment AVs are prototypes rather than a part of standard production, and therefore expensive. However, costs are expected to fall rapidly with further development and mass production. KPMG (2015) estimate the additional costs in the long run of full automation for commercial applications as low as £5,000 per vehicle in the UK. Wadud (2017) estimated the costs and benefits of automation through three different scenarios (Table 3). For example, the cost of equipping a 38-tonne trailer truck ranges from £12,500 in his optimistic scenario, through to £20,000 with his pessimistic scenario. In respect of savings, automation is expected to provide a reduction in commercial driver labour costs ranging from 80% to 60%. In general, it can be said that the benefits of automation are higher for commercial vehicles than for cars, so it is worth adopting full automation earlier in the freight sector (Wadud, 2017).

**Table 3: Cost and benefit input of automated systems in different scenarios**

| | Optimistic (£) | Baseline (£) | Pessimistic (£) |
|---|---|---|---|
| **Cost of automation** | | | |
| **38-tonne trailer truck** | 12,500 | 15,000 | 20,000 |
| **18-tonne trailer truck** | 12,000 | 14,500 | 19,000 |
| **7.5-tonne trailer truck** | 11,500 | 14,000 | 18,000 |
| **Taxi** | 9,400 | 11,400 | 15,000 |
| **Private car** | 9,400 | 11,400 | 15,000 |
| ***Driving time benefits:*** | | | |
| **Commercial driver salary reduction** | 80% | 60% | 60% |
| **Private car productive use of time** | 60% | 40% | 25% |
| **Fuel-efficiency benefits** | 10% | 5% | 5% |

**Source: Wadud (2017), Table 6**

In the case of innovative solutions for last-mile deliveries, the definition and assessment of business models is more complicated. Further research is needed for both investment and operating costs, which can be assessed based on the specific market potential of each solution. Different scenarios can be considered and assessed only when further information about the likely business models are available.

However, Keeney (2016) reports on a study to identify the beneficiaries of disruptive technological innovations, such as 3D printing (shown in The same study pointed out that "while the 3D printing manufacturing space will remain fiercely competitive, 3D printed parts that are being designed into supply-chains should prove to be more durable and more defensible than those in the consumer and prototyping spaces". Indeed, according to Keeney, prototyping is a well-established market, accounting for $12.5 billion. However, 3D printing is also penetrating injection and cast-moulding applications, opening up a potential addressable market of an additional $30 billion globally. Different international companies (e.g. Airbus, Nike, Adidas, and GE) use 3D printing for direct product manufacturing, while Ford uses it for moulds and prototypes, with plans eventually to 3D print finished products (Keeney, 2016). Such future applications of 3D printing for finished products, are predicted to be an additional $500 billion market (Figure 11).

Table 4). The range of actors and processes involved reinforces the idea that this remains a nascent technology.

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**Table 4: Beneficiaries and benefits of 3D printing**

| Beneficiaries | Benefits |
|---|---|
| **Software and modelling tool providers** | Should collapse the time and distance between design and production |
| **Innovative materials manufacturers** | Will enable performance and form factors that otherwise would be impossible |
| **Scanning and measurement companies** | Will help incorporate real-world measurement as an important design input for production |
| **Service centres** | Will help manufacturers transition from traditional to additive techniques, accelerating adoption of additive techniques into design-cycles |
| **Innovative manufacturers** | Should enjoy competitive advantages, as they provide customers with better performance and more customised products at a faster pace and cheaper cost than their competitors |

**Source: Keeney (2016)**

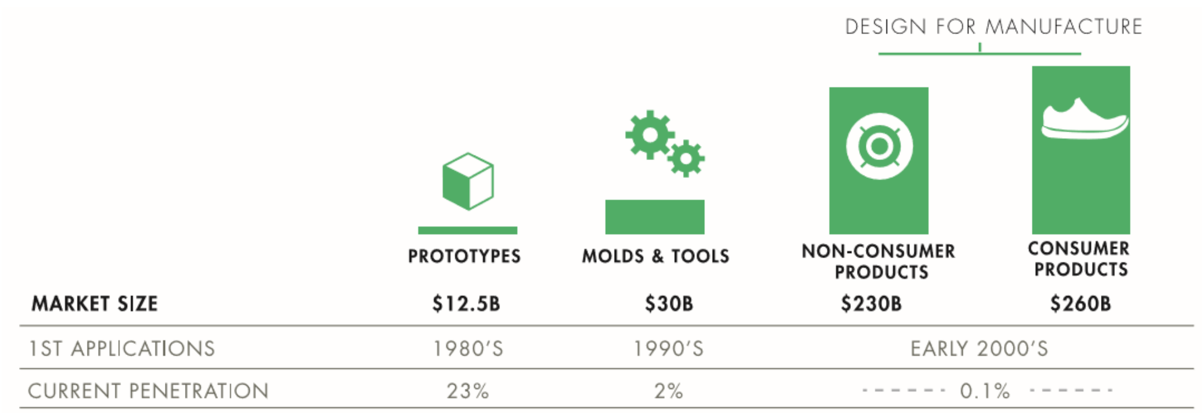


**Figure 11: 3D printing global market penetration**

**Source: Keeney (2016), Figure 3, Graphic reproduced with permission of ARK Investment Management, LLC**

However, as noted in Section 3, multi-material 3D printers are not available at the moment, and it might be difficult to print product made by materials with different process requirements. For example, a product made by metal and plastic cannot be printed by a 3D printer, because metal requires significantly higher temperatures than plastic. For this reason, the materials need to be very similar in terms of structural behaviour, and in this case there is still a need to change the print head when shifting from one material to another.

In summary, multi-material 3D printers are still in the experimental stage – even when they can be used, they exhibit low reliability in terms of quality. This, together with high equipment costs and long product realisation time, currently make 3D multi-material printers a poor alternative to more traditional industrial printers.

# 7. Stakeholder requirements

Before analysing the stakeholders involved and their needs, it is worth clarifying the difference between users and stakeholders: *users* are all parties that directly interact with a system, whereas *stakeholders* are those parties that not only have an interest in a system, but are also directly or indirectly affected by it.

Identifying the relevant stakeholders for automated transport systems is necessary to identify the enablers of, and barriers to, automation for freight in an effective way. Clarifying the interests of different stakeholders is important when seeking to estimate the potential of new technologies.

For example, the main stakeholders involved in the adoption of truck platooning are the following.

## a. The carrier

This is a company responsible for transporting goods for a client (e.g. a consignor), and is physically in charge of the transport. The carrier aims to complete transport assignments according to agreed time constraints, at minimal cost. Carriers are the key customers of automated and collaborative trucks (platooning), and business models will target them throughout (Bakermans, 2016).

The literature shows that they are interested in this type of new technology and are positive towards fuel-saving and safety-improving concepts in general. However, some are worried about the added complexity and risk of delays due to the challenges related to coordination between different carriers.

## b. The shipper

This is the actor which owns the goods. Shippers generally contract a logistics provider to transport their goods. This is the most important actor, because the shipper can be considered the transport service’s customer. For example, in the same way that currently, a shipper can require the use of low-emission trucks, it could require carriers to use truck platoons for environmental or financial reasons (Bakermans, 2016).

## c. The truck driver

The driver is responsible for driving the truck from origin to destination according to given time constraints, at minimal cost. Drivers are key actors because their willingness to accept an automated system impacts on the time it takes to reach market acceptance. The study carried out by Neuweiler and Riedel (2017) pointed out that some drivers are worried about risks and their own safety, in addition to the impact of automation on the driver's future role.

Conversely, several drivers expressed both interest and optimism regarding the benefits of automated systems such as platooning. According to Bakermans (2016), the truck drivers of the future will no longer be responsible for driving; rather, they will conduct other tasks such as administration, with a related increase in role efficiency.

## d. The regulator

National road authorities are responsible for supporting policymakers in defining regulations to implement new technologies: they have a key role in the first stage of implementing truck platooning. Regulations should take into account the impact of platooning on road capacity, road safety and the environment. Collaboration between different national road authorities is needed to avoid extra costs for cross-border activities. Also, new assessment criteria and tools are needed to allow and foster automated vehicles on public roads (Bakermans, 2016).

## e. The systems provider

This category of stakeholder includes the vehicle manufacturer responsible for the fulfilment of automated trucks, and advanced technology manufacturers responsible for the sensor and cooperative control systems built into the assembled vehicles, to enable their participation in platooning. The major truck manufacturers, such as Scania, Volvo, MAN, Iveco, DAF and Daimler, are able to implement platooning techniques in their trucks, and it is critical for cost reduction that they are integrated, rather than after-market solutions.

Several pilot projects and tests have been developed (Bakermans, 2016). Truck manufacturers are willing to invest in platooning because they are convinced of its positive effects, and are generally positive towards platoon interoperability between brands (COMPANION, 2016).

## f. The policymaker

Policymakers are responsible for defining and implementing new regulations for new technologies to be adopted in the freight sector. Due to the multiple societal benefits predicted from automation and platooning of trucks, central governments may choose to legislate to facilitate truck platooning by establishing specific operating conditions, such as mandating particular technical standards which will ensure interoperability. However, policymakers need to have a clear quantification of the potential impacts of platooning to be convinced that the overall effects of policy change would be positive, and that unintended or undesired consequences (such as a possible reduction in the use of rail freight) are either unlikely or, in the event they do arise, at acceptable levels.

In addition to those identified above, other important stakeholders have a central role in the context of the business model for platooning (COMPANION, 2016).

### g. Driver training service providers

These are responsible for training professional truck drivers. Their role is very important, especially in the short-term, because drivers will need somewhat different knowledge and skills in order to be able to transition to autonomous/platooned trucks.

### h. Service providers of business support and education systems

These offer support to carrier companies during the first stage of implementing platooning. Their role is important during the short term and mid term of the transition to platooning, as sources of information about the benefits of, and effective business practices associated with, adoption.

### i. System providers for platooning coordination

These are responsible for developing, distributing and maintaining the systems for coordinating trucks into platoons. They may also be the system operators. Their role will be increasingly important in line with the extent of adoption of automated systems during the transition period, as these are the organisations that will have deep technical knowledge of the control systems, their safe operation, and appropriate responses in the case of unintended or unexpected incidents. It will be these organisations that 'train the trainers' of drivers involved in platooning.

## 8. Enablers and barriers

The most likely enablers of, and barriers to, the adoption of new technologies in the freight sector are highlighted in Figure 12.

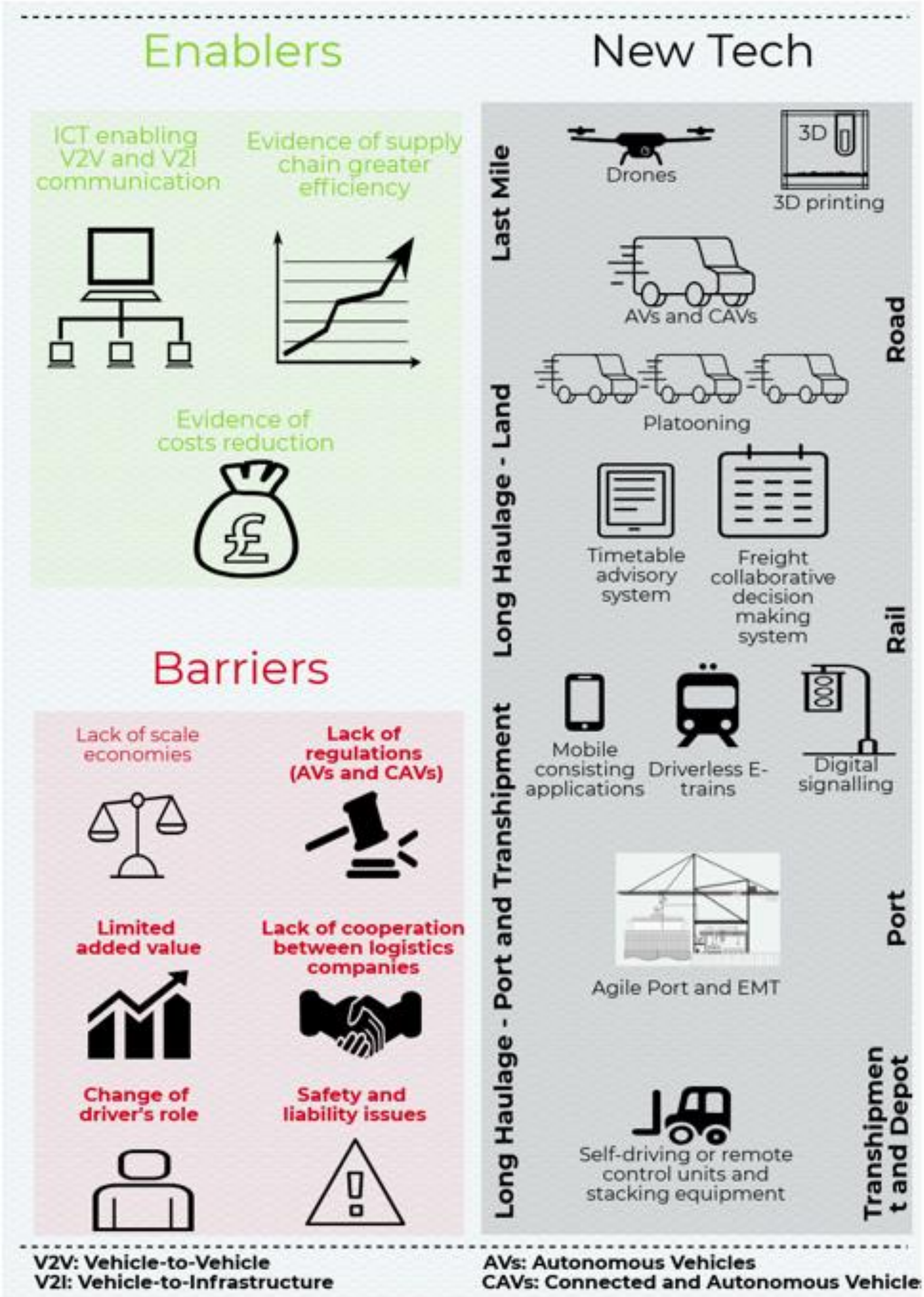


**Figure 12: Enablers of, and barriers to, the adoption of new technology in the freight sector**

## a. Enablers

The availability of cutting-edge **information and communication technologies (ICTs)** is a clear prerequisite to successfully adopting new automation technologies in the freight sector. In particular, the provision of nationwide superfast/Gigabit broadband and high-speed mobile networks will be fundamental to supporting all aspects of the UK economy in the 21st century. With specific respect to the freight sector, such high-capacity data transmission networks will unlock potential for:

- the development and deployment of V2V, vehicle-to-infrastructure and vehicle-to-cloud communication technologies, as required for the automation of road haulage vehicles
- increased capacity to transmit logistics data between freight providers (and to customers), to improve efficiency in freight operations
- the operation of automated drones for last-mile deliveries

Currently, logistics providers use a mix of different data structures. Standardised data structures and transmission protocols will be required to maximise the potential for data sharing across the freight sector. ICTs might enable supply-chain managers and, in general, all the actors of the supply chain (e.g. shippers, logistics operators, retailers, end consumers) to improve performance of their activities by virtue of more efficient information flows. Such a development would improve the overall quality of the services provided across the supply chain. Emerging solutions such as the block-chain[28] or e-market platforms (or port community system platform for the shipping sector) also might affect the introduction of automation in different logistics industries, making automation more attractive to potential investors due to the provided high integration of automated systems to the supply chain.

Companies that provide ICT services gain an essential role in this case, being responsible for designing and offering up-to-date systems to improve the competitiveness of the supply chain.

Compelling and reliable evidence of **supply chain efficiency gains** and **cost reductions** is also necessary to incentivise private-sector stakeholders (e.g. supply-chain managers, automotive sector, logistics operators) to invest in new technologies. An analysis by Keeney (2017) suggests that autonomous electric trucks could be expected to reduce the cost of trucking from $0.12 per ton-mile to $0.03 per ton-mile during the next five to ten years – an operating cost reduction of 75%. Such significant operating cost savings will offset the higher capital costs of emerging technologies (Figure 14).

However, estimates such as these need to be supported by real-world trials to validate the claims, which are likely to need state support so that financial risks are

[28] “Block-chain is a digital database containing information (such as records of financial transactions) that can be simultaneously used and shared within a large decentralized, publicly accessible network; also : the technology used to create such a database” – Merriam-Webster, https://www.merriam-webster.com/dictionary/blockchain.

shared between public and private bodies. Findings such as the cost savings identified by Keeney (2017) also need to be effectively communicated to key stakeholders across the freight sector, to demonstrate the potential benefits of the new technologies.

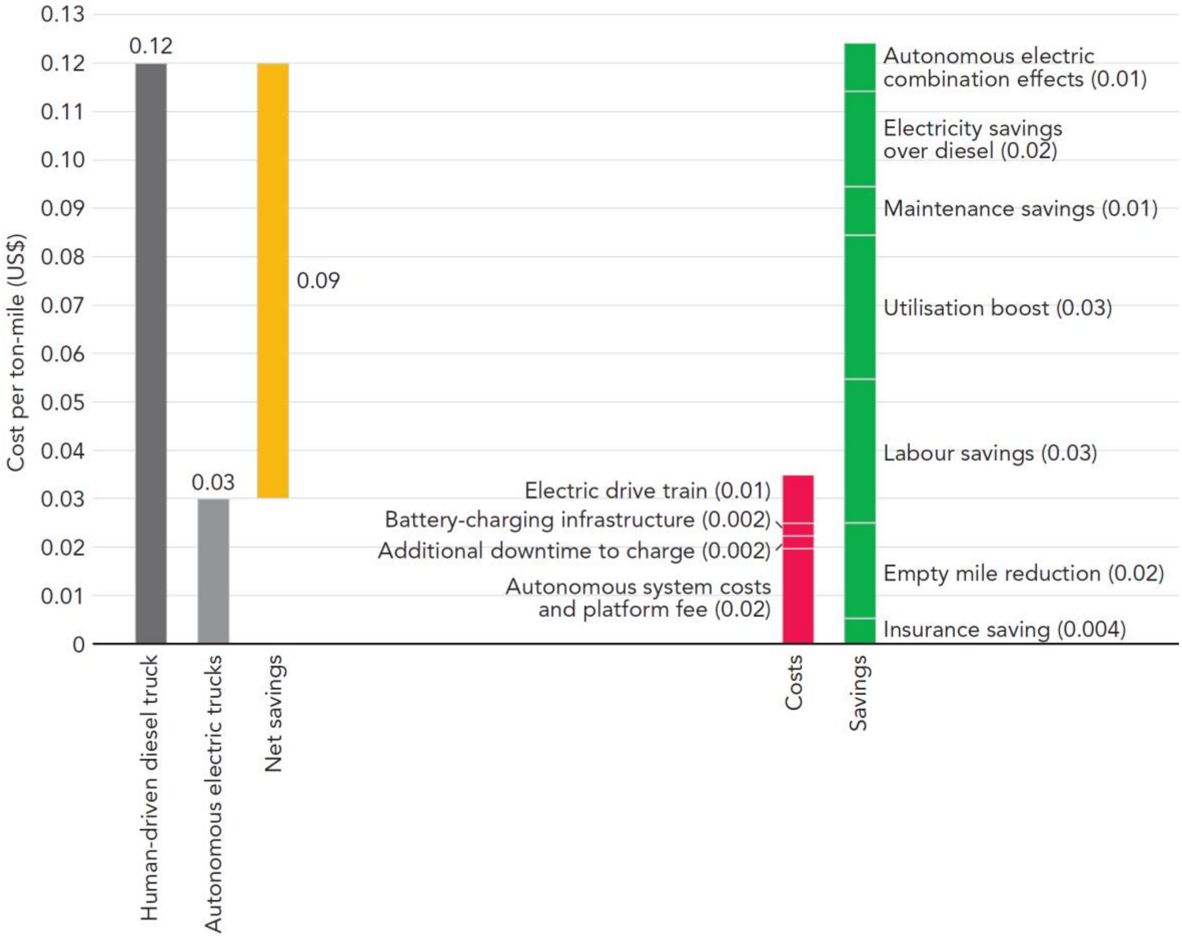


**Figure 13: Electric vehicle savings and autonomous vehicle savings[29]**

**Source: Keeney (2017), Figure 1, modified graphic reproduced with permission of ARK Investment Management, LLC**

Figure 13 shows costs savings with autonomous and electric trucks. The most important benefits arising from AV adoption are labour cost savings and higher vehicle utilisation (i.e. they are used for a greater portion of available hours). Moreover, if the vehicle is electric, there are modest additional net savings, mainly due to (currently) higher drive-chain costs (the parts of the vehicle which make it move) being offset by lower energy costs. There is a 0.01 cent cost saving per US ton-mile that can be attributed to both electric vehicles and AVs. Electric vehicles lower operating costs, and when the autonomous mode is turned on, operating

[29] Red indicates the additional costs due to electric and autonomous trucking, while green indicates cost savings regarding traditional trucking, if the electric-automated mode is used. Both are expressed in additional or reduced $ per US ton-mile.

savings are magnified. Notably, the study carried out by ARK reflects the US context. In Europe it might be different, because road traffic conditions on the long haul in the USA (e.g. long distances, low congestion) are such that AVs can maximise their performance and the benefits can be fully exploited. It is also worth noting that diesel is more expensive in Europe, so probably more significant savings can be achieved in European countries by conversion to electric power. However, it is not easy to make assumptions about the difference on cost-per-ton mile due to uncertainty around future regulations (e.g. tax on electricity used for transport, distance-based charges).

Figure 14 shows the future prospects of freight transport costs by mode. Autonomous electric trucks are compared with other means of transport, suggesting that they would be significantly more competitive. As in the case of Figure 13, this is based on a US study. The equivalent analysis for Europe might be even more positive, as the cost of transport by train is higher in Europe than in the USA, making AVs potentially more competitive in the UK rather than in the USA, although with possible negative consequences for rail freight.

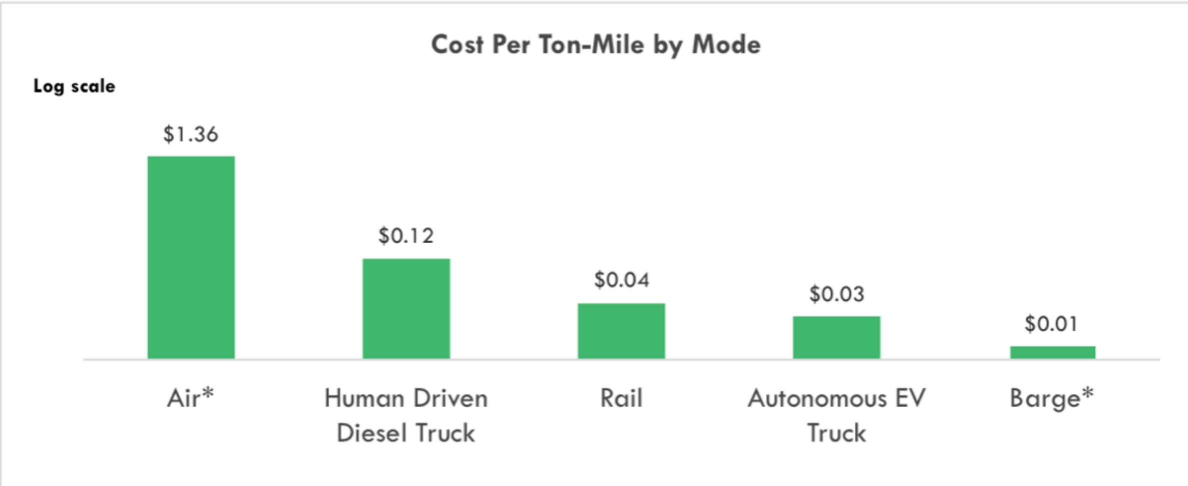


**Figure 14: Cost per ton-mile by mode of transportation[30]**

**Source: Keeney (2017), Figure 2, graphic reproduced with permission of ARK Investment Management, LLC**

Significant costs savings can be achieved also with remote and automated shipping. According to Rolls-Royce (2016) there might be direct (e.g. mainly related to the vessel – improved efficiency of space in ship design, crew, fuel consumption) and indirect (e.g. mainly at company and network in the shipping sector – optimised operations and processes, improved overall performance, reduced human errors, improved safety and service quality) benefits. These benefits could provide the UK shipping sector with a key tool to gain long-term competitive advantages from

[30] cost per ton-mile for air and barge is using 2014 and 2011 data, respectively (latest available). EV – electric vehicle.

autonomous shipping. In particular, according to Opensea.pro (2017), having no crew on board would:

- drastically reduce operating costs – e.g. crew living expenses are more than 50% of a vessel's operating costs, resulting in a saving of about $1 million a year for handy-size bulkers, and $1.5 million for handy-size product tankers

- increase revenue – e.g. more space on board for loading cargo; till $0.50 million higher revenue a year for a vessel's deadweight increased by 10% (e.g. as estimated for a handy-size vessel performing one Indonesia–India trip per month)

- reduce voyage expenses due to the reduced weight – e.g. 5% lighter (Rolls-Royce, 2016), till $0.30 million per year for a handy-size bulk carrier that sails for about 250 days per year

Another noteworthy advantage is reduction of costs due to piracy: autonomous vessels will be difficult to board, and the absence of a crew which could be held hostage would discourage pirates. Assuming effective cybersecurity, on-board control of the ship could be made unavailable and immobilised through remote control, making it relatively easy for naval authorities to reach it.

## b. Barriers

Conversely, the **absence of infrastructure**, including ICTs and the complementary roadside systems required to enable operation of AVs (signals, signs and sensors) will hold back innovation in the freight sector; as will the lack of an appropriate **regulatory framework** for the use of automation technology. Indeed, it is the absence of an appropriate legal framework that is constraining the large-scale deployment of automated trucks and platooning, rather than technological problems per se.

In the early stages of technological development, there may be **limited added value** associated with taking on new technologies, given their high capital costs. Hence, early adopters need to be incentivised (e.g. through financial support) to take on such risks. The distribution of cost savings also needs to be explicitly considered. For example, in the case of platooning, it is of course the case that the 'following' vehicles save fuel and there is no benefit to the leading vehicle in this regard, while there may be additional operating costs or liabilities, particularly if the lead vehicle is human-driven. In such circumstances, it may be necessary to introduce a **pricing mechanism** to ensure that benefits are evenly distributed across all parties involved in the platoon.

Linked to the requirement for compelling evidence of the benefits and reliability of new technologies, **collective beliefs** and normative views about appropriate modes of operation held within institutions could act as a brake on innovation. For example, in relation to the use of platooning in road haulage, evidence from the COMPANION (2016) project indicated that negative perceptions among drivers could present a barrier to its adoption by firms. Drivers were found to perceive that platooning is unpleasant and uncomfortable; platooning limits drivers' 'freedom'; and manual driving is better and safer than automated operation. Also, drivers might be worried about future employment, as in a fully automated freight future their jobs would either radically change or disappear altogether. Opposition from drivers might represent a significant barrier to implementing automated systems, as their presence is required in the transition period from Level 1 to Level 5 automation (see Section 3.3.1).

The same problem could occur with warehouse employees. The long-term vision is that the warehouses of the future will be fully automated. This would improve overall logistics performance notably (e.g. reduced time, error and cost, and improved safety), but would significantly reduce the number of humans employed in the sector. These people might show opposition to new technologies and automation due to the high impact that these have on the employment sector.

Furthermore, new skills are not easy to acquire and their transfer takes time, while the current labour force might resist change. A national policy to manage the **consequences of the adoption of automation across the economy** might be a top-down option for reassuring workers that they can be net beneficiaries from this revolution. Clearly, convincing evidence that automation technology is **safe** – and indeed, safer than manual operation – is required to overcome early misperceptions concerning risk. High-profile (if low-probability) safety issues arising during trials of AVs (as happened with the death of a driver using a Tesla vehicle equipped with autopilot; Tesla, 2016) could have long-lasting impacts on the prospects of adoption.

A comparative **lack of economies of scale** for new technologies also puts them at a competitive disadvantage to current modes of operation. To give two examples, for most consumer products, 3D printing of individual items will have much higher unit costs than conventional batch production, while the delivery of individual parcels by drone will be costlier than their distribution in consolidated loads on multiple drop rounds by vans. Consumer-based 3D printing and drone distribution will also require a substantial capital investment, in the latter case on landing stations as well as unmanned aerial vehicles. This is also likely to deter many potential users. Nevertheless, even if economies of scale that depend on new network elements might be difficult to achieve, especially in the short to medium term (due to high infrastructure investment costs), efficiencies might still be achieved by improving operating practices, for example, by optimising routes taken through the network). Therefore, it is important to establish mutually-beneficial mechanisms that enable logistics companies to **collaborate and share best practice**. Smaller companies with less buying power will need support (e.g. either financially, or through the provision of training) to enable them to alter their operating practices.

# 9. Building the future

Neuweiler and Riedel (2017) identified that the majority of the research projects carried out in this field focus primarily on the technical aspects of autonomous driving, rather than on the impacts and implications of the adoption of automation. They analysed 399 papers on the topic of autonomous driving, which mainly focus on technological development (91.2%), and few covering user acceptance (1.3%), regulations (1.5%) and environmental impacts (1.3%).

In sum, as described in the previous sections, high potential benefits would come from automated systems for freight. However, there is a lack of research to estimate the overall economic benefits. For the most part, the research which has considered economic benefits has investigated the benefits of fuel consumption reduction, rather than the social and environmental benefits. Nevertheless, despite the uncertainties about and unknowns of this challenging topic, it is worth noting that both industry and governments are willing to experiment and invest (Tavasszy, 2016).

## a. Implications: a macroeconomic perspective

Automated systems could solve problems with the current transport system. In theory, fully automated driving could double existing average road infrastructure capacity through exploiting autonomous systems' safety margins to the limit: for example, in terms of following and passing distances, and by smoothing traffic flow. In addition, for a given traffic level, connected and autonomous operation could contribute to achieving environmental policy goals (reduced fuel consumption), and significantly reduce collisions.

However, there are still important uncertainties about legal responsibility in the event of a collision (Flämig, 2016). The transition to remote-controlled and autonomous vessels will produce industry disruption, with impacts on shipping business operations and a change of role for some shipping actors, generating high uncertainty as to the future of shipping market competitors: new technologies might be beneficial for big players (e.g. increased integration of global companies, optimisation of fleet), while detrimental for smaller operators. Conversely, new players will enter the market due to the creation of new services for digitalisation and autonomous technologies, as is happening in the automotive sector.

## b. Implications for sector employment and inequalities

Automation is a key way in which companies can compete through increased efficiency in freight transport and logistics operations. However, as Lawrence et al. (page 17, 2017) argue, automation is "likely to change the shape of the labour market, the occupations that individuals work in, and the type of work tasks humans perform". Considering that the nature of work will change due to automation, there is a need to identify the specific activities that will also change. McKinsey (2017) argues that fewer than 5% of all jobs can be fully automated with existing technologies, but that 60% of occupations have at least 30% of constituent activities that could be automated today.

A large number of different jobs are likely to be affected by automation (Figure 15), but some sectors are more susceptible to automation than others (Figure 16). This is the case for occupations related to transport and storage, which are among those more susceptible to automation.

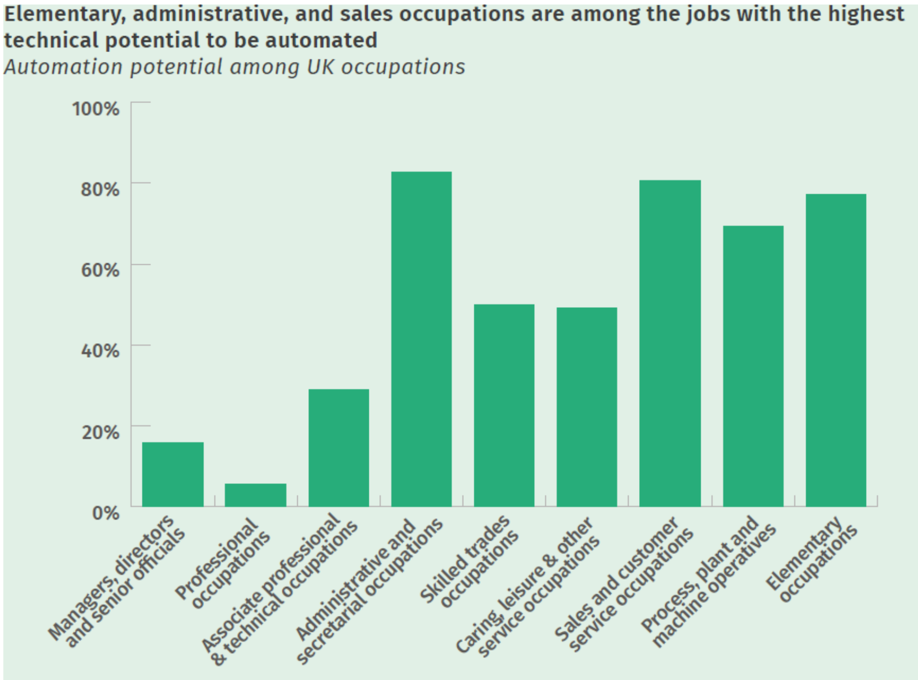


**Figure 15: Automation potential among UK occupations[31]**

**Source: Lawrence et al. (2017), Figure 1.7**

The analysis carried out by Lawrence et al. suggests that automation may be responsible for future growth in socio-economic inequalities due to the different education and skill levels of employees in roles more or less susceptible to automation. In short, workers with lower levels of skill are more at risk of complete automation of their jobs. In fact, 46% of workers with a low level of educational qualifications in the UK risk being replaced by automated systems, and the wholesale, retail, transport and manufacturing sectors have a large proportion of occupations that are technically susceptible to automation. The percentage falls to 12% for workers with undergraduate degrees or higher. This implies high impacts on the inequalities that already exist in terms of future salaries and income in the UK population.

According to the Cabinet Office (2017), automation in the UK could threaten gender equality, as role-automation is more of a risk for women (46.8% compared to 40.9% of traditionally male roles are potentially replaceable by automated systems), and inequalities between ethnic groups (as some ethnic groups, e.g. Black, Pakistani and Bangladeshi, are overrepresented in low-skill jobs). The implications for the freight sector would seem to be to redouble efforts to ensure equal opportunities, particularly if the nature of roles which are not automated will also change into the future (Table 5).

[31] The figure presents estimates of the proportion of jobs which could feasibly be automated within different industries and regions. Analysis carried out by Lawrence et al. (2017) using the Quarterly Labour Force Survey (ONS 2017d, 2015–16 data) and Frey and Osborne’s probabilities of computerisation (2013). (See Lawrence et al., 2017 and Annex for methodology.)

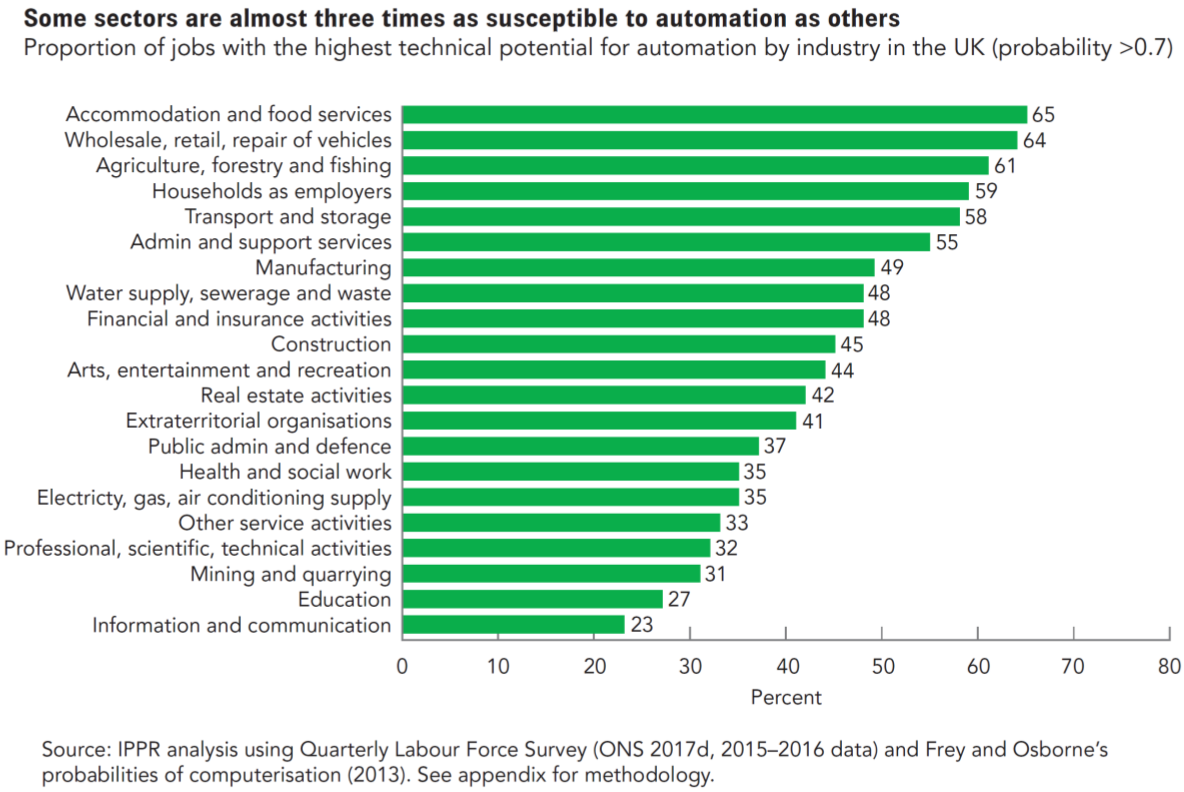


**Figure 16: Percentage (horizontal axis) of roles in different UK industrial sectors with the technical potential for automation[32]**

**Source: Lawrence et al. (2017), Figure 1.8**

[32] The figure presents estimates of the proportion of jobs which could feasibly be automated within different industries and different regions. Analysis carried out by Lawrence et al. (2017) (See Lawrence at al. (2017) and see Annex for methodology.)

**Table 5: Industries with high numbers of jobs with the highest technical potential for automation and low qualification levels among the workforce**

| Industry | Proportion of jobs with high potential for automation (p>0.7) | No. of jobs with high potential for automation | Proportion of workers without NVQ Level 4 qualification (%) |
|---|---|---|---|
| **Wholesale, retail, vehicle repair** | 63.7 | 2,638,000 | 76.3 |
| **Transport and storage** | 57.7 | 912,000 | 78.8 |
| **Accommodation and food service** | 64.7 | 1,093,000 | 78.0 |
| **Manufacturing** | 48.5 | 1,453,000 | 67.6 |

**Source: Lawrence et al. (2017), Table 1.1**

Driving activities will become less important with automation, and it is likely that drivers will be expected to have higher qualifications to perform new administrative tasks or technical tasks (e.g. monitoring of the autonomous truck) (Neuweiler and Riedel, 2017).

However, the prospect of job losses does need to be put in the context of an international shortage of truck drivers. For example, the American Trucking Association estimates that this will grow from 48,000 vacancies in the middle of the current decade, to 175,000 available posts in 2024 (Costello and Suarez, 2015). Although of smaller magnitude, the same problem also exists in the UK, so to some extent automation can be understood in this specific sector as solving a labour shortage problem.

Moreover, in respect of the short run, the American Transportation Research Institute (2016) has observed that during the first period of implementation, low-level (1–2) AV trucks such as those used in platooning, will increase current drivers' flexibility and improve their productivity, while they will still take over control when needed, check lateral movement, handle paperwork, and manage loading and unloading operations. Conversely, fully automated trucks (e.g. Level 5) would reduce the need for drivers, but experts estimate that this level of automation is unlikely to be commercially available for 15 to 20 years (Ginsburg and Uygur, 2017). Even then, the American Transportation Research Institute (2015) suggests that limiting factors will mean 'last-mile', final step in the chain, deliveries continue to be made by trucks driven by human drivers, with automation restricted to the main, long-haul portion of the chain.

Lower-level automated trucks may reduce the stress and monotony of driving for long hours, and enable drivers to be involved in other activities during the trip, while at the same time altering training needs (Ginsburg and Uygur, 2017). For this reason, the role of automated truck operatives is expected to appeal more to younger jobseekers, addressing the issue of an ageing driver workforce (in the USA, a median age of 52 years in private companies has been identified) (American Transportation Research Institute, 2015).

## c. Implications for the trucking industry and logistics service providers

In 2016, the American Transportation Research Institute assessed the 'top US trucking industry issues' as those identified in the left-hand column of Table 6. The right-hand column summarises the benefits that were identified as potentially brought by autonomous technology.

**Table 6: List of top trucking industry issues and key autonomous truck benefits**

| Top issues | Benefits |
|---|---|
| **Hours of service** | Allows for driver rest and productivity to occur simultaneously |
| **Compliance, safety, accountability** | Will decrease raw safety management system scores, although percentile scoring needs to change |
| **Driver shortage** | Driving is more attractive with higher productivity, less time away from home, and additional logistics tasks; fewer drivers may be needed |
| **Driver retention** | Companies with autonomous technology may attract and retain drivers |
| **Truck parking** | If 'productive rest' is taken in the cab during operations, less time will be required away from home at truck parking facilities, and fewer facilities will be needed |
| **Electronic Logging Device Mandate** | Modifications will be necessary, depending on the level of autonomy |
| **Driver health and wellness** | Driver could be less sedentary; injuries could be reduced |
| **The economy** | Carriers that use autonomous trucks may see productivity and cost benefit |
| **Infrastructure/congestion/ funding** | Urban congestion could be mitigated through widespread use of autonomous vehicles (including cars |
| **Driver distraction** | Drivers will not be distracted if the vehicle is in autonomous mode |

**Source: American Transportation Research Institute (2016), Table 10**

Automation may affect a logistics service provider according to its size. In particular, several logistics operators and experts interviewed by Neuweiler and Riedel (2017) declared that small-or medium-sized transport companies need to find niche segments to stay in the market. Conversely, large companies can benefit from optimisation and lower operating costs, even though companies need to be able to afford the initial investment. For this reason, larger companies are likely to be the drivers of innovation, while the smaller ones will follow. However, even if future logistics are fully automated, there will still be a need for logistics services providers (such as fourth-party and fifth-party logistics) to provide customer assistance. Furthermore, most participants in the study conducted by Neuweiler and Riedel (2017) believe that automated systems will imply the need for new services, such as “maintenance services, platform services and platooning service providers, loading/unloading support, document management, breakdown services, hazardous freight handling, IT services and cloud services”. Most experts stated “value-adding services” as source of “competitive advantages”.

## d. Implications for the environment

According to Bakermans (2016), the implementation of truck platooning will imply a reduction in fuel consumption, with pollutant emissions reduction directly related to the volume of fuel used. For this reason, it can be argued that implementing truck platooning would have a positive environmental impact, although it would be subject to establishing what other changes in freight flows might occur, such as a possible reduction in highly energy-efficient rail freight.

As discussed, last-mile deliveries are the most complex environment to evaluate due to the complexity of the network, high number of stakeholders involved and human presence. Due to the characteristics of traffic in urban areas (e.g. stop–start, congestion) and the pollutant character of HGVs and LGVs, last-mile deliveries are majorly responsible for air pollution and noise. This results in a strong impact on public health due to the presence of humans in large numbers, who are exposed to various emissions. For this reason, urban deliveries are one of the major causes of unsustainability in terms of environment and human health. Noteworthy positive impacts could arise from the adoption of innovative solutions for last-mile deliveries, to reduce the flows of HGVs and LGVs and make good urban distribution more efficient. However, according to Kunze (2016), there is a need to define the methodology to assess urban ecological impacts in terms of air polluting emissions, noise and congestion. In general, review of the current studies suggests that electric AVs and platooning are more deliverable and important to ensure better air quality. Drones could be useful in urban areas, but as previously mentioned, there are major barriers related to safety, security and noise emissions.

A summary of implications is shown in Figure 17.

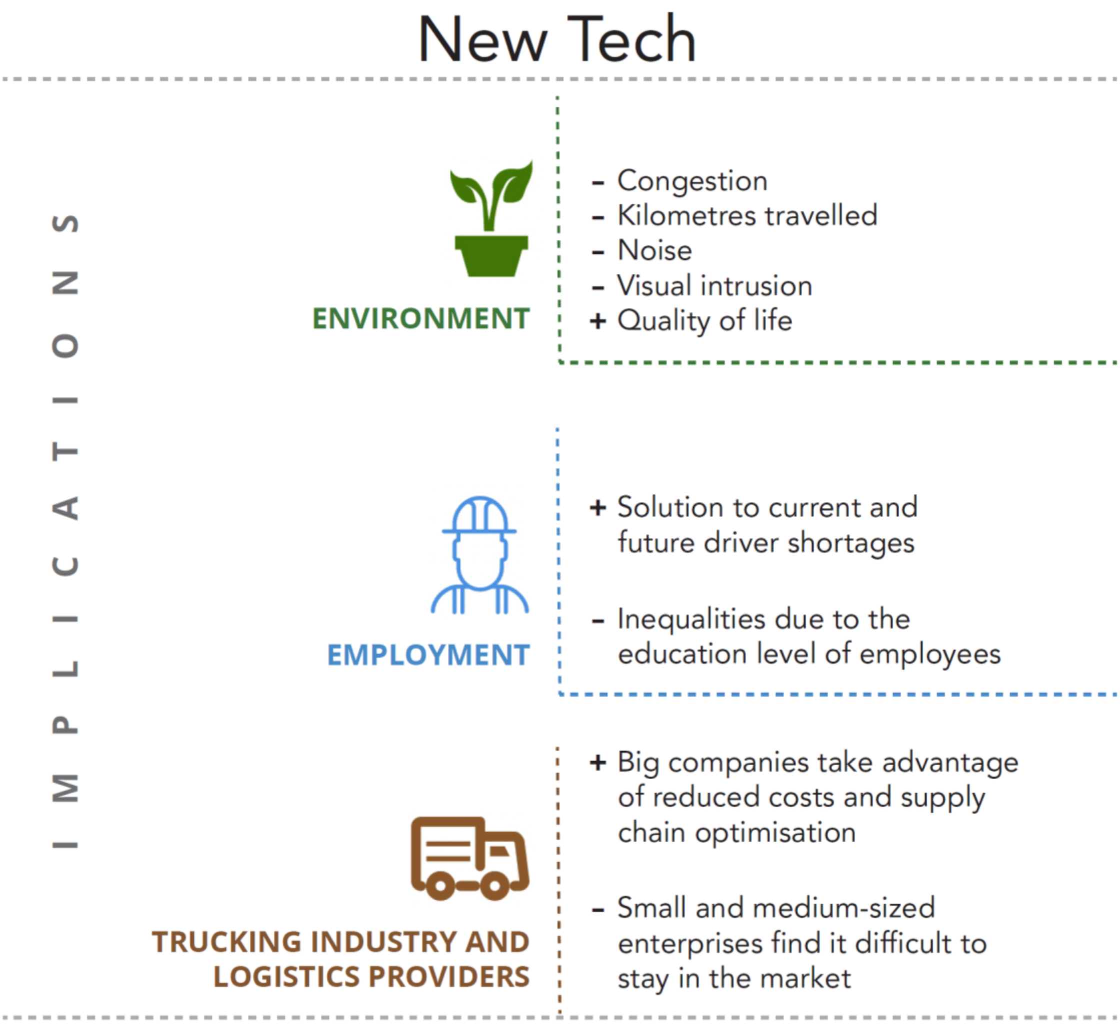


**Figure 17: Implications of automated systems and new technologies**

## e. What the ‘freight future’ might look like in the UK

This review has pointed out the advantages and disadvantages of automated freight systems, and the enablers of, and barriers to, their implementation. Despite significant breakthroughs in terms of technological development in recent years, fully applying and adopting automation in the freight transport of the future remains uncertain. Operational and strategic changes in the freight sector require new solutions that provide clear and sure benefits to the actors involved across the supply chain (e.g. companies, logistics operators, shippers, customers, etc.). Today, companies’ competitiveness is based mainly on the efficiency of their supply chains, which have potential to be improved with automated systems. However, supply-chain sectors (e.g. warehouses, ports, railways, road transport, etc.) are characterised by different degrees of automation development, which makes the task of imagining the shape of the future more difficult. For these reasons, the authors believe that there might be different ‘freight futures’ depending on the environment of application.

### Maritime transport

In the maritime case, both shipping and ports could be automated. For shipping, autonomous vessels could be remotely driven, coordinated, controlled and monitored to reduce the high costs associated with human resources and improve overall efficiency. For ports, high-level automation is likely to show more rapid adoption, because there are some automated handling systems which have been implemented already. Full automation might make UK ports more efficient and competitive, resulting in reduced operational times and negative externalities produced in the port environment (e.g. air polluting emissions, congestion due to queue of trucks accessing the gate, etc.). For example, automated control of information flows and physical flows of goods would allow for more efficient handling of movements in and out of terminals. Combined with standardised cargo handling systems, these innovations will enable terminals to optimise ship hosting.[33] Automated lorries would access the automated gates of the terminal, be automatically checked and automatically exit. The full automated process would make ports internationally competitive, not only due to time savings but also due to the high-quality service offered to customers (e.g. track-and- tracing) and overall cost reduction (e.g. safety improvement, reduction of number of errors, reduced labour costs). Such developments would allow the UK to be considered among the leading world players as a transhipment point between Europe and the USA, while also being a reference logistics point for the Asian market.

### Railways

New technologies and automation will support the railway system to become more competitive in respect to other means of transport. In fact, ICTs and automated transhipment systems will reduce intermodal[34] transfer times – one factor responsible for making rail freight less competitive today. As mentioned previously, it is worth noting mid-term future potential to utilise existing and planned high-speed lines as ‘rolling motorways’. However, based on a holistic approach and looking at the freight transport system as a whole, planning at the outset, capacity management and developing transhipment points to efficiently integrate rail with road are required.

### Autonomous vehicles

AVs and CAVs might require more time to be commonly used for freight transport on the long haul, due to lack of regulation and full technological development. In the long-term future, when the technology is ready, platooning and automated trucks will improve road safety, thanks to reduced rate of road collisions. They will also allow reductions in per-unit energy consumption and air pollution.

[33] Cargo Handling systems are mechanical equipment used for the movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal

[34] The time costs of changing mode of transportation (e.g. road to rail, road to shipping, etc.)

However, these results will be possible only if all modes of transport in the freight sector are integrated, by improving transhipment and modal shift[35]. For example, if road freight automation were to result in all goods being transported by road (due to the high value benefits coming from automated road systems), then the transport system might collapse due to greater demand for road space, which might cause the opposite overall effect to the one intended, particularly if automation in the passenger car sector, using the same infrastructure, has similar effects. A holistic approach is needed to integrate different automated means of transport into an inclusive freight transport system. To this end, a 'successful freight future' will require policymakers' support in terms of designing effective policies to push the development of automated systems, and coordination among different modes of transport.

### Automated systems

Fully automated systems for last-mile deliveries might replace more traditional delivery settings (e.g. trucks or vans), but it might not be until very far into the future that they become widely used. This is due to their complexity (e.g. different actors and products, integration with the urban transport system, etc.), which does not always make automated systems suitable to delivery needs, and level of technological development, which in the mid-term will not be sufficiently reliable. Small automated vehicles or pods might be adopted more easily, if specific policies (e.g. regulations, insurance, safety and security, etc.) are forthcoming. 3D printers also might require more time in terms of technological development, and even then may not prove to be commercially viable propositions: multi-material 3D printers might not perform as industrial printers in the mid to long term, and may require a long time to become a valuable alternative to the production processes such as moulding and stamping that they seek to replace.

### Drone technology

Drones could be used in a short- to medium-term period within a warehouse to replace almost all the humans who work there, making warehousing much more efficient than it is now (e.g. reduction in error, time and cost, with improvements in safety). However, they might not be easily used for last-mile deliveries due to their noise outputs and limited citizen approval. In the city of the near future, last-mile deliveries will remain a challenge because a unique solution to make them more efficient does not exist. However, the long-term future city might have an automated system integrated with a more traditional one that is able to support humans to make deliveries (with AVs), reduce the number of commercial vehicles (because customers might 3D print the products that they buy in their own homes or at common shared 3D printing locations), and make cities more sustainable, with improved quality of life.

[35] Modal shift means replacing a saturated means of transport with another to make the first less congested.

# 10. Recommendations

As suggested in the discussion of enablers of, and barriers to, innovation provided in Section 8, national government potentially has a role to play in contributing to creating an environment that stimulates innovation in the freight sector. At a high level, an integrated package of measures that we identify as being part of this future environment, and which would involve government as a facilitator alongside other stakeholders are as follows:

1. Continued investment in nationwide, high-speed, high-capacity data transmission networks (both fibre-optic and mobile).

2. Ensuring that legislative and regulatory frameworks are adapted to enable the use of AVs on the public highway network. This includes giving due consideration to standards for vehicles, roadside infrastructure and the regulation of AV operation on public highways. Work is already underway in this space. This includes the 2018 Automated and Electric Vehicles Act, the law commission project on automated vehicles (2018) and developmental work at UNECE.

3. Ensuring that future rail freight strategy considers the potential deployment of 'rolling motorways' on new sections of the rail network, along with complementary transhipment points, as is happening on the European continent.

4. Supporting and fostering the implementation of automated and innovative systems to reduce the number of commercial vehicles in urban areas, and improve the liveability of cities. This is a challenging point, due to the complexity of the urban environment (e.g. involved stakeholders, high presence of human beings, complex traffic), so it is highly recommended to undertake a consistent and integrated package of actions to:

   (a) investigate both general public and expert stakeholder perceptions and acceptance.

   (b) understand how to integrate new technologies efficiently in the current system during the transition period;

   (c) design a specific regulatory framework to promote a safe, environmentally-friendly and efficient urban context.

   (d) develop a strategic plan to support the private sector to adopt and develop new systems of freight handling and movement. This includes provision of financial support for research and development programmes, with evaluated trials (to generate compelling evidence of efficacy), and training programmes to increase workforce capacity regarding the adoption of new operating practices.

The centre for connected and autonomous vehicles are already undertaking some work and thinking in this space, around some of the recommendations in 4.

In addition, beyond these more coordination and planning roles, we note that government may wish to give consideration to more strategic and fundamental regulatory legislation, with a view to automation being adopted in the safest, most ethically aware and socially just way. The process also might address the debate as to whether a new national authority on robot and artificial intelligence ethics might be necessary. A possible remit of such a body might be to ensure human safety in proximity to autonomous technologies, to reflect on liability issues in cases where autonomous technologies fail, and to advise on equitable strategies to deal with circumstances in which human labour is replaced by automated technology.

Alongside an ongoing national context which fosters innovation, there is also a need for further primary research into the issues identified in this report, with a focus on the UK context.[36] First, it would be beneficial in particular to undertake an in-depth analysis of the UK supply chain (considering different sectors, e.g. automotive, food, coal) to identify prospects for the applicability of different automated freight systems. This could be carried out at regional and national levels, giving consideration to the major freight corridors. Second, it is necessary to develop enhanced models of, and performance measurement tools for, freight transport systems. The data generated by such tools could feed into decision support systems designed to appraise the most effective policy packages, through evidence-based, cost–benefit assessments, to stimulate automation in freight transport.

[36] This study has been limited to a desk review of existing evidence, and it is acknowledged that a large number of studies and trials have been carried out in the USA. This has a different operating environment to the UK, characterised by a specific landscape, remote communities and major open-cast mining technologies.

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