vivideconomics

The value of freight

Report prepared for the National Infrastructure Commission

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FUTURE OF FREIGHT

Evidence Base

This report by Vivid Economics was commissioned as part of the evidence base for the National Infrastructure Commission's study on the future of freight.

As with all supporting evidence commissioned by the National Infrastructure Commission, the views expressed and recommendations set out in this report are the authors' own and do not necessarily reflect the position of the Commission.

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Executive Summary

The UK freight system plays a vital role in supporting economic activity. The freight system helps meet the UK's most essential needs: it supplies food to supermarkets and fuel to petrol stations, carries medical products to hospitals, and delivers letters and parcels to homes and businesses. The freight system also plays a vital role in supporting economic activity: it transports raw materials and intermediate products to factories, goods to ports and products to retailers, supporting manufacturing, exports and consumers.

However, a set of important challenges remain. Freight both contributes to and is exposed to road congestion; it is responsible for 6% of total CO2 emissions; and is a labour intensive industry, with costs rising as wages increase in line with economic growth.

This study investigates and assesses the efficiency of the UK freight system, identifies the technologies most likely to drive a 'step change' in the efficiency of freight, and considers the economic and other benefits that improved efficiency could deliver.

This study finds that the freight system must continue to evolve. The freight system must improve outcomes in all key areas of efficiency: it must remain cost-competitive; minimise its impact on congestion; reduce its greenhouse gas emissions in line with the UK's climate targets; and remain resilient to future stresses. A summary of study findings on each of these issues is set out below.

Cost

The cost of UK freight system is equivalent to around 4% of GDP. While diesel and wage costs have driven freight costs up, they have fallen as a share of GDP. We estimate that the UK spends up to £80 billion per year on road freight, rail freight and warehousing. Of this, road freight accounts for around £38 billion; rail freight for around £1 billion; and warehousing for £20-38 billion. Labour costs make up around one third of road freight and warehousing costs. As labour costs rise with incomes, road freight costs have risen over time. However, exposure to freight costs is declining and freight costs as a share of GDP have fallen over time.

New technologies - particularly, connected and autonomous vehicles, and robotics and automation - could significantly reduce freight costs. In the near-term, there may be some opportunities to reduce costs through incremental improvements in freight efficiency (for example, by reducing empty running and part-loading). The cost of freight can also be reduced by reducing congestion. In the longer-term, new technologies could deliver more significant cost reductions. Connected and autonomous vehicles could decrease the cost of road freight by around one third; robotics and automation could decrease the cost of warehousing by a similar amount. Together these technologies could reduce the cost of the UK freight system by £26 billion, equivalent to around 1.3% of GDP. Digitalisation and data science could offer further cost savings, though the magnitude of potential savings is very difficult to quantify.

A cheaper freight system will provide direct economic benefits. A reduction in the cost of freight, whether this is achieved through improving efficiency, reducing congestion or through automation, will free up resources (such as labour) for more productive uses and increase economic output. The reduced cost of freight will be reflected in lower production costs, benefiting both producers and consumers.

Speed and reliability

UK road freight suffers severe and worsening congestion problems, and addressing congestion is a high priority. Congestion could account for over 16% of the cost of road freight, equivalent to around £6 billion per year. Road congestion in the UK is among the highest across European countries, and is worsening. Congestion imposes economic costs; while estimates of the cost of congestion typically only account for lost time, congestion also increases expenditure on vehicles and fuel. The impact of congestion on of delays to freight journeys is currently poorly understood. Based on the available evidence, we estimate a range for the impact of congestion on delays. At the higher end of the range, we estimate that congestion could delay HGV journeys by around 23% today, potentially rising to 35% by 2050. Overall, we estimate that the total cost of congestion to the UK freight system today could be more than £6 billion, or 0.3% of GDP.

A number of factors contribute to congestion and its impact on the freight system. First, the UK's road and rail network capacity is strained by high levels of transport demand. Second, utilisation of the road network, particularly by passenger transport, is highly inefficient. Third, freight is typically consolidated in regional distribution centres located outside the urban areas that they serve, which increases the number of vehicle movements to retailers and other customers to, from and within urban areas. Fourth, van use is growing significantly; while the role of vans in freight transport is uncertain, growth in the use of vans to deliver freight would increase the volume of freight traffic.

The causes of congestion are complex, and a number of solutions could contribute to reducing congestion levels in future. Some infrastructure investment may be needed to mitigate congestion, though overall demand management is likely to provide a more cost-effective solution than a large-scale infrastructure investment programme. Road pricing could be an effective policy instrument to manage congestion. Location of freight distribution centres inside urban areas would reduce freight's contribution, and exposure, to congestion. Finally, further work is needed to understand the role of policy in driving efficient use of vans within the freight system.

Environmental impact

Freight transport is responsible for 6% of total greenhouse gas emissions today but if unabated, could make up around 20% of allowed emissions in 2050. Near- or full-decarbonization of freight transport is

likely to be needed to meet the UK's climate targets. We estimate that freight transport as a whole emitted around 27 MtCO2 in 2016. If CO2 emissions from freight transport are not addressed, they could increase a further 20% to 2050 given increasing demand for travel. The Climate Change Act requires that greenhouse gas emissions in 2050 to decrease from 468 MtCO2e in 2016 to 160 MtCO2e in 2050. If freight transport emissions continue unabated, they would make up around 20% of this total. However, due to the challenges of reducing emissions in other sectors it is unlikely that unabated freight emissions can be accommodated over the long term.

The fundamental cause of freight transport emissions is the use of diesel fuel. However, a range of secondary factors contribute to the level of freight emissions. The highly centralised nature of the freight system increases travel distances as freight is diverted to consolidation centres between origins and destinations. The majority of freight is carried by road, which is less energy-efficient than rail. There are limitations to the size of freight vehicles, which could increase the number of vehicles and trips needed to meet freight demand. And moderate levels of empty running and part-loading might indicate a degree of inefficiency in freight operations.

A shift to alternative fuelled vehicles is urgently needed to decarbonise freight. Given such a shift, wider reforms to the freight system are less urgent. A complete shift to alternative fuelled vehicles would eliminate tailpipe greenhouse gas and air quality pollutant emissions in road freight. Prospects for deployment of alternative fuelled freight vehicles are strong: while these currently lag behind passenger vehicles, development of the technology is underway, and large cost reductions are expected in the near term. In contrast, the scope to decarbonise freight through alternative solutions such as moving to a more decentralised freight system, shifting significant freight volumes to rail, increasing the size of freight vehicles and reducing empty running and part-loading, highly uncertain and likely to be very limited. A shift to alternative fuelled vehicles is therefore an urgent policy priority.

Resilience

The risks faced by the UK freight system are changing as a result of climate change and digitalisation. A comprehensive review of freight resilience is needed to secure the freight system against future risks. A shift to alternative-fuelled vehicles will reduce the risks of fuel supply shocks, and a shift to connected and autonomous vehicles could reduce the vulnerability of the freight system to labour action. However, other risks are emerging. First, risks of infrastructure failure and extreme weather events could increase with climate change, and risks associated with information failures could increase as digitalisation increases reliance on complex information networks and exposure to failures in IT systems or cyber-attacks. Second, improvements in freight efficiency are likely to have reduced the resilience of the freight system. Firms increasingly hold fewer inventories in order to minimise the cost of warehouse space in urban areas. As a result, firms are increasingly exposed to disruptions in the reliability of the freight system. Given the new risks facing the freight system, and the need to make the right trade-off between efficiency and resilience, a comprehensive review of freight system resilience is needed to ensure that the freight system remains efficient while securing it against future risks.

1 Introduction

1.1 Background

The freight system plays a vital role in supporting economic activity. Freight transports raw materials and intermediate products to factories, to support manufacturing; it transports finished products to retailers, to meet consumer demand; and it transports goods to ports, to support exports. By enabling goods to be moved long distances at low cost, freight allows products to be manufactured at large scale in the most suitable locations in the UK and overseas.

The freight system is extensive, sophisticated and efficient. The freight system has evolved considerably, and continues to do so. In the early 19th century the development of Britain's canal network enabled the industrial revolution. Later that century development of the rail network substantially expanded coverage and speed of the freight. In the 20th century development of the road network, including the motorway network, again offered a a step change in coverage and speed. By 2017 the freight system transported 1,397 million tonnes of freight, supporting almost £400 billion in manufacturing sales and transporting 140 million tonnes of goods to ports for export. Faced with significant commercial pressures the freight system has innovated, responding to increasingly challenging customer requirements for smaller, faster deliveries and developing centralised distribution systems to reduce the costs of warehousing on increasingly expensive urban land.

However, a set of important challenges remain. The majority of UK freight is carried by road; as a result, freight both contributes to and is exposed to road congestion, and is responsible for 6% of total CO2 emissions. In 2006 the Department for Transport estimated that the cost of congestion to the UK business sector could amount to £12 billion by 2025, and the wider social costs could amount to double this amount. Further diesel is the dominant fuel in road freight, and unlike passenger vehicles, there has been no significant improvement in fuel efficiency over time. The Climate Change Act target for an 80% reduction in greenhouse gas emissions relative to 1990 levels is likely to require substantial decarbonisation of the freight sector. Further, freight is a labour intensive industry, and costs are increasing as wages rise in line with economic growth.

New technologies could offer solutions to these challenges, though are at an early stage. Alternative fuelled vehicles are beginning to emerge in passenger transport, and are under development in freight transport. Connected and Autonomous Vehicles (CAV) are under development, and could allow vehicles to function without a driver; key elements of this technology (satellite navigation, mobile communications and information processing technologies) are already in widespread use in freight transport. Robotics and automation are a common feature of industrial production, and could begin to play an important role in logistics and warehousing. Digitalisation has opened up new opportunities in route optimisation, inventory management and collaboration, and these opportunities will increase as digitalisation continues. And new delivery technologies such as unmanned aerial vehicles (drones) and delivery droids are delivering goods directly to consumers in a number of trials. And 3D printing could transform the pattern and content of freight flows.

Further evolution of the freight system will be needed to continue to deliver major economic benefits. To deliver the greatest value, the freight system must remain cost-competitive while minimising its impact on congestion and reducing its greenhouse gas emissions in line with the UK's climate targets. Adoption of new technologies, in combination with effective regulation, are likely to be needed to achieve this outcome.

1.2 Objectives

In this context, the National Infrastructure Commission has commissioned Vivid Economics to identify and evaluate the opportunities to improve the UK freight system. Specifically, the National Infrastructure Commission are seeking to understand:

- The efficiency of the UK freight system, how this compares with other countries, and how it could be improved in future;
- The potential for new technologies to deliver a 'step change' in the efficiency of the freight system;
- The mechanisms by which improved freight efficiency can deliver economic value, and the potential economic value of the improvement in freight efficiency which new technologies could deliver.

1.3 Approach

We adopt a multidimensional definition of freight efficiency. The freight system must balance multiple, sometimes competing, objectives. It must deliver products to customers when needed, and do so at low cost to maintain the competitiveness of UK businesses and affordability for consumers. It must reduce its environmental impact, and in particular, contribute to meeting the UK's climate targets. And it must continue to fulfil its function in response to stresses. We therefore define freight efficiency as in terms of cost, speed and reliability, environmental impact, and resilience of the freight system.

We first assess the efficiency of the UK freight system in terms of its performance on dimension. For cost, speed and, reliability, as well as environmental impact, we develop quantitative estimates of UK performance. For resilience, our analysis is more qualitative. Where data is available, we also compare performance in the UK and other European countries using the Eurostat database, which provides the most detailed comparative dataset of economic and technical characteristics across the freight system.

We then identify and assess the underlying factors driving freight efficiency. These factors include the spatial organisation of the freight system, its modal share, the quantity and quality of its physical infrastructure, the efficiency with which the road and rail networks are used, the vehicle technologies and fuels it uses, the capacity of its vehicle stock, and its operational efficiency. As with the dimensions of overall efficiency, we develop quantitative estimates of these factors in the UK, and compare performance in the UK with other European countries where possible. Where quantitative data is not available, we provide a qualitative assessment.

We then assess a range of technologies likely to emerge in the freight system in future. We identify a range of technologies likely to emerge in the freight system in future, and assess the potential for each technology to deliver 'step-change' improvements to freight efficiency. Technologies assessed comprise alternative fuelled vehicles, connected and autonomous vehicles, robotics and automation, digitalisation and data science, unmanned aerial vehicles (drones), delivery droids and 3D printing. We separately consider the potential for each technology to deliver a significant improvement in the cost, speed and reliability, environmental impact, and resilience of the freight system. We then assess the likely severity of any barriers to deploying that technology and the prospects for that technology to emerge at scale.

Finally, we identify the potential for improved freight efficiency to deliver economic benefits to the UK. Through a literature review and drawing on economic theory, we identify the mechanisms through which an improvement in the cost, speed and reliability, environmental impact and resilience of the freight system could deliver economic benefits to the UK. Based on our assessment of the potential for future technologies to deliver 'step-change' improvements to freight efficiency we then evaluate and provide broad estimate of the likelihood and potential magnitude of the economic benefits that would arise from a more efficient freight system in the UK.

1.4 Structure of this report

This report sets out the findings of this analysis:

1. **Section 2: Efficiency of the UK freight system** assesses the efficiency of the UK freight system, in terms of its cost, speed and reliability, environmental impact and resilience.
2. **Section 3: Drivers of efficiency** identifies the drivers of freight efficiency, assesses the performance of the UK freight system with respect to these drivers, and identifies the opportunities for policy to improve the cost, speed and reliability, environmental impact and resilience of the freight system.
3. **Section 4: Potential step-change technologies** identifies the emerging technologies that have the potential to deliver step-change improvements to the cost, speed and reliability, environmental impact and resilience of the freight system.
4. **Section 5: Value of freight efficiency** identifies the economic benefits which improved performance of the UK freight system with respect to the drivers of freight efficiency could deliver, and assesses the magnitude of the benefits that could be realised, given appropriate regulation and innovation in the emerging technologies.

2 Efficiency of the UK freight system

Key messages

- **The cost of UK freight system is equivalent to around 4% of GDP. While freight costs have risen, driven by higher diesel and wage costs, they have fallen as a share of GDP.**
- **UK road freight suffers severe and worsening congestion problems, and addressing congestion is a high priority. Congestion could account for over 16% of the cost of road freight, equivalent to around £6 billion per year.**
- **Freight transport is responsible for 6% of total greenhouse gas emissions today but if unabated, could make up around 20% of allowed emissions in 2050. Therefore, near- or full-decarbonization of freight transport is likely to be needed to meet the UK's climate targets.**
- **The risks faced by the UK freight system are changing as a result of climate change and digitalisation. A comprehensive review of freight resilience is needed to secure the freight system against future risks.**

2.1 Cost of the UK freight system

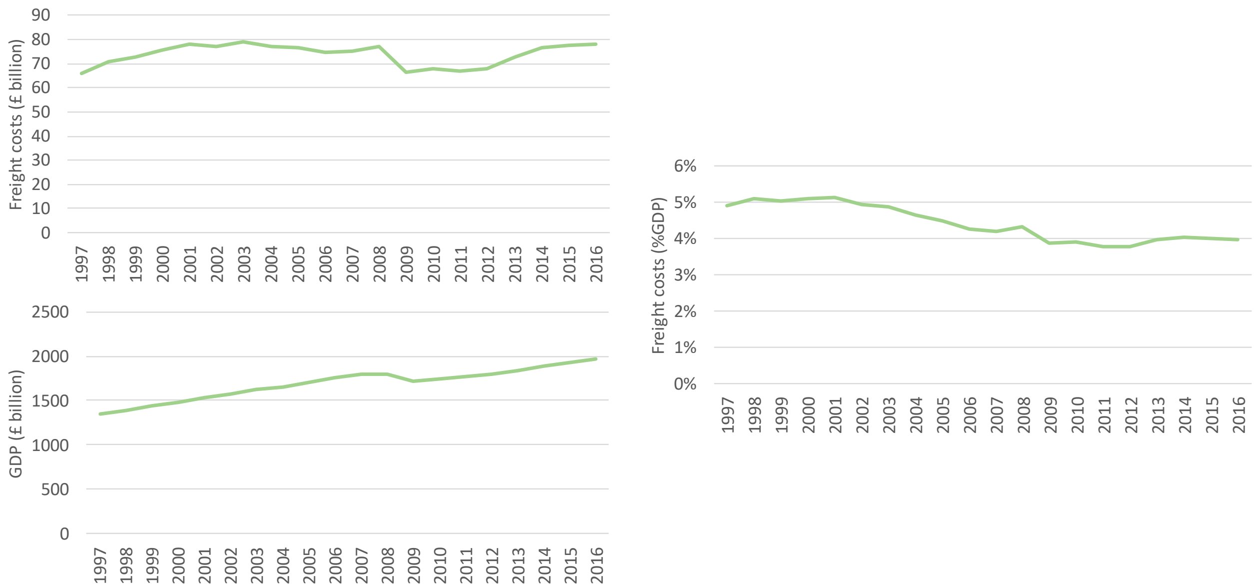
The total cost of the UK freight system is equivalent to around 4% of GDP. In 2016:

- Total expenditure on warehousing amounted to £38 billion, equivalent to 2% of GDP
- Total expenditure on freight transport amounted to around £40 billion, equivalent to 2% of GDP. Within this, road freight costs made up at least 95% of freight transport costs, totalling around £38 billion and equivalent to 2% of GDP; while rail freight costs made up less than 5% of freight transport costs, totalling around £2 billion and equivalent to 0.1% of GDP.

Our approach to estimating the cost of the UK freight system is set out in Annex 1.

The cost of the whole UK freight system as a share of GDP has decreased over time. Figure 1 shows the historical data on the cost of the freight system; UK GDP; and the cost of the UK freight system as a share of GDP. Costs are in real terms, i.e. adjusted for inflation. Overall, the cost of the freight system has increased from around £65 billion in 1997 to around £80 billion in 2016, a 20% increase over this period. At the same time, GDP has increased by around 50%. As a result, the cost of the freight system as a share of GDP has decreased slightly, from around 5% of GDP in 1997 to around 4% of GDP in 2016.

Figure 1. **GDP has risen faster than the cost of freight over the last two decades**

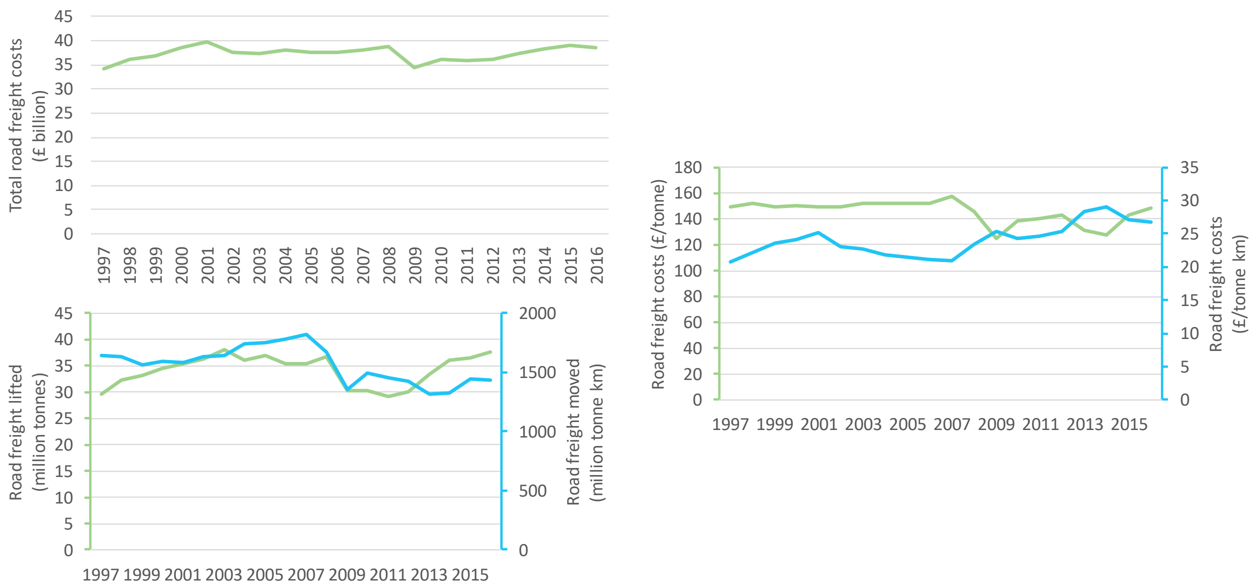


Note: *Values expressed in real (2017) prices*

Source: *Vivid Economics; Office for National Statistics*

Road freight costs have risen over time, but the volume of freight has fallen. Figure 2 shows the historical data on total costs of road freight, road freight activity and the resulting cost per unit of road freight. The cost of road freight system has increased from around £34 billion in 1997 to around £38 billion in 2016, a 12% increase over this period. Over the same period, the total volume of freight *lifted* has decreased 13% from around 1.6 billion tonnes in 1997 to around 1.4 billion tonnes in 2016. However, freight is now shipped for increasingly longer distances, such that the total volume of freight *moved* has remained broadly constant over this period, at around 150 billion tonnes km. As a result, the total cost of each tonne of road freight has risen 29% over this period. This increase is the result of two factors. First, the cost of moving road freight has increased around 13%. Second, the average distance freight is moved has increased around 14%.

Figure 2. **Road freight costs have risen over time**

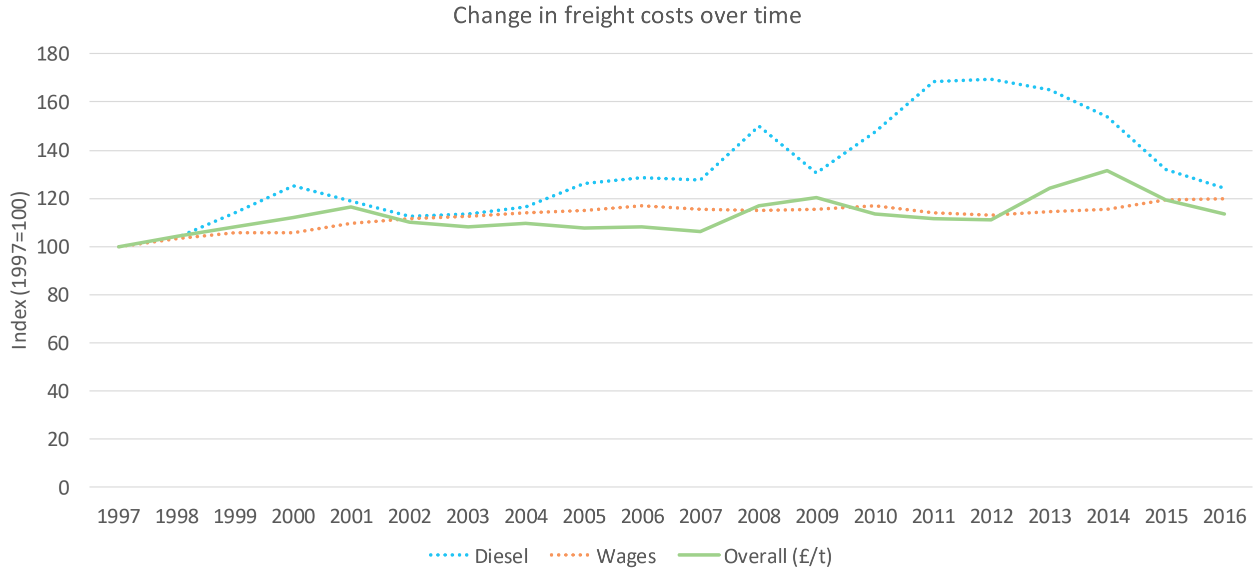


Note: *Values expressed in real (2017) prices*

Source: *Vivid Economics; Office for National Statistics; Department for Transport*

The rising cost of moving a tonne of freight have been driven by rising fuel and wage costs. Figure 3 shows the change in the cost of road freight, and the cost of fuel and wages over time. Over the period 1997-2016, Diesel costs rose 24%, and wages of HGV drivers rose 20%. The particularly pronounced rise in desel costs over the period 2009-12 does not appear to have driven freight costs up over that period; it is possible that the industry absorbed these costs to remain competitive during the economic downturn over that period. Data on vehicle costs is not available, though unlike diesel or wages there is no empirical evidence or theoretical rationale suggesting that vehicle costs have increased over this time frame. Given freight costs have increased by less than diesel and wage costs, it is also possible that that vehicle costs have decreased as a result of innovation in manufacturing (for example, car costs decreased around 30% between 1997 and 2013).

Figure 3. **Rising fuel and wage costs explain the increase in freight costs**



Note: *Values expressed in real (2017) prices*

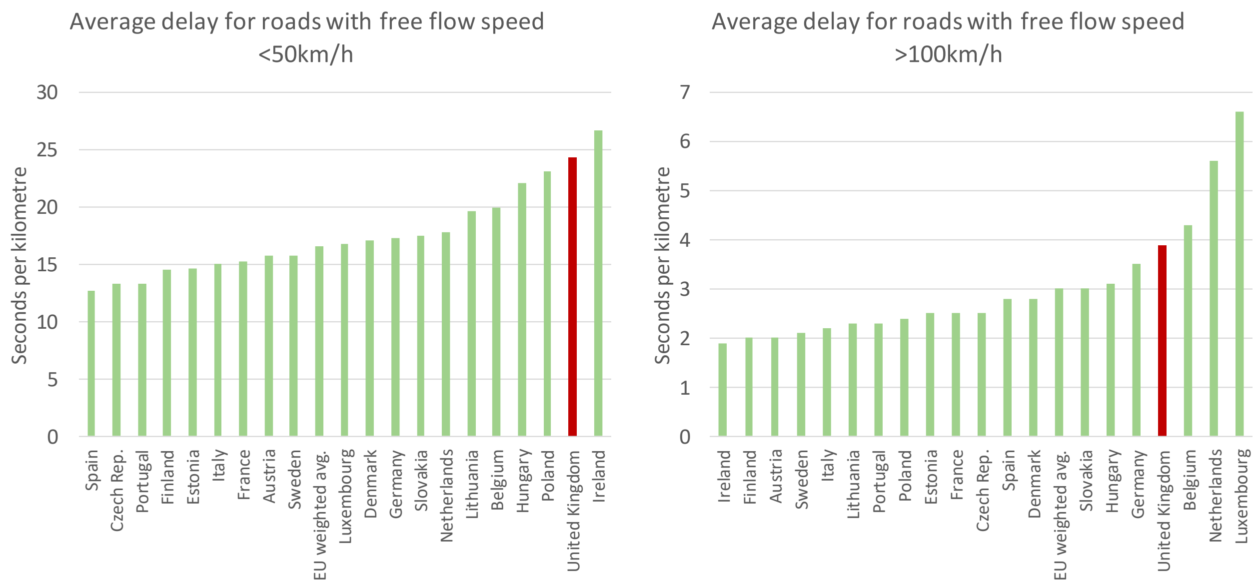
Source: *Vivid Economics; Office for National Statistics; Department for Transport; Department for Business, Energy & Industrial Strategy*

2.2 Speed and reliability of the UK freight system

2.2.1 Road freight

Road congestion in the UK is among the highest across European countries. Figure 4 shows the average delay on the road network on different types of road. The UK performs poorly across all types of road. On roads with average speeds of less than 50 km per hour in free-flow conditions, the UK has the second longest delays; and on roads with average free-flow speeds of more than 100 km per hour, the UK has the fourth longest delays.

Figure 4. **Road congestion in the UK is among the highest across European countries**

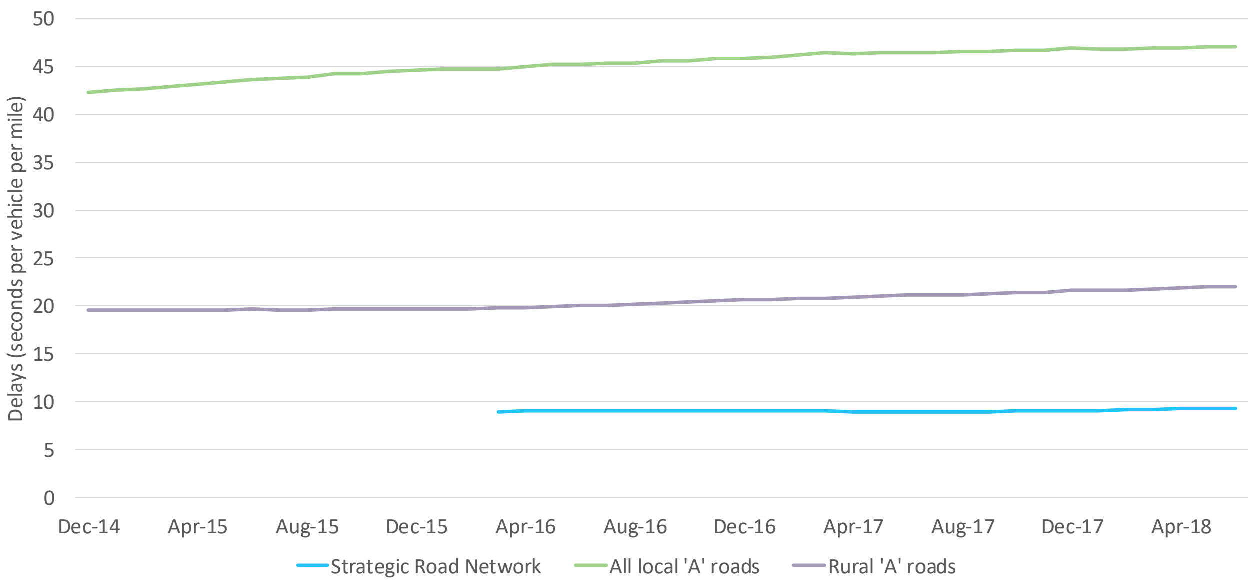


Source: European Commission Joint Research Centre

Delays due to congestion on the strategic road network and major rural roads are generally smaller than on urban roads. The average delay in England is around 15 seconds per vehicle per mile on the strategic road network, and 35 seconds per vehicle per mile on rural A roads; this compares to an average delay of 128 seconds per vehicle per mile on urban A roads (Department for Transport, 2018).

Congestion is worsening across all types of road. Figure 5 shows that between 2014 and 2018, the average delay has increased by around 4% on the strategic road network, 11% on rural A roads and 13% on urban A roads. The variation in the increase in delay can be explained by the difference in average speeds on each type of road, with the highest average speeds on the strategic road network, followed by rural and urban A roads, respectively.

Figure 5. **Congestion is worsening across the road network**



Source: *Department for Transport*

The economic costs of congestion are considered to be large. In 2006 the Department for Transport estimated the cost of congestion to business alone was around £7 billion in 2003, and could rise to £18 billion to 2025. Further, DfT estimated that the cost to all road users (including commuters and those travelling for non-work purposes) could reach £24 billion by 2025.

Previous estimates of the cost of congestion only account for lost time. For example, the Department for Transport in 2007 estimated that the cost of congestion to freight transport alone under £0.5 billion in 2003, with the hours lost due to delays valued at the wage rate of freight vehicle drivers.

However, congestion also increases expenditure on vehicles and fuel. By increasing the time taken on freight journeys, delays reduce the number of trips a vehicle and driver can make, and the volume of freight they are able to move. As a result, more vehicles and drivers are needed to meet freight transport demand. Delays also increase the amount of fuel needed on a journey, as there is a fuel efficiency penalty associated with lower than optimal speeds, frequent acceleration and deceleration and engine idling. However, this penalty has been estimated at around 5% (Palmer and Piecyk, 2010), and is therefore significantly smaller than the impact on congestion on journey times and associated expenditure on vehicles and drivers.

A small increase in delays could drive a large increase in freight costs. In principle, to meet overall freight transport demand, an increase in average journey times due to congestion would require a comparable increase in the number of vehicles and drivers. In practice, freight operators might respond to small increases in journey times by improving the efficiency of their operations; however, once opportunities to improve efficiency have been exhausted freight operators would need to invest in vehicles and drivers. However, freight operators are required to meet freight transport demand with a high degree of reliability.

Therefore the required increase in the number of vehicles and drivers could actually be significantly greater than the increase in average journey times. This is because the increase in journey times due to congestion is highly variable. On some journeys, delays will be shorter than average, while on others, delays will be longer than average. Freight operators must ensure that they deliver goods to customers on time even when delays are significantly longer than average. As it is not possible to predict when this will occur, freight operators must schedule start and end times for all journeys to account for the possibility of longer than average delays. The resulting increase in scheduled journey times further reduces the number of trips vehicles and drivers can make, and the volume of freight they are able to move; and increases the number of vehicles and drivers needed.

The magnitude of delays to freight journeys is currently poorly understood. The impact of congestion on HGV journey times can be estimated using data on average speeds and average delays on different types of road. The Department for Transport publishes two estimates of speeds and delays. As these do not appear consistent with each other, we estimate the impact of congestion on HGV journey times using each estimate, and present the overall impact as a range. The estimates comprise:

- **DfT Road Traffic Forecasts.** The Department for Transport's produces regular forecasts for traffic demand, congestion and emissions to 2050 in England and Wales. Road Traffic Forecasts are produced using the Department for Transport's National Transport Model (NTM). Forecasts for traffic demand are based on observed levels of traffic demand in 2015, and expectations of how the demand for travel will grow between 2015 and 2050.
- **DfT Road Congestion Statistics.** The Department for Transport separately publishes statistics on road congestion and journey time reliability. These statistics are compiled from journey time data from in-vehicle global positioning systems (GPS) and flows estimated using both automatic traffic counters and DfT's manual traffic count data.

While both sources imply similar congestion levels on the motorway network, congestion levels on A roads estimated in Road Traffic Forecasts are significantly lower than those reported in Road Congestion Statistics. Road Traffic Forecasts estimates an average speed on A roads for all vehicle types of around 37 miles per hour, and an average delay of around 18 seconds per mile in 2015; this implies congestion delays journey times by an average of 23%. In contrast, Road Congestion Statistics reports an average speed on A roads for all vehicle types of around 26 miles per hour, and an average delay of around 45 seconds per mile in 2015; this implies congestion delays journey times by an average of 48% - more than double the increase in journey times.

At the lower end of the range, we estimate that congestion could delay HGV journeys by around 12% today, potentially rising to 18% by 2050. We draw our low estimate of the impacts of congestion directly from Road Traffic Forecasts. Road Traffic Forecasts estimates of average speeds and delays for HGVs imply that congestion delayed journey times by 2% on motorways, 14% on Trunk A roads; 23% on Principal A roads; and 15% on minor roads in 2015; based on levels of HGV travel on each type of road, these estimates imply that overall congestion delayed HGV journey times by 12% in that year. This is considerably lower than the impact of congestion on all traffic reported above, as HGV traffic is less concentrated around peak times (see Section 3.4). Road Traffic Forecasts also projects average speeds and delays for HGVs over the period to 2050, based on the projected increase in traffic growth. While projections suggest only a slight increase in HGV traffic (a 1% increase to 2030 and 9% increase to 2050), they suggest a very significant increase in car and van traffic (by 17% to 2030 and 34% to 2050 for cars; and 22% to 2030 and 52% to 2050 for vans). DfT projections of average HGV speeds and delays associated with these greater traffic levels imply that the increase in journey times due to congestion could reach 14% by 2030, and 18% by 2050.

At the higher end of the range, we estimate that congestion could delay HGV journeys by around 23% today, potentially rising to 35% by 2050. To develop our high estimate of the impacts of congestion, we adjust our low estimate to account for the difference between congestion levels estimated in Road Traffic Forecasts and those reported in Road Congestion Statistics. This results in a doubling of the increase in journey times on Trunk and Principal A roads and minor roads (there is no change in the increase in journey times on motorways, as both sources imply similar congestion levels). The adjusted estimate suggests that congestion could have delayed journey times by 2% on motorways, 25% on Trunk A roads; 45% on Principal A roads; and 27% on minor roads in 2015; with an overall increase in journey times of 23%. Applying the same adjustments to the increases in journey times implied by DfT projections of average HGV speeds and delays in future years imply that the increase in journey times due to congestion could reach 27% by 2030, and 35% by 2050[1].

Overall, we estimate that the total cost of congestion to the UK freight system today could be more than £6 billion, or 0.3% of GDP. Based on two separate estimates of speeds and delays published by the Department for Transport, we estimate that congestion could delay HGV journeys by 12-23% today. As a result of this increase in delays, a comparable increase in the number of vehicles and drivers is needed to meet freight transport demand. However, the impact of delays on fuel consumption is small, and a 12-23% delay would not result in a comparable increase in fuel consumption. As the cost of drivers, vehicles and fuel each make up around one third of the costs of road freight, congestion increases the cost of the road freight system by at least 2/3 of the increase in journey times. Based on the 12-23% increase in HGV journey times due to congestion, and a comparable increase in the number of drivers and vehicles needed to meet freight demand, we estimate that congestion could increase the cost of road freight by 8-16%. Given the £38 billion cost of road freight estimated in Section 2.1. this implies that the total cost of congestion to the UK freight system could be £3-6 billion, or up to 0.3% of GDP.

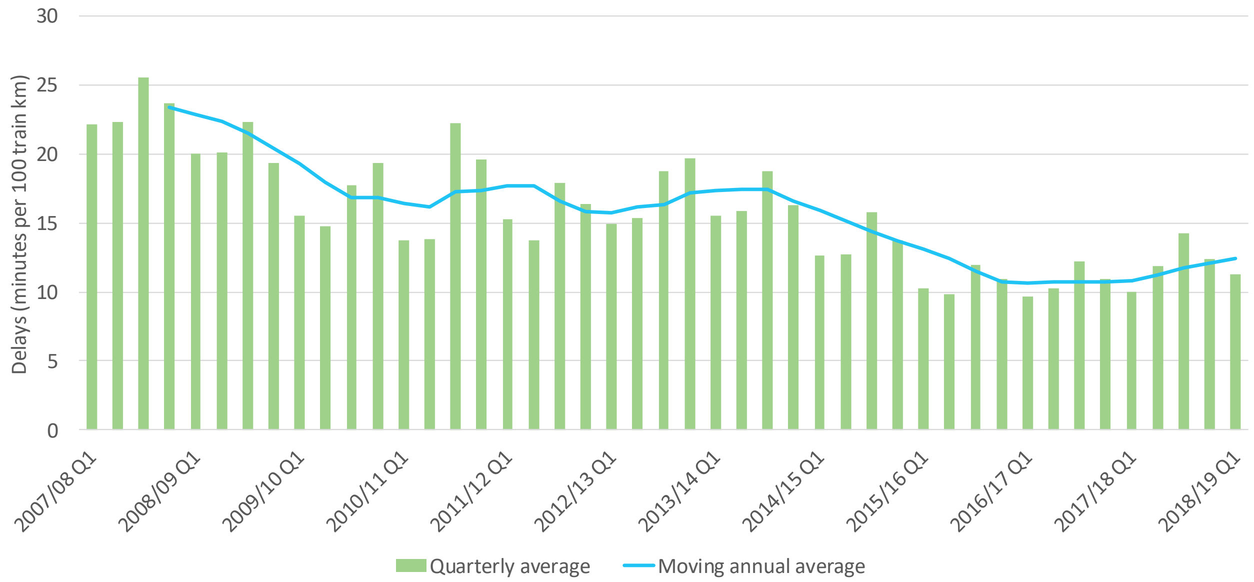
2.2.2 Rail

Rail freight has comparable reliability to the strategic road network. Average delays of UK freight trains were around 12 minutes per 100 train-kilometres, or around 7.5 seconds per km in 2018. This is comparable to the average delay of around 6 seconds per km on the strategic road network (while delays on smaller and urban roads are longer, this is a poor comparison as the rail network is not a substitute for the use of smaller and urban roads). As a result of these relatively small delays, 94% of trains arrive within 15 minutes of the scheduled time (Office of Rail and Road, 2018).

[1] This upwards adjustment does not take into account that congestion may not reach such levels, if increasing congestion costs decrease the demand for freight.

Unlike road freight, the reliability of rail freight is improving. There has been a significant improvement in the reliability of freight trains over the last decade; annual average freight trains delays have fallen from 23.4 minutes per 100 train km in 2007/08 to 12.4 minutes/100 train-kilometres in 2018/19.

Figure 6. **Delays in rail freight have fallen by half over the last decade**



Source: Office of Rail and Road

The reasons for the improved reliability of rail freight are not fully understood. It is difficult to identify the reasons for the improved reliability of rail freight based on available evidence:

- There has been no measurable reduction in reduced disruption from engineering and maintenance works; this has remained roughly constant over the period 2005/06 to 2018/19, as measured by the Possession Disruption Index for freight.
- There has been no overall improvement of rail transport services; this has worsened in recent years, with the percentage of passenger trains which were cancelled or 'significantly' (over 30 minutes) late increasing from 2.5% in 2006/07 to 4.6% in 2018/19.
- It is possible that the improved reliability of rail freight is due to improved operational efficiency, or perhaps greater automation, though there is not sufficient evidence to substantiate this hypothesis.

The speed and reliability of rail freight is constrained by the prioritisation of passenger trains. Passenger trains are prioritised on the rail network; when delays result in scheduling clashes between passenger and freight trains, freight trains are typically held in passing loops to reduce the extent of delay to the passenger trains. While prioritisation of passenger trains does result in greater delays to freight trains, this is likely to be an efficient outcome given the high value of passenger travel time.

2.3 Environmental impact of the UK freight system

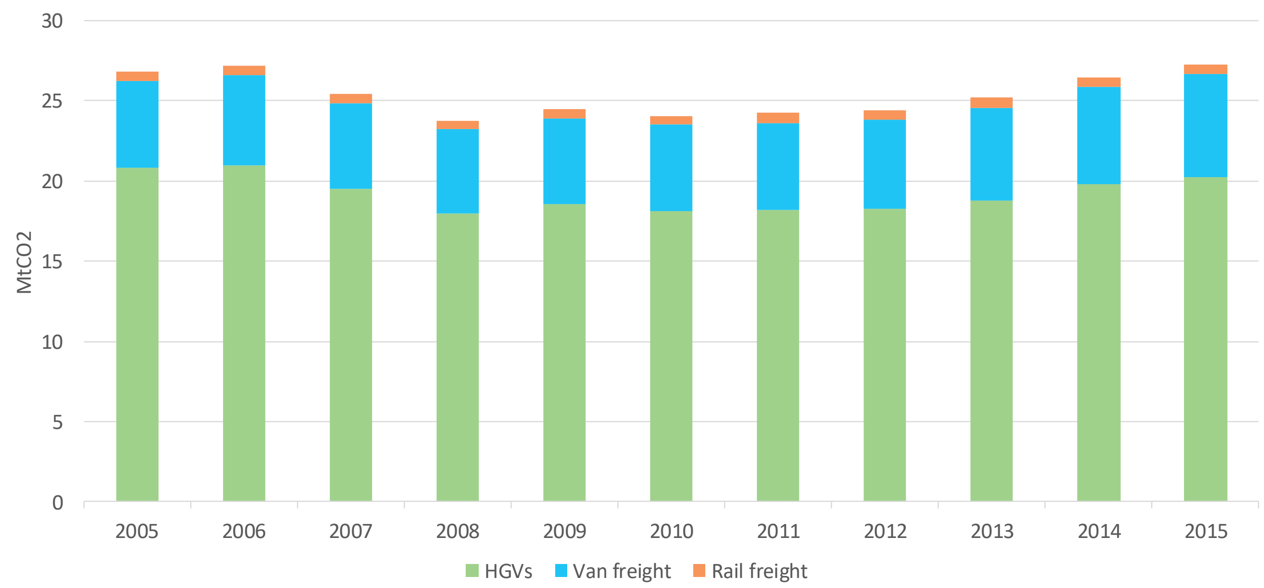
2.3.1 CO2 emissions

We estimate that freight transport as a whole emitted around 27 MtCO2 in 2016. This is equivalent to 22% of total UK transport CO2 emissions (126 Mt in 2016) and 6% of total CO2 emissions (468 Mt in 2016).

- HGVs emitted around 20 MtCO2 in 2016.
- While data on emissions from van freight is not available, vans emitted around 19 MtCO2 in 2016; assuming that the share of freight in van traffic has remained relatively constant over time, we estimate that vans used in freight emitted a further 6 MtCO2, though there is a high degree of uncertainty around the true value.
- Finally, rail freight powered by diesel locomotives emitted around 0.6 MtCO2 in FY 2017-18, or around 28% of total 2 MtCO2 of direct rail emissions.

Freight transport CO2 emissions have remained broadly constant over the last decade. Figure 7 shows freight transport emissions for HGVs, vans (estimated) and rail over the period 2006-2016. Over this period, HGV emissions decreased slightly from 21 MtCO2 in 2006 to a low of 18 MtCO2 in 2011, before returning to broadly their 2006 levels by 2016. The decrease is due to the reduction in freight volumes driven by the contraction in economic output following the 2008 financial crisis.

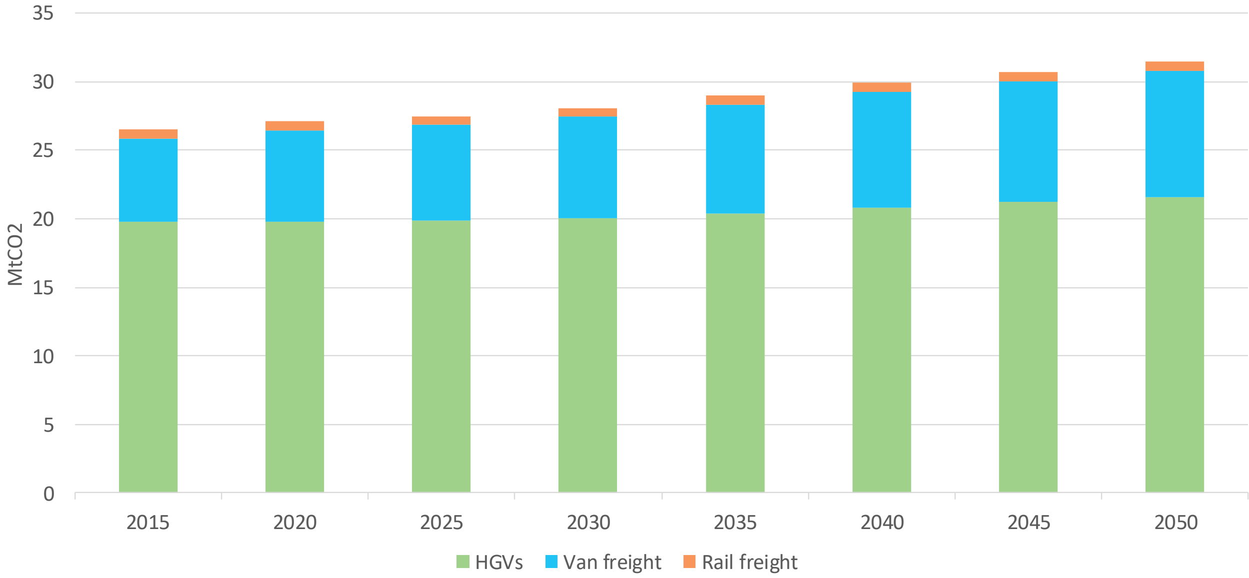
Figure 7. **Freight transport emissions have remained broadly constant over the last decade**



Source: Vivid Economics; Department for Business, Energy & Industrial Strategy; Department for Transport

If CO2 emissions from freight transport are not addressed, they could increase a further 20% to 2050. Department for Transport projections suggest that over the period to 2050, HGV traffic could increase by around 10% (from 15 billion vehicle miles in 2015 to 16.5 billion in 2050) and van traffic could increase by around 50% (from 43 billion vehicle miles in 2015 to 65 billion in 2050). Projections for volumes of rail freight are not available, but in the absence of a significant change in the share of freight carried by mode, it is plausible that rail freight transport could increase at broadly the same rate as HGV transport, driven by the overall projected increase in freight demand. Given this projected increase, if the CO2 intensity of freight vehicles were to remain at the same level as today's level (implying minimal improvements in the fuel efficiency of transport technology, and no significant shift to alternative fueled vehicles), CO2 emissions from freight transport could increase by around 20%, from 27 Mt in 2016 to 31 Mt by 2050.

Figure 8. **If unaddressed, CO2 emissions from freight transport could increase by around 20% by 2050**



Source: *Vivid Economics; Department for Business, Energy & Industrial Strategy*

If unabated, CO2 emissions from freight transport could make up around 20% of allowed emissions in 2050. The Climate Change Act specifies that the UK's greenhouse gas emissions should decrease by 80% relative to 1990 levels by 2050. Greenhouse gas emissions in 2016 were 468 MtCO2e, a 41% reduction on 1990 levels of 794 Mt; the remaining 39% reduction would require emissions in 2050 160 MtCO2e. If freight transport emissions continue unabated and rise to 31 MtCO2 in 2050, they would make up around 20% of this total.

Near- or full-decarbonization of freight transport is likely to be needed to meet the UK's climate targets. It is unlikely that unabated freight emissions can be accommodated over the long term, due to the challenges of reducing emissions in other sectors. To identify pathways to achieving this target, the Committee on Climate Change developed three scenarios for emissions reductions in each sector, each reflecting the range of potential cost and technical challenges of reducing GHG emissions specific to each sector.

– Given extensive deployment of all but the most uncertain and challenging decarbonisation measures (represented by the Stretch scenario), emissions in the power, buildings, transport, industry and non-CO2 sectors make up 185 Mt, and negative emissions technologies such as bioenergy with carbon capture and storage would be needed to reduce emissions by a further 26 Mt to meet the 2050 target.

- Should barriers to decarbonization measures prove severe (represented by the Barriers scenario), sectoral emissions could make up 244 Mt, requiring negative emissions technologies to deliver up to 85 Mt of abatement.
- Only in the event of full take up of the most uncertain and challenging decarbonisation measures (represented by the Max scenario) could emissions in the power, buildings, transport, industry and non-CO2 sectors be low enough not to require negative emissions technologies.

Given the need for negative emissions technologies in all but the most ambitious scenario, it is highly unlikely to be possible to meet the 2050 target at manageable cost without near- or full-decarbonization of freight transport is likely to be needed to meet the UK's climate targets.

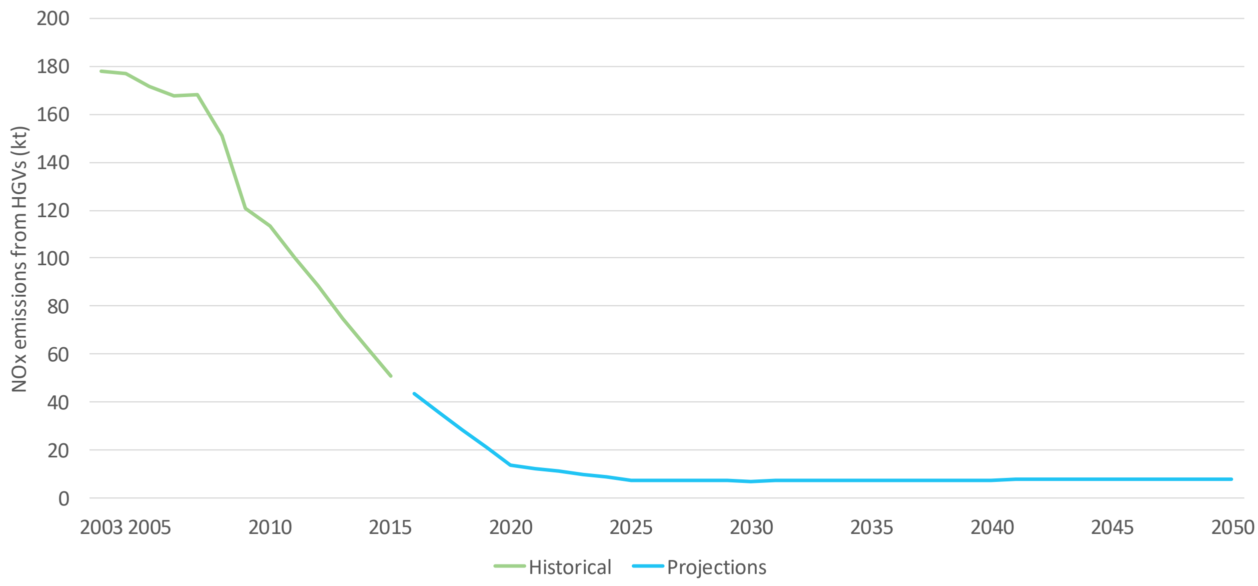
2.3.2 Other pollutant emissions

Poor air quality is a serious risk in the UK. According to the UK Government, poor air quality is the largest environmental risk to public health in the UK (Defra 2017). The Royal College of Physicians estimate that around 40,000 deaths per year can be attributed to outdoor air pollution in the UK. Specific health challenges linked to air pollution include cancer, asthma, stroke, heart disease, diabetes, obesity, and dementia with the cost to individuals, business and the health services valued at over £20 billion per year (Royal College of Physicians 2016).

Road traffic is a leading source of poor air quality. In 2016 total emissions of nitrogen oxides (NOx) were around 920 kilotonnes (kt), of which road transport made up 430 kt (47%). NOx includes nitrogen dioxide (NO2) and produces additional NO2 through subsequent chemical reactions. Total emissions of large particulate matter (PM10) were around 145 kt, of which road transport made up 20 kt (14%).

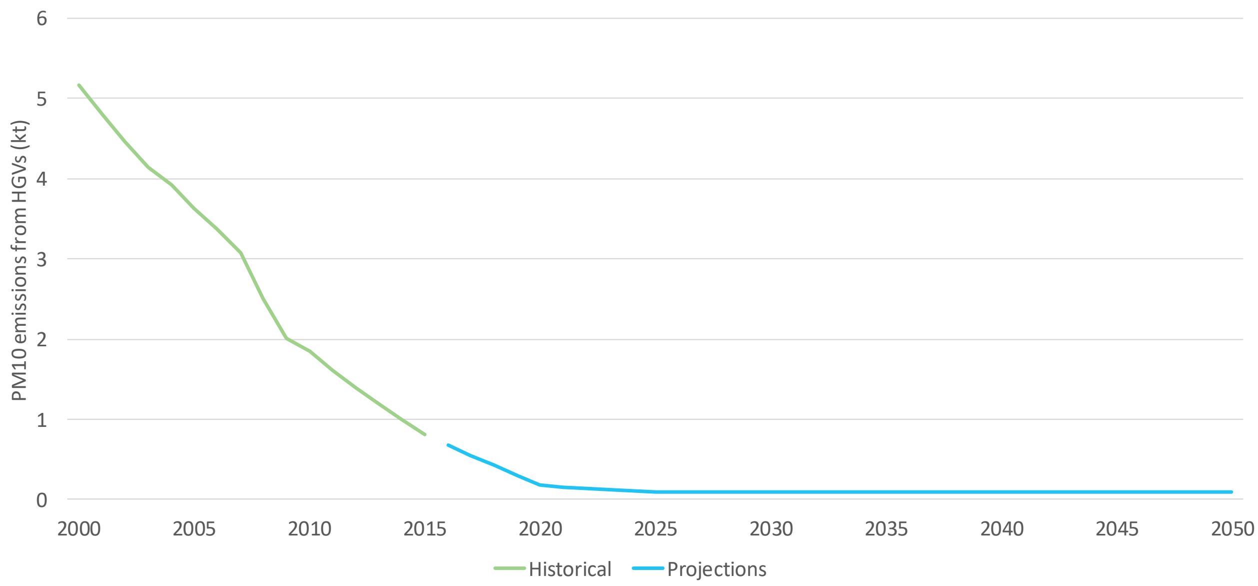
However, nitrogen oxide and particulate matter from HGVs have decreased significantly, and further decreases are expected. Figure 9 and Figure 10 show historical and projected NOx and PM10 emissions from HGVs in the UK. This decrease in pollutant emissions has been achieved through improved vehicle standards, and future standards are expected to decrease emissions further. Figure 11 shows the emissions limits prescribed by the European emission standards ('Euro Standards') for heavy trucks between 1992 and 2013. The Euro Standards have required a 95% reduction in NOx emissions and a 97% reduction in PM emissions over this period.

Figure 9. **Recent decreases in UK NOx emissions are expected to continue**



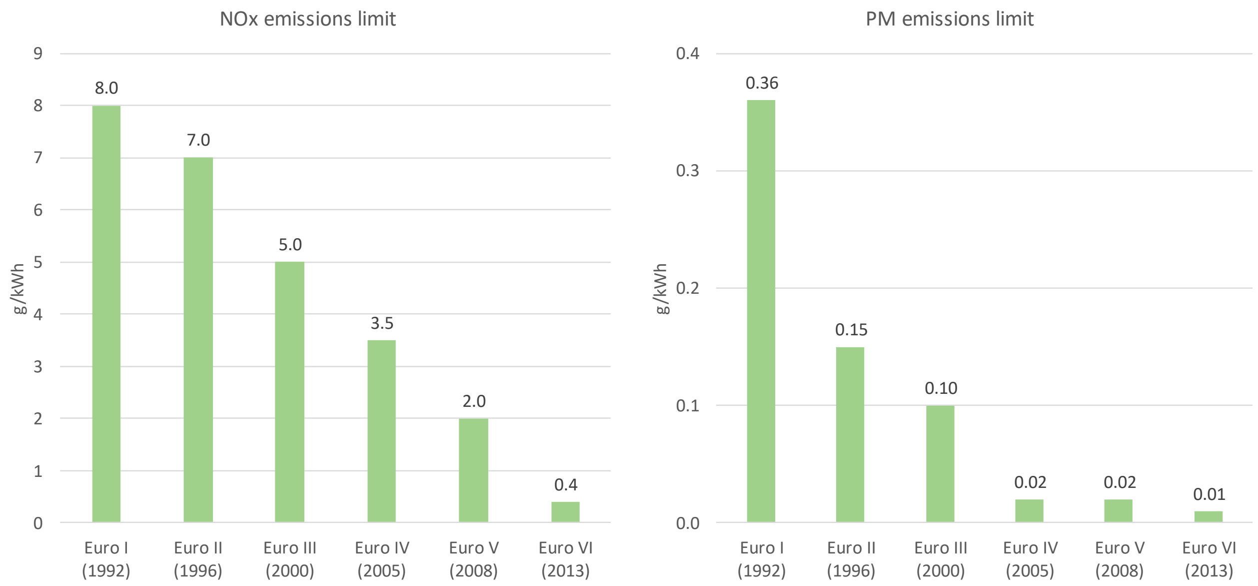
Source: *Department for Transport*

Figure 10. **Recent decreases in UK PM10 emissions are expected to continue**



Source: *Department for Transport*

Figure 11. **Euro Standards have driven significant reductions in NOx and PM emissions since 1992.**



Source: Vivid Economics, European Commission, International Council on Clean Transportation

2.4 Resilience of the UK freight system

We define freight system resilience is the ability to minimize the impact of a disruption to the freight system. This is in line with a characterisation of supply chain resilience by McKinnon in a report for The OECD International Transport Forum (McKinnon, 2014).

Resilience therefore has a number of dimensions. The resilience of a freight system will depend on the probability of disruptions, the severity of those disruptions when they occur; ability to limit the short-term impact of the disruption by exploiting alternative solutions, and ultimately the ability to resolve the disruption and return to normal function.

There is a fundamental trade-off between efficiency and resilience. The efficiency of the freight system under normal conditions can be improved by minimising redundancy. Therefore, freight efficiency implies making maximal use of transport infrastructure, vehicles and drivers, so that unnecessary expenditure on new infrastructure, vehicles and drivers can be minimised. However, resilience generally improved by increasing redundancy, and having a degree of spare capacity across these resources to increase the range of solutions to meeting freight transport demand in the event of a stress event affecting infrastructure, vehicles or drivers.

Freight systems are exposed to a number of risks. Risks include infrastructure failures, fuel supply shocks, extreme weather events, labour strikes and information failures. This section qualitatively examines the resilience of the freight system with respect to each of these risks; and then considers the overall resilience of the freight system in the context of improved efficiency and reduced redundancy.

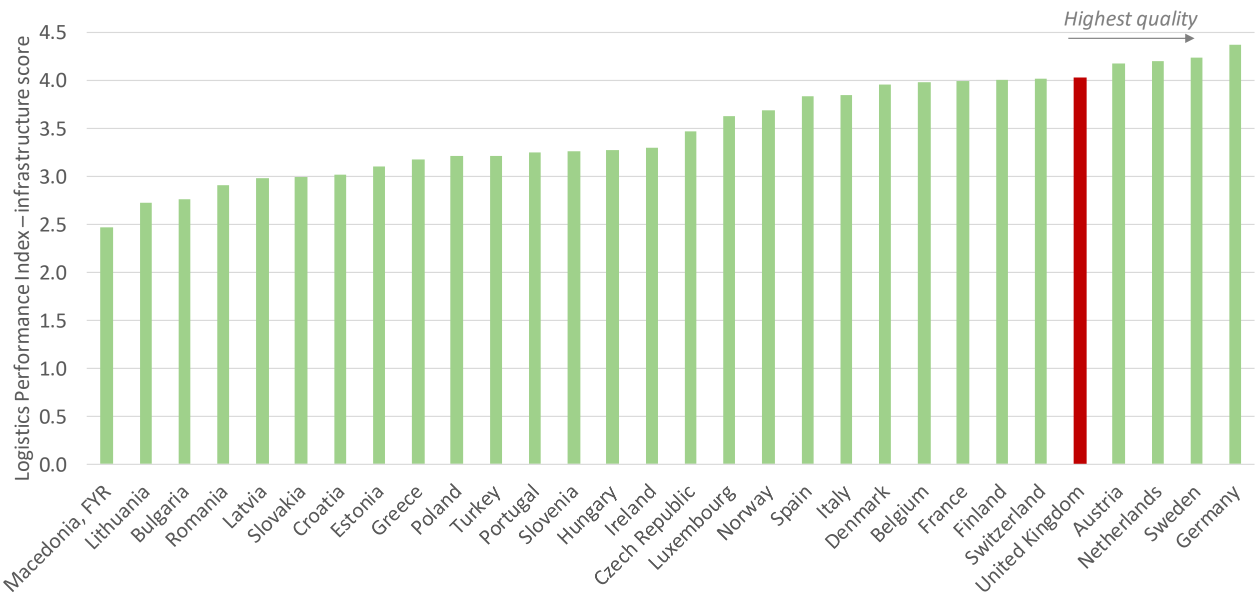
2.4.1 Infrastructure failures

Infrastructure failures can have a significant economic impact. A number of failures in major infrastructure assets have been reported in recent years. For example:

- The collapse of a bridge in Genoa, Italy in 2018 forced trucks to take longer routes, and affected 14,500 businesses including a major container port.
- Following the identification of cracks in the Leverkusen Bridge, Germany in 2012, heavy vehicles were banned from the bridge; the disruption was severe given 14,000 trucks used the bridge each day. The closure resulted in a 30km increase in the average journey length, and a 40 minute increase in the average journey time, with commensurate impacts on fuel expenditure.
- In August 2017 the collapse of a new tunnel at Rastatt, Germany, resulted in the closure of the Rhine Valley rail line. A study into the impact of the incident estimated that the total losses incurred by rail freight operators, logistics companies and their customers as a result of the incident amounted to more than €2bn. The figure includes losses of around €1 billion for the freight operators, around €800 million for manufacturing industries (Hanseatic Transport Consultancy, 2018).

The high quality of UK transport infrastructure reduces but does not eliminate the probability of infrastructure failures. Figure 12 below shows how the UK ranks relative to other European countries for the Infrastructure component of the Logistics Performance Index compiled by the World Bank. The quality of the UK transport infrastructure is one of the highest among European countries; only Germany, Sweden, the Netherlands and Austria are considered to have higher quality infrastructure, and the UK performs better than France, Italy and Spain on this measure. Nevertheless, two of the examples of infrastructure failure cited above occurred in countries considered to have high quality infrastructure. Therefore, it is important that the UK freight system should be capable of adapting to the failure of a key piece of transport infrastructure should this occur.

Figure 12. **The UK's transport infrastructure is of high quality**



Source: *World Bank*

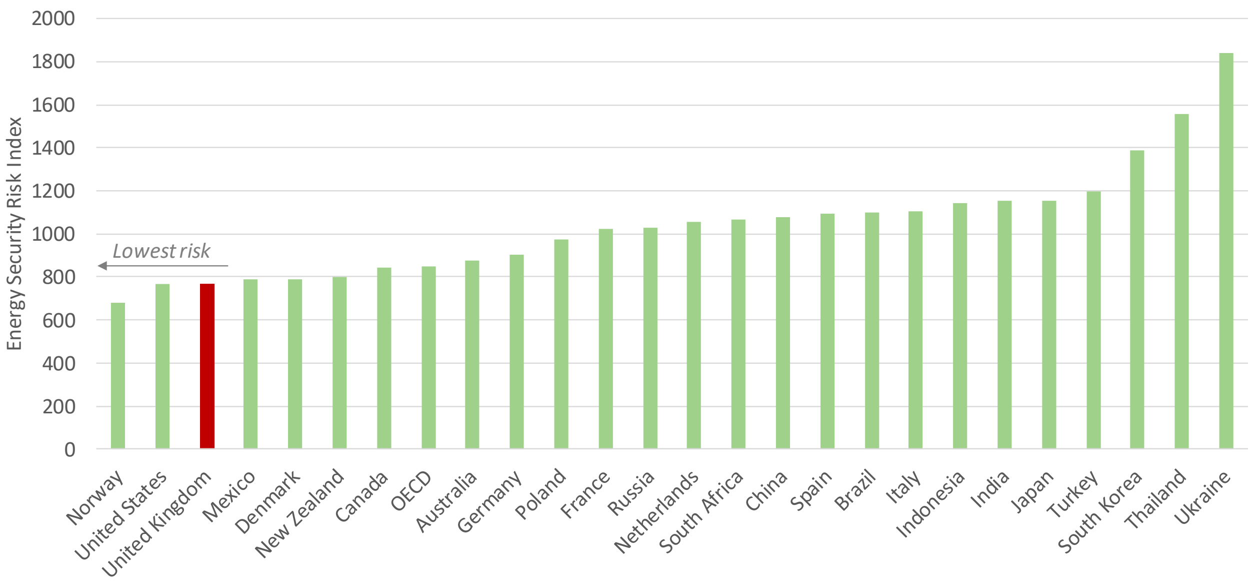
Infrastructure failures could increase in future due to the impacts of climate change. Climate change is expected to increase the number and severity of extreme weather events in the UK. The direct impact of these events on the freight system are discussed in section 2.4.3, below; in addition to these, extreme weather events could also cause damage to infrastructure assets, increasing their probability of failure. Sources of damage include damage to railway tracks and road surfaces from high levels of precipitation and flooding; deterioration of road surfaces from extreme heat; and increases in freeze-thaw damage from more frequent cold snaps.

2.4.2 Fuel supply shocks

Fuel supply shocks are uncommon, but can have severe economic consequences. Two oil supply shocks occurred in the 1970s; in the 1973 oil crisis, prices increased 400% in a single year; in the second, prices increased 100% in a year. The economic consequences of these crises for the UK were severe, though the specific impact on the freight sector is unclear. While comparable oil price rises have occurred since the 1970s (most recently in the 2000s), these were not caused by supply shocks, and did not have comparable economic consequences.

The UK has access to a diverse range of fuel sources, reducing the probability of fuel supply shocks. Figure 13 assesses the energy security of a range of countries based on their reliance on fuel imports, reliability and diversity of fuel suppliers, magnitude of energy costs as a share of economic activity, and intensity of energy use. The UK is assessed as having very low energy security risks, as a result of a high level of diversity in its fuel supply, and low energy intensity.

Figure 13. **The UK has very low energy security risks**



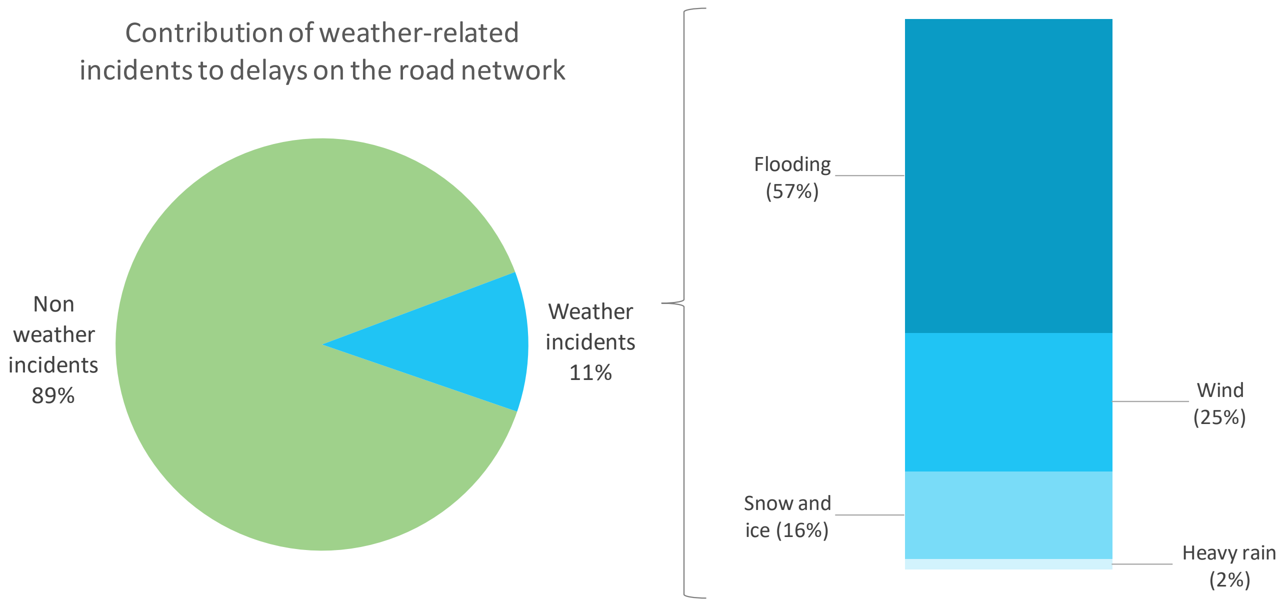
Source: *Global Energy Institute*

In the event of a fuel supply shock, alternative solutions to deliver freight would be limited. As set out in Section 3.4, diesel is the dominant fuel in road freight; 96% of vans and 99% of trucks are diesel vehicles. Therefore, in the event of a fuel supply shock, alternative solutions to deliver freight would be limited. A price spike could therefore result in some combination of an increase in product prices, and a reduction in demand for freight and freight-intensive products. Some modal shift to rail (where fuel is a less important component of overall costs) or efforts to improve operational efficiency could mitigate some of the impact of the price spike on freight costs. Over a longer period of time, some structural transformation of the freight system could reduce diesel consumption. Some decentralisation could take place, with less use of large national consolidation centres and a greater role for consolidation and warehousing within urban areas.

2.4.3 Extreme weather events

The UK road and rail networks are currently vulnerable to weather-related incidents. Weather-related incidents are common in the UK. For example, the 2013/14 winter floods affected transport infrastructure with many roads underwater, several villages only accessible by boat, and the South West railway disrupted by flooding on the Somerset Levels. The contribution of weather-related events to delays on the road and rail networks are shown in Figure 14 and Figure 15. On the road network, weather-related events currently account for 11% of delays; of these, flooding is the most common cause of weather-related delays. On the rail network, weather-related events currently account for 24% of delays; of these, snow and ice is the most common cause of weather-related delays.

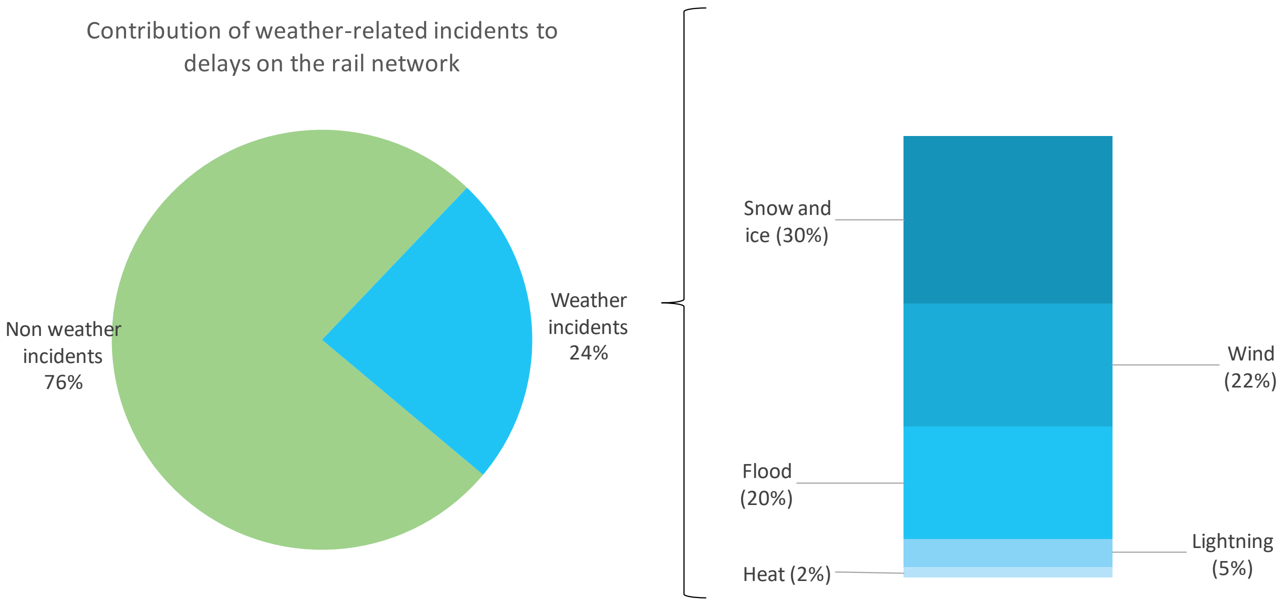
Figure 14. **Weather-related incidents account for 11% of delays on the road network**



Note: *Data based on incidents in England between 2006 and 2014*

Source: *UKCCRA 2017, RSSB (2015), Network Rail (2014), ASC (2014), CCC (2014)*

Figure 15. **Weather-related incidents account for 24% of delays to rail services**



Note: *Data based on incidents in England between 2006 and 2014*

Source: *UKCCRA 2017, RSSB (2015), Network Rail (2014), ASC (2014), CCC (2014)*

Vulnerability to weather-related incidents could increase with climate change. Climate change is expected to increase the number and severity of extreme weather events in the UK. The impact of these events on infrastructure assets are discussed in section 2.4.1, above; in addition to these, extreme weather events could also directly disrupt the operation of the freight system. Incidence of flooding, buckling of rail lines due to heat stress, and hazardous conditions due to winter storms could all increase.

2.4.4 Labour strikes

If drivers exercise market power, the impact on the freight system can be severe. In the UK, labour action has caused severe disruption to the UK freight system on two occasions: the 1979 truck drivers' strike, and the September 2000 fuel protest.

- **1979 UK truck drivers' strike.** In 1979 a large number of truck drivers carried out a labour strike and disrupted freight flows in an attempt to secure a wage increase. This action severely constrained food movements at the upper levels of the supply chain, though retailers held sufficient inventories to limit the extent of disruption to consumers (McKinnon, 2006).
- **2000 UK fuel protest.** In 2000, groups of hauliers and farmers blockaded oil refineries and fuel distribution depots and blocked major roads in protest at increases diesel prices. Disruption was severe: within two days, around half the UK's petrol stations ran out of fuel and within five days (as the protests were ending), much of the manufacturing sector was about to close-down, serious food shortages were developing and hospitals were beginning to offer only emergency service. It is estimated that around 10% of industrial output, valued at (£250 million per day), was lost over this period (McKinnon, 2006).
- **2018 France rail labour strike.** In Spring 2018 a large number of rail workers carried out a strike over a 36 day period in protest at the Government's plans to implement cost cutting measures at the state-run SNCF rail company. The total cost of the strike to SCNF is estimated at €790m overall, including a reduction in turnover for freight transport of €60m, and estimates of wider costs include a €5-20 per tonne increase in cereal prices due to the higher costs of alternative freight transport options.

History demonstrates that the UK freight system is vulnerable to labour action, though union membership has declined over the past two decades. Precise figures for overall membership of trade unions in the freight sector are not available. In the UK as a whole, around 24% of the labour force is a member of one or more unions, close to the average level for OECD countries. Membership of trade unions in the transportation and storage sector is higher than the UK average, though has fallen significantly over the last two decades. Over the period 1995 and 2017, membership of trade unions in the transportation and storage sector has fallen from 51% in 1995 to 36% in 2017. However, the UK fuel protest occurred without union involvement.

2.4.5 Information failures

Growing digitalisation in the freight sector is increasing vulnerability to failures in information systems. Cyber-attacks are one cause of information system failure. In June 2017 a major 'ransomware' cyber-attack dubbed 'NotPetya' crippled IT systems of thousands of large businesses around the world. A number of freight companies were affected:

- The attack disabled the IT systems of parcel firm TNT, which began processing shipments by hand. It is estimated that the attack cost TNT $300m in lost earnings, and the share price of TNT's parent company FedEx fell 3% following the attack.
- The attack also forced Danish shipping group Maersk to halt operations at 76 port terminals, and to redirect ships to alternative locations, at a similar estimated cost of $300m.

The increasing use of telematics in vehicle technology could heighten vulnerability of the freight system to cyber-attacks. Telematics is the use of satellite navigation, mobile communications and information processing technologies in road vehicles. Telematics is underpinning the development of connected and autonomous vehicles, an emerging technology that could allow vehicles to function without a driver. Telematics raises the prospect that freight vehicles themselves could be subject to cyber-attacks, causing major disruptions to the freight system. While no organisation could be free from the risk of such cyber-attacks, small and medium-sized freight firms are considered to be the most vulnerable as they as are less likely to have the specialise IT staff needed to manage these risks.

2.4.6 Overall resilience

The risks faced by the UK freight system are changing. Some risks are likely to decrease in future. A shift to alternative-fuelled vehicles will reduce the risks of fuel supply shocks, and a shift to connected and autonomous vehicles could reduce the vulnerability of the freight system to labour action. However, other risks are likely to increase. Risks of infrastructure failure and extreme weather events could increase with climate change, and risks associated with information failures could increase as the digitalisation increases the reliance of the freight system on complex information networks and exposes it to vulnerability from failures in IT systems or cyber-attacks.

Improvements in freight efficiency are likely to have reduced the resilience of the freight system. As described in Section 3, the freight system has evolved under commercial pressures to minimise unnecessary cost. An important trend has been the reduction in inventories held by firms, driven by high cost of warehouse space in urban areas. The average number of firms rotated their inventories in the manufacturing, wholesale and retail sectors has increased from 7.2 times per year in 1986 to around 12 times per year by 2004 (McKinnon, 2006). As a result the reduction in inventories, firms are increasingly reliant on the reliability of the freight transport system to deliver goods when needed, and therefore increasingly exposed to disruptions in the reliability of that system.

A comprehensive review of freight system resilience is needed to identify the appropriate balance between efficiency and resilience. As resilience requires a degree of redundancy in freight system assets (warehousing, infrastructure, vehicles and drivers) there is a trade-off between efficiency and resilience. Given the importance of the freight system in the economy, a careful judgment must be made about what trade-off is appropriate. Further, the risks to the UK freight system are difficult to quantify, and are constantly evolving. Therefore, a comprehensive review of freight system resilience is needed to ensure that the freight system remains efficient while securing it against future risks.

3 Drivers of efficiency

Key messages:

- **In response to cost pressures, the UK freight system has evolved a centralised structure, resulting in increased travel distances and CO2 emissions. However, given the urgent priority of shifting to alternative fuelled vehicles, there is no clear environmental case to move to a more decentralised model.**
- **At the regional level, freight distribution centres are typically located far from customers in urban areas, resulting in greater vehicle movements and associated congestion. Location of freight distribution centres inside urban areas would reduce freight's contribution, and exposure, to congestion.**
- **While the majority of UK freight is carried by road, rail is inherently more energy-efficient and lower-emitting. However, given the urgent priority of shifting to alternative fuelled vehicles, there is no clear environmental case to incur the costs of delivering a higher share of rail freight.**
- **The UK's road and rail network capacity is strained by high levels of transport demand, giving rise to congestion. While some infrastructure investment may be needed to mitigate congestion, overall demand management is likely to provide a more cost-effective solution than a large-scale infrastructure investment programme.**
- **UK road and rail freight are predominantly powered by diesel; a shift to alternative fuel vehicles will be needed over the long-term.**
- **Key message: the UK freight system has taken advantage of the cost and environmental benefits offered by larger HGVs. The efficiency benefits of reducing restrictions in vehicle size are highly uncertain, and this is not an urgent policy priority.**
- **Van use is growing significantly and contributing to congestion, and its role in freight is poorly understood. Further work is needed to understand the role of policy in driving efficient use of vans within the freight system.**
- **UK levels of empty running and part-loading are moderate; initiatives to reduce empty running and part-loading to date suggest some limited opportunities to improve performance.**
- **Utilisation of the road network is highly inefficient, leading to high levels of congestion. Road pricing could be an effective policy instrument to manage congestion.**

3.1 Spatial organisation

The UK freight system is relatively centralised. Goods are often not shipped directly from the origin (point of production or import) to the destination (retailer or customer). Rather, goods are typically taken to large centralised consolidation centres, sometimes distant from both origin and destination, where they are stored and sorted to enable efficient onward distribution. The typical sequence of freight distribution involves three phases (DfT, 2008):

- Primary distribution, in which freight is moved from its point of production or import to a primary consolidation centre;

- Secondary distribution, in which freight is moved from the primary consolidation centre to a regional distribution centre; and
- Tertiary distribution, in which freight is moved from the regional distribution centre to a retailer or customer.

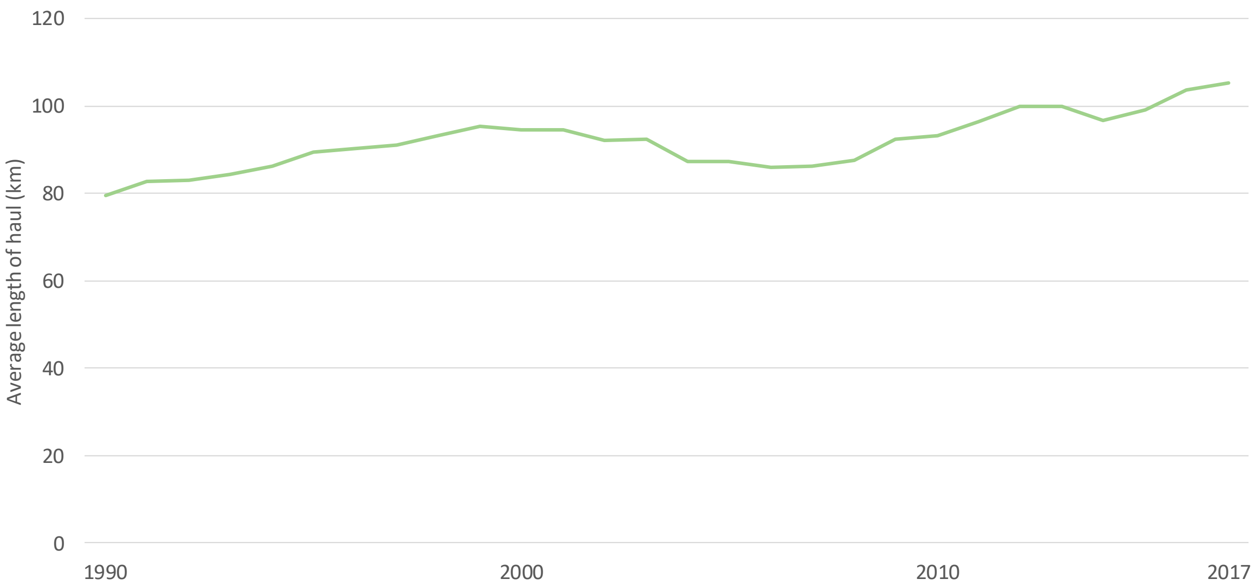
Centralisation therefore occurs at both the inter-regional and regional levels: at the inter-regional level, centralisation occurs through the use of national primary distribution centres rather than transporting freight directly to its destination regions; and at the regional level, centralisation occurs through the use of regional distribution centres rather than more decentralised consolidation closer to customers. This section discusses the implications of centralised consolidation at the inter-regional and regional levels for freight efficiency.

3.1.1 Centralisation of freight at the inter-regional level

At the inter-regional level, centralisation occurs through the use of national primary distribution centres rather than transporting freight directly to its destination regions. The East and West Midlands is the most important region for freight consolidation in the UK. These regions account for the largest share of inter-regional road freight transport: 27% of inter-regional freight is transported to these regions, and 29% of inter-regional freight originates in these regions (Department for Transport, 2017). They also account for around 30% of the UK's total warehouse space (United Kingdom Warehousing Association, 2015), and include very large warehouse developments, typically 30,000m^2 and as large as 75,000m^2 suitable for large-scale freight consolidation (Chartered Institute of Logistics and Transport, 2014).

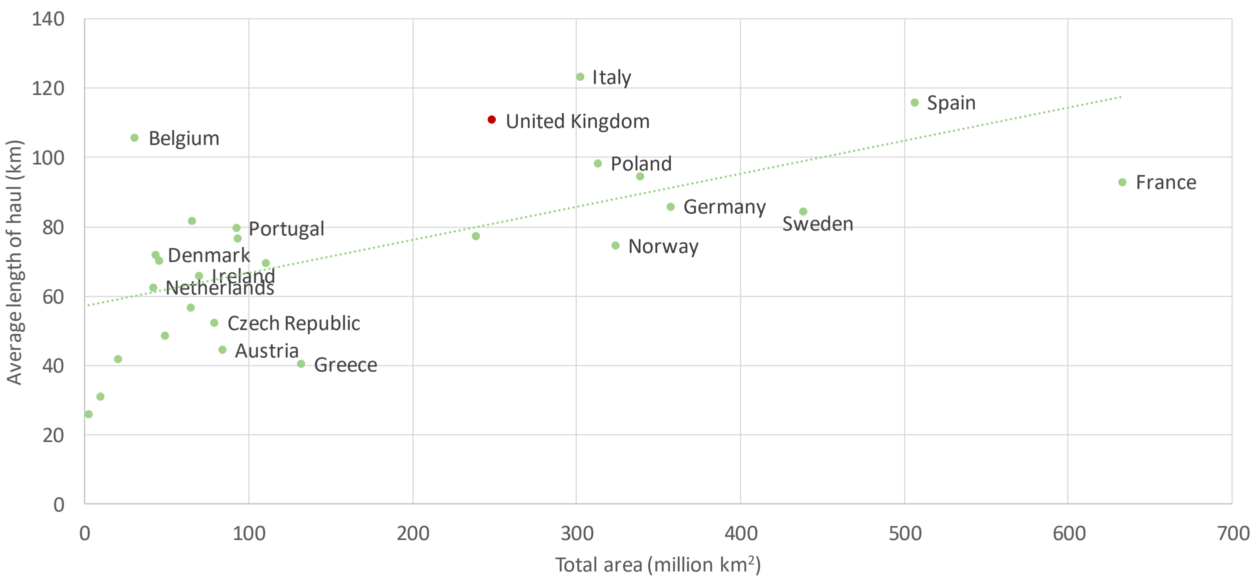
It is likely that the UK's system of centralised freight has resulted in longer travel distances and higher CO2 emissions. Transporting freight to national consolidation centres before onward distribution to its final destination increases the distance freight is moved. Figure 16 shows that between 1990 and 2017 the average length of haul has increased around 25%, from around 80 km in 1990 to around 105 km in 2017. Figure 17 shows that average length of haul in the UK is one of the highest among European countries, and is significantly higher than in other countries of comparable size (in Spain, which has twice the land area of the UK, average length of haul is only around 5% higher). Given transport CO2 emissions are driven by distance travelled, it is likely that the UK's system of centralised freight has resulted in higher CO2 emissions. It is less likely to have resulted in significantly higher levels of congestion, as these occur predominantly in urban areas.

Figure 16. **The average length of haul has increased around 25% between 1990 and 2017**



Source: *Vivid Economics, Department for Transport*

Figure 17. **The average length of haul in the UK is one of the highest among European countries**



Source: *Vivid Economics, Eurostat*

There is some evidence that the trend towards increasing centralisation has slowed or reversed. The dominance of the Midlands as a location for warehousing has declined: in the period 1996-2000, 44% of new warehousing developments (by floor area) were located in the Midlands; while by 2006-2010 this figure had dropped to 33% (Baker and Sleeman, 2011). The drivers of this shift are not clear, but may include shortages of suitable sites or skilled labour or rising fuel prices. They may also include the emerging trend of port-centric logistics, which involves locating warehousing at or close to major ports to reduce overall transport costs. The port-centric logistics model has gained favour in recent years; for example, Asda and Tesco have both opened large import centres at Teesside (Baker and Sleeman, 2011), and in 2013 DP World has completed development of the London Gateway port, comprising a deep-sea container terminal and warehousing and distribution facilities.

Although centralised freight increases travel distances and CO2 emissions, it may contribute to minimising the total market costs of the freight system. The driving force behind centralisation has been the lower cost of small numbers of large warehouses in a centralised system, relative to the costs of large numbers of small warehouses in urban areas, as a result of both lower land prices and economies of scale in consolidation activities. Offsetting this cost saving is an increase in the costs of transportation arising from the greater travel distances in a centralised freight system. It is likely that decisions driving the current centralised spatial organisation of the freight system were made in order to minimise the total market cost of transporting, consolidating and distributing freight to customers.

Given the urgent priority of deep decarbonisation of road freight by shifting to alternative fuelled vehicles, the case for reducing centralised freight consolidation is not clear. Section 3.3 explains the need for near- or full-decarbonization of freight transport to meet the UK's climate targets, and identifies alternative fuelled vehicles as the key solution to achieve this outcome. Given that reducing centralised freight consolidation in order to reduce volumes of freight transport cannot achieve near- or full-decarbonization of freight transport; and that achieving near- or full-decarbonization through a shift to alternative fuelled vehicles would erode the environmental benefits of reducing centralised freight consolidation, the case for incurring the additional costs of a more decentralised system is not clear.

3.1.2 Centralisation of freight at the regional level

The freight system is also relatively centralised at the regional level. Typically, following primary distribution in which freight is moved from its point of production or import to a primary consolidation centre, it is then moved to a regional distribution centre, usually located outside the urban areas that it serves, where it is further consolidated before being distributed to retailers and other customers within the urban areas.

Regional centralisation increases the number of vehicle movements, increasing CO2 emissions and contributing to congestion.

- Due to the difficulties of operating large freight vehicles in urban areas, freight distribution to customers in urban areas is typically carried out in smaller vehicles, requiring a larger number of vehicles for freight delivery.

- If the freight were consolidated within the urban area, the distances travelled by these vehicles would be small.
- Consolidation of freight at regional distribution centres outside the urban area therefore results in small vehicles travelling longer distances.
- The result of this pattern of freight distribution is an increase in transport costs, in CO2 emissions, and in urban congestion.

Urban consolidation centres are an alternative approach to final distribution. An urban consolidation centre (UCC) is a consolidation and distribution centre situated close to the urban area that it serves. The use of an urban consolidation centre allows freight from national or regional distribution centres to be transported close to the customer in large vehicles before final distribution in smaller vehicles over short distances. Consolidating freight within urban areas significantly reduces the distances travelled by small freight vehicles, relative to consolidating freight at regional distribution centres outside urban areas. Urban consolidation centres are therefore expected to reduce transport costs, greenhouse gas emissions, and congestion.

However, the costs and benefits of urban consolidation centres are poorly understood. The Transport Systems Catapult reviewed four successful implementations of UCCs in the UK (Heathrow; Regent St; Bristol Broadmead; Bristol-Bath Freight) and concluded that all four UCCs have delivered significant reductions in freight travel. In two UCC schemes (Heathrow and Regent St) participation was mandatory, and enforced by the customer. In the other two (Broadmead and Bristol-Bath) participation was limited, suggesting that costs to the freight operators outweigh the benefits of scheme participation. Further work is needed to understand the barriers to voluntary use of urban consolidation centres, and determine the prospects for UCCs to reduce the contribution to and exposure of freight to congestion.

The current pattern of regional centralisation may be driven by a combination of market forces and market failures, both of which need to be considered when comparing alternatives. Regional consolidation may represent an efficient trade-off of transport, and rural and urban warehousing land costs by freight operators and customers. However, regional consolidation may also be driven by inadequate allocation of urban land, and the failure to account for the wider social costs of congestion in making location decisions for distribution centres, and commercial and cultural barriers to load consolidation.

A shift to freight consolidation within urban areas would require reforms to the land use planning system. Land use in the UK is governed by the National Planning Policy Framework (NPPF), which governs planning new development at the at the local planning authority level. Currently, the NPPF does not provide for the strategic planning of freight sites or other infrastructure, including the allocation of land for freight distribution inside urban areas.

Allocating land for freight distribution inside urban areas could reduce the contribution to and exposure of freight to congestion, though further work is needed to understand the costs and benefits of intervention. Allocating land for freight distribution inside urban areas has both costs and benefits. The costs include the opportunity cost of urban land, and in particular housing land whose scarcity and value is signalled by the very high house prices prevailing in London and the South-East of England. The benefits include a reduction in the contribution to and exposure of freight to congestion. A comprehensive impact assessment would identify the costs and benefits of allocating urban land to freight uses would be needed is needed to establish the case for strong action on modal shift.

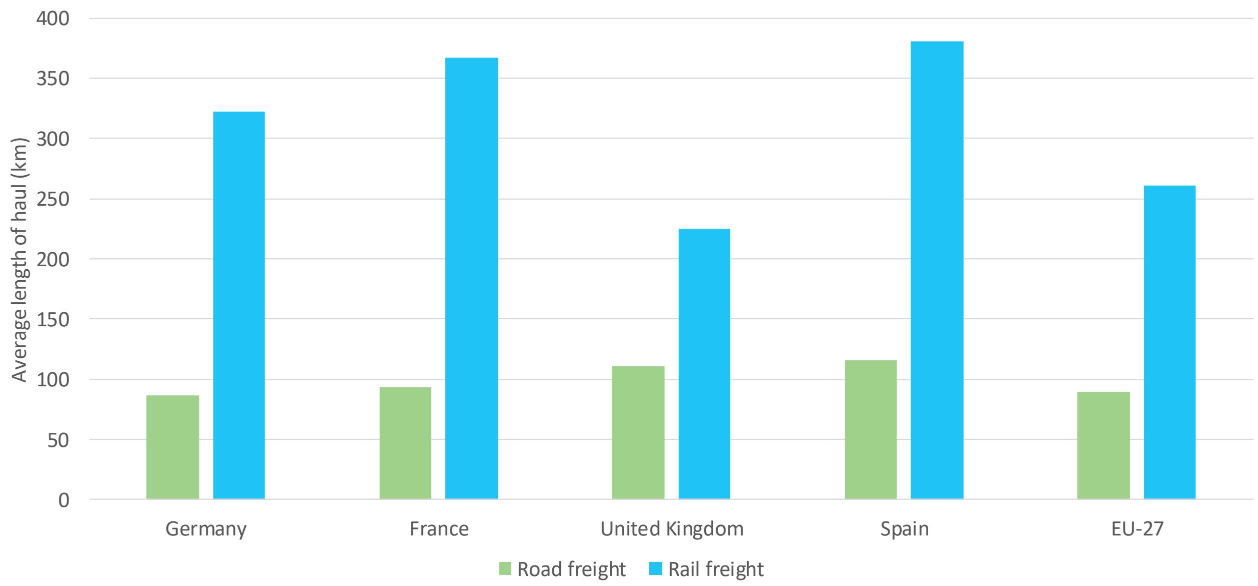
3.2 Modal share

The majority of UK freight is carried by road. In 2015, 88% of freight was carried by road, and 12% by rail. Minimal volumes of freight are carried by inland waterway. Road plays a more dominant role in the UK freight system than in other European countries; across the EU as a whole, 75% of freight was carried by road, 18% by rail and 6% by inland waterway. In some European countries, rail plays a much more significant role, with a modal share of 52% in Estonia, 66% in Lithuania and 80% in Latvia (Eurostat, 2018).

Road and rail freight are suited to different types of load. Road and rail freight possess different characteristics, which determine the costs and benefits of their use in moving different types of load. First, rail freight involves significantly larger investments than road freight: The average train load is around 300 tonnes, and trains can cost several millions of pounds, while the largest road freight vehicle has a carrying capacity of 44 tonnes, and costs around £100,000 (University of Westminster, 2010). Second, rail is highly capital-intensive, with the locomotive and carriages making up much of the cost, while road freight is less capital-intensive, with fuel costs typically making up a significant (one third) share of total costs. Third, rail vehicles are also highly modular such that the cost of additional capacity (the addition of an extra carriage) is relatively low, while with road freight additional capacity requires the costly investment in additional vehicles and drivers.

As a result, rail is ideally suited to carrying longer distances, and road to shorter distances. Over short distances, where variable costs are limited, road freight has an advantage due to its low capital costs. Over long distances, where variable costs can be significant, rail freight has an advantage due to its high energy efficiency and low fuel costs. Figure 18 shows the average length of haul of road and rail freight in the UK, and in other European countries. In the UK, the average length of haul of rail freight (around 225km) is around twice that of road freight (around 110km). In other European countries, the difference is even greater, with the average length of haul of rail freight around three times that of road freight in Germany, France, Spain and in the EU as a whole.

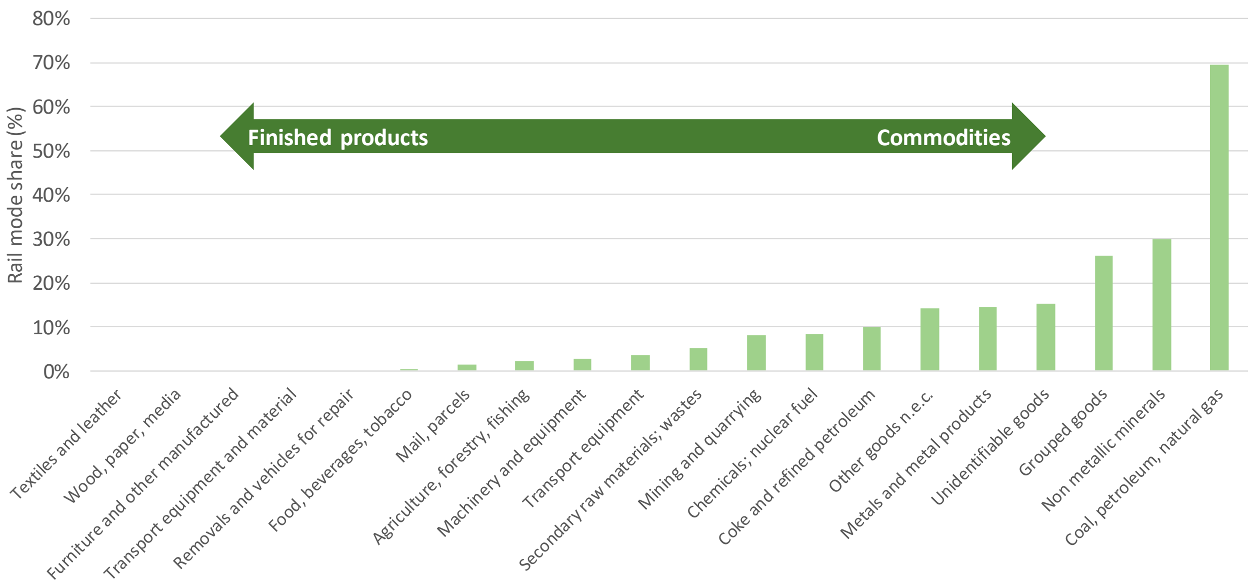
Figure 18. **Mode choice is highly dependent on length of haul**



Source: *Vivid Economics, Eurostat*

Rail has also historically been suited to large volumes of homogenous loads, while road has been suited to a wider range of loads. Due to the high capital costs of rail freight vehicles, their large capacity and the low cost of increasing capacity by increasing the number of carriages, rail freight has historically been better suited to goods that can be transported in large volumes. Historically such goods have been commodities (such as coal, aggregates, and metals), though other homogenous products such as automobiles and containerised loads are also suited to rail freight, and the rail freight market for these products has grown in recent years. In contrast, road freight is better suited to a wider range of goods that are transported in smaller volumes. Road is therefore better suited to finished goods. Figure 19 illustrates how the share of rail freight varies by type of product carried, with goods for which rail has a significant mode share tending to be commodities (and likely containerised loads, described in the Eurostat data as 'other' and 'unidentifiable').

Figure 19. **Mode choice is highly dependent on the type of product moved**



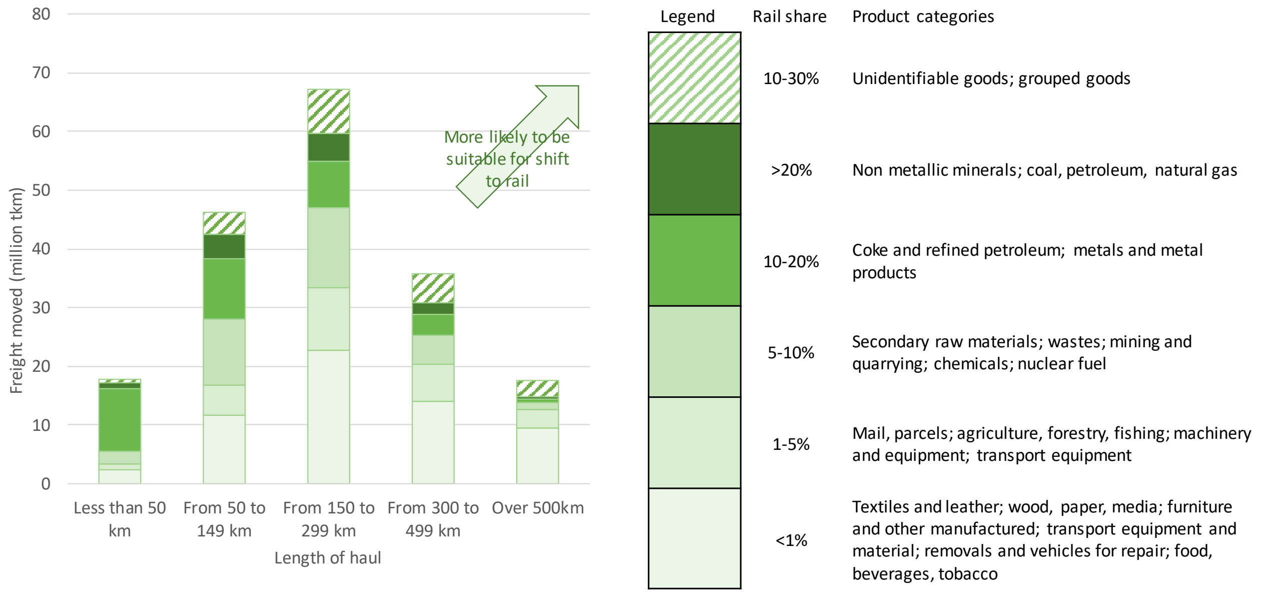
Source: Vivid Economics, Eurostat

However, rail freight is inherently more energy-efficient and lower-emitting. In 2017, CO2 emissions from HGVs were around 138 gCO2 per tonne km, while CO2 emissions from rail freight were around 33 gCO2 per tonne km (The Office of Rail and Road, 2018). CO2 emissions from road freight are therefore only a quarter those of road freight.

At moderate distances, road and rail may offer comparable cost and quality. Although road freight is generally more competitive at short distances and rail freight at long distances, at moderate distances road and rail may offer comparable cost and quality. The distance at which such a shift may be possible will depend on multiple factors including the goods to be moved, congestion levels, infrastructure quality and availability, and availability of backhaul flows (University of Westminster, 2010). Harris & McIntosh (2003) estimate that 'rail generally has difficulties competing for distances of less than 160 kilometres', though they emphasise that there are instances where rail is competitive at much shorter distances, and where it is not competitive at longer distances.

There may be some opportunities to shift freight from road to rail. Figure 20 shows the composition of road freight, by distance moved. Around 35% of road freight tonne km is accounted for by distances shorter than 150km, and is unlikely to offer significant opportunities to shift from road to rail. A further 25% of road freight tonne km is accounted for by product categories for which rail has a less than 1% mode share, and that may be fundamentally poorly suited to transportation by rail. The remaining 40% of road freight tonne km is accounted for by distances greater than 150km, and product categories for which rail has at least a 1% mode share, suggesting some potential to shift from road to rail. A more conservative assessment, considering only road freight carried distances greater than 300km and product categories for which rail has at least a 5% mode share, suggests that there may be some potential to shift from road to rail for around 16% of road freight.

Figure 20. **There may be an opportunity to shift from road to rail in some freight market segments**



Source: *Vivid Economics, Eurostat*

Investment in rail infrastructure could shift freight from road to rail, though the cost is uncertain. In a study commissioned by the Department for Transport, Arup/AECOM investigated the policy measures required to realise potential for modal shift from road to rail. Arup/AECOM identified a range of measures to increase the modal share of rail, and selected from these a package of the leading interventions thought most valuable in the views of the expert team. These measures include a programme of capacity and gauge enhancements, building new rail terminals; a series of network enhancements targeted at commodities for which demand for rail freight is expected to grow; a programme of investment in new rail terminals and a programme of financial assistance for the rail freight sector. Arup/AECOM estimated that these measures have the potential to shift around 20% of road freight to rail, reducing the share of road freight to 70% and increasing the share of rail freight to 30%. However, while some information of the costs of these projects is given, full lifetime costs are not provided, so further work is needed to estimate the cost-effectiveness of the measures needed to drive such levels of modal shift.

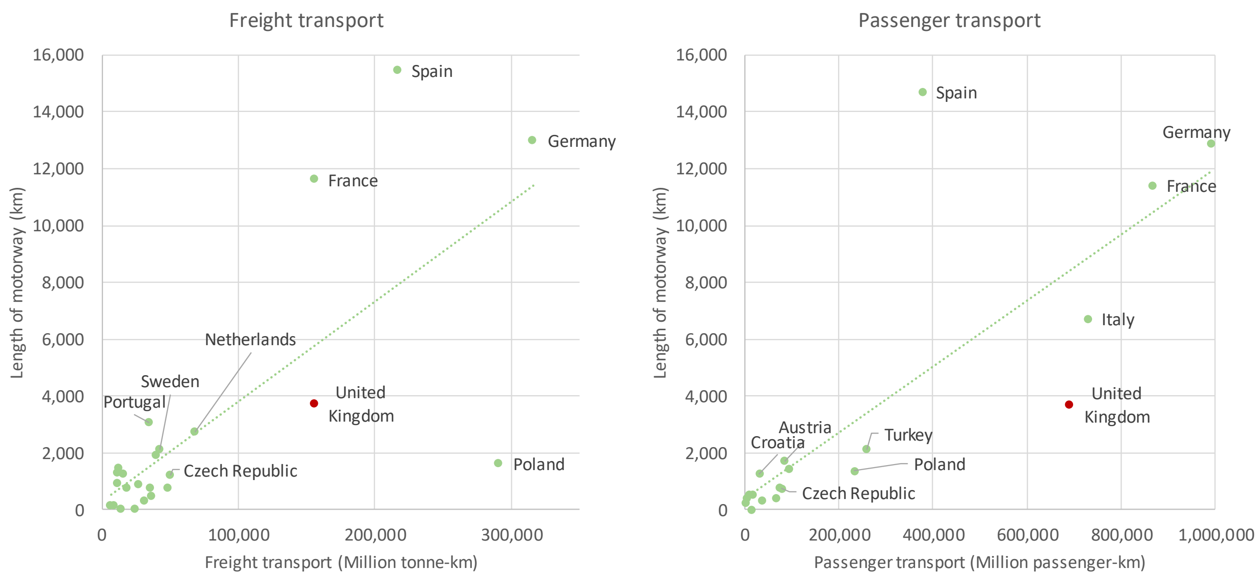
Given the urgent priority of deep decarbonisation of road freight by shifting to alternative fuelled vehicles, the case for incurring the costs of delivering a higher share of rail freight is not clear. As it is highly unlikely that the share of rail in freight transport could be increased to levels that deliver deep decarbonisation of freight transport, a shift to alternative fuelled vehicles is therefore an urgent priority for the road freight sector. Under such an outcome, the advantages of a higher share of rail freight are not clear. A comprehensive impact assessment, identifying the costs and benefits of delivering a higher share of rail freight in the context of a shift to alternative fuelled vehicles is needed to establish the case for strong action on modal shift.

3.3 Physical infrastructure

3.3.1 Road infrastructure

Given the volume of UK freight and passenger transport, the UK's road network is relatively small. Figure 21 shows the length of the motorway network in the UK and other European countries. Overall, countries with large levels of freight and passenger demand have large motorway networks to accommodate this demand. For both freight and passenger transport, the UK motorway network is relatively small compared to countries with comparable levels of transport demand. For example, the UK has roughly similar levels of freight transport demand to France (around 150 billion tonne km per year), but only around one third of the motorway network (around 4000 motorway km in the UK, relative to around 12,000 in France). Similarly, the UK has higher levels of passenger transport demand than Spain (around 700 billion passenger km per year in the UK, relative to around 400 billion in Spain), but only around one quarter of the motorway network (Spain's motorway network is around 15,000 motorway km).

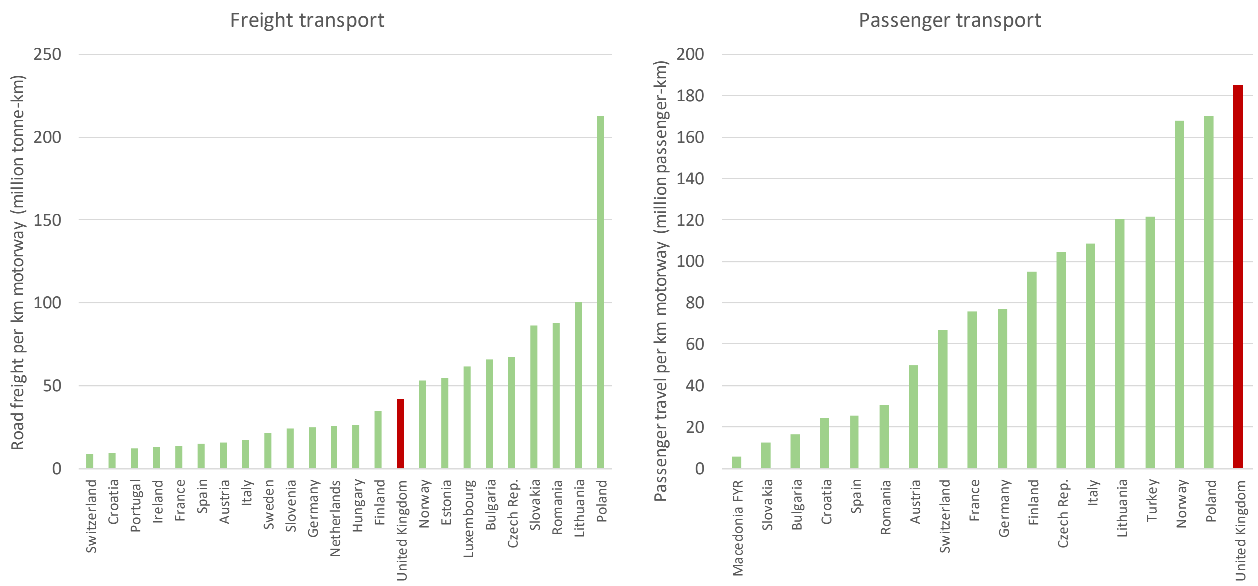
Figure 21. **The UK motorway network is small relative to freight and passenger transport demand**



Source: *Vivid Economics, Eurostat*

Furthermore, road freight must compete with high levels of passenger demand for use of the network. Figure 22 shows the level of road freight and passenger transport which the motorway network must accommodate in the UK and other European countries. For both freight and passenger transport, there is considerable variation in utilisation of the network. For freight transport, the UK motorway network has moderate levels of utilisation – significantly higher than Spain, France and Germany, but lower than Poland, for example. However for passenger transport, the UK has the highest level of motorway network utilisation in Europe, and more than double levels in France and Germany.

Figure 22. **Utilisation of the UK motorway network is moderate for freight, but high in Europe for passenger transport**



Source: Vivid Economics, Eurostat

It is likely that the UK's high levels of road congestion is determined in large part by its limited road capacity relative to traffic levels. Congestion is partly determined by the capacity of the road network and the overall quantity of traffic. As set out in Section 2.2, road congestion in the UK is among the highest across European countries; and the UK road network is relatively small given the volumes of freight and passenger transport it must accommodate.

However, investment in new road capacity alone is a poor solution to congestion. Investment in new road capacity alone is unlikely to represent a cost-effective solution to road freight congestion, for several reasons.

— First, as described above and in section 3.3, congestion is primarily driven by passenger transport. Therefore, passenger transport is likely to be the primary beneficiary of investment in new road capacity.

— Second, there is strong evidence that the impacts of new road capacity on congestion is limited by induced demand. Induced demand occurs when investment in new road capacity results in an increase in overall traffic, as new sources of travel demand take advantage of the greater convenience delivered by the new capacity. The existence of induced demand has been widely accepted since a review by the Department for Transport Standing Advisory Committee on Trunk Road Assessment (SACTRA) in 1994 (Department for Transport, 1994), and more recent evidence has continued to validate its impact (WSP, 2018).

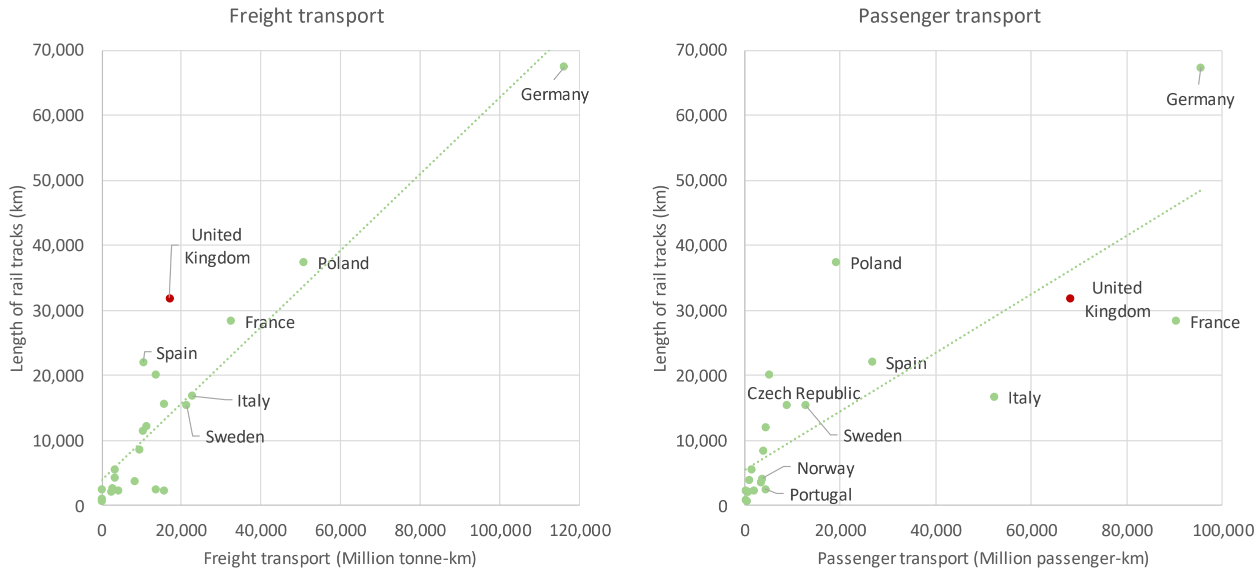
— Third, congestion is also partly determined by efficiency with which traffic uses the network, in terms of the time of day and specific routes. Frequently, opportunities to vary these factors represent a more cost-effective way to address congestion than new transport infrastructure investments that are only needed at peak times.

There may be a case for new investment in discrete transport schemes as part of a wider package of measures to reduce congestion. While an overall increase in new road capacity is unlikely to be cost-effective due to induced demand and the high cost of investing in infrastructure that is only needed at peak times, it is possible that there are specific sections of the road network where congestion is severe, occurs over a wide time window, and where opportunities to reduce demand are limited. In such cases, investments in new capacity may be cost-effective.

3.3.2 Rail infrastructure

The UK's rail network is fairly extensive for the volume of freight transport, but relatively small for the volume of passenger transport. Figure 23 shows the length of the rail network and the level of freight and passenger demand in the UK and other European countries. For freight transport, the UK rail network is fairly extensive compared to countries with comparable levels of transport demand. For example, the UK demand for rail freight is around half that of France (around 17 billion tonne km per year in the UK, relative to around 33 billion in France), but the rail network in both countries is of comparable size (around 30,000 track km). However, for passenger transport, the UK rail network is relatively small. For example, UK demand for passenger transport is around 70% that of Germany (67 billion passenger km per year in the UK, relative to 95 billion in Germany), but the rail network is less than half the size (31 billion track km in the UK, relative to around 68 billion in Germany).

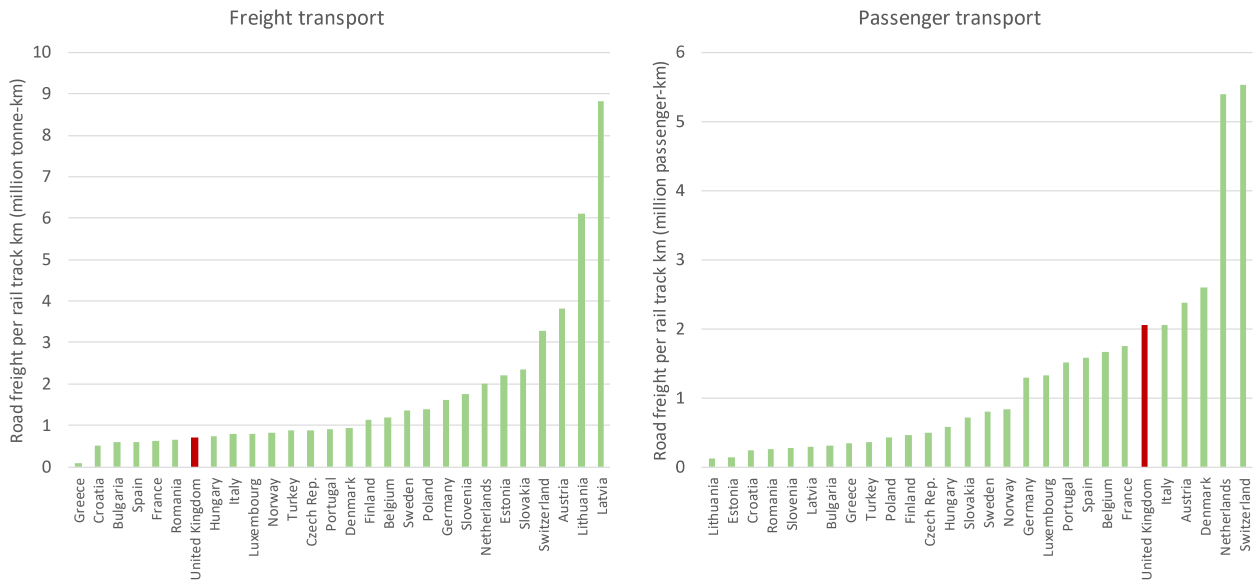
Figure 23. **The UK rail network is extensive relative to freight transport demand, but small relative to passenger transport demand**



Source: *Vivid Economics, Eurostat*

Therefore as with road freight, rail freight must compete with high levels of passenger demand for use of the network. Figure 24 shows the level of road freight and passenger transport which the rail network must accommodate in the UK and other European countries. For freight transport, the UK rail network has relatively low levels of utilisation – significantly lower than Germany, but higher than Spain and France. However for passenger transport, the UK rail network has very high levels of utilisation, though the rail network in other countries (for example, Denmark, Netherlands and Switzerland) have higher levels.

Figure 24. **Utilisation of the UK rail network is low for freight, but very high for passenger transport**



Source: Vivid Economics, Eurostat

Much of the UK rail network is relatively poorly suited to freight. The Department for Transport sets an objective that the Strategic Freight Network (the portion of the UK rail network comprising the most important freight routes) should a have a loading gauge of at least W10 standard, i.e. capable of accommodating deep sea containers (Department for Transport, 2009). At present, only 16% of the current network meets this standard; and loading gauges are low by international standards (McKinnon, 2018). However, the UK network performs well with respect to axle loads: 85% of the current network is capable of accommodating axle loads of 22.5 tonnes, and therefore meets the European Commission's objective Trans-European Transport Network (TEN-T) objectives that all of the Core Freight Network (the portion of the complete European rail network comprising the most important nodes for freight) should be capable of accommodating axle loads of 22.5 tonnes by 2030 (Network rail, 2017).

Rail offers poorer connectivity than road. Road has a major advantage relative to rail in that the road network connects individual premises and the rail network does not. In order to use the rail network, freight operators must transport freight by road from its origin to the closest rail terminal where it begins its rail journey, and then from the terminal where it ends its rail journey to its final destination. The process of unloading and loading involves transaction costs that are not faced by road. Intermodal terminals provide one solution to reducing these transaction costs (though do not eliminate them entirely); however, in the UK the number of intermodal terminals is small (excluding ports, there were only 36 intermodal terminals in 2017; McKinnon, 2018).

Some population centres have no access to rail, though their number is small. Some commentators argue that the UK's rail network is inadequate. For example, Arup/AECOM argue that following closure of sections of the rail network between the 1960s and 1980s, the UK rail network currently 'has a significantly impaired capability compared to many developed European countries', and point out that the town of Washington in County Durham, a major automotive manufacturing location with a population over 50,000, has no direct rail access. However, the number of large towns with no direct rail access is small, comprising Oldham (Greater Manchester), Gosport (Hampshire), Dudley (West Midlands) and Newcastle-under-Lyme (Staffordshire); of these towns, only Washington, Oldham and Newcastle-under-Lyme are located in areas that generate or receive substantial freight volumes. It is therefore unlikely that absence of rail stations in some towns could the account for the failure of the rail network to achieve a higher share of freight transport.

3.4 Network utilisation

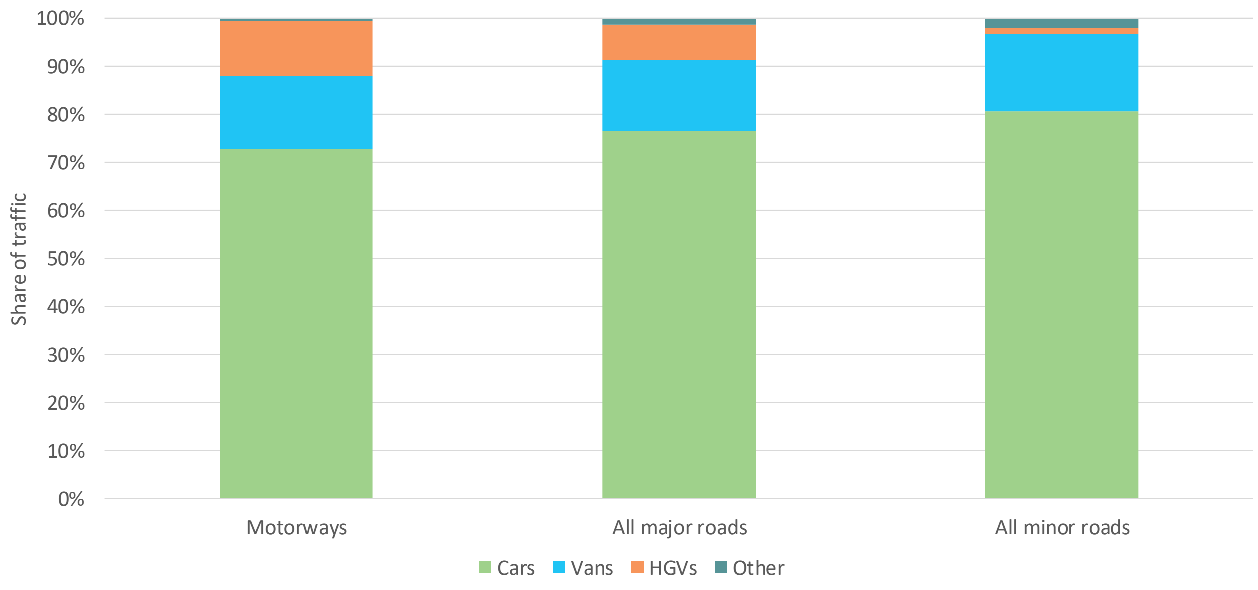
Network utilisation is an important determinant of congestion. While congestion is partly determined by the capacity of the road network and the overall quantity of traffic, it is also partly determined by efficiency with which traffic uses the network, in terms of the time of day and specific routes.

It is likely that passenger transport is the primary driver of congestion. Passenger transport is responsible for the majority of network use, and predominantly uses more congested roads. Figure 25 shows the share of traffic by mode on motorways, major roads and minor roads. Cars account for the majority of traffic on all types of road (73% of the traffic on motorways, 76% on major roads and 81% on minor roads). Further, travel on motorways (where congestion is lowest) accounts for only 32% of car traffic, while travel on other major and minor roads (where congestion is highest) accounts for 68% of car traffic. Passenger transport is also more concentrated around peak times. Figure 26 shows the share of traffic for all modes, and for cars, vans, and HGVs, in each hour during weekdays. On weekdays, there is minimal traffic during the night; peak times for all traffic (when congestion is at its highest) occurs in the morning between 8am and 10am, and again in the evening between 5pm and 6pm; and there is a lull in the middle of the day between the two peaks. The profile of car traffic closely matches that for all traffic, with minimal traffic during the night; and similar peaks and mid-day lull. The evening peak for car traffic is more pronounced than for overall traffic, indicating that car traffic contributes disproportionately to congestion at these times.

Freight transport contributes less to congestion, and is less exposed to its impacts. In contrast to passenger transport, freight transport is responsible for only a small share of network use, and predominantly uses less congested roads. Figure 25 shows that HGVs account for the minority of traffic on all types of road (11% of the traffic on motorways, 7% on major roads and only 1% on minor roads); and that a greater share of HGV travel occurs on less congested motorways, and a smaller share on more congested major and minor roads. Freight transport is also less concentrated around peak times. Figure 26 shows that relative to other modes, HGVs have greater levels of traffic during the night, and no morning or evening peaks or mid-day lull; instead, traffic levels are relatively uniform between 8am and 5pm. It is clear that HGV traffic contributes disproportionately less to congestion during the morning and evening peak.

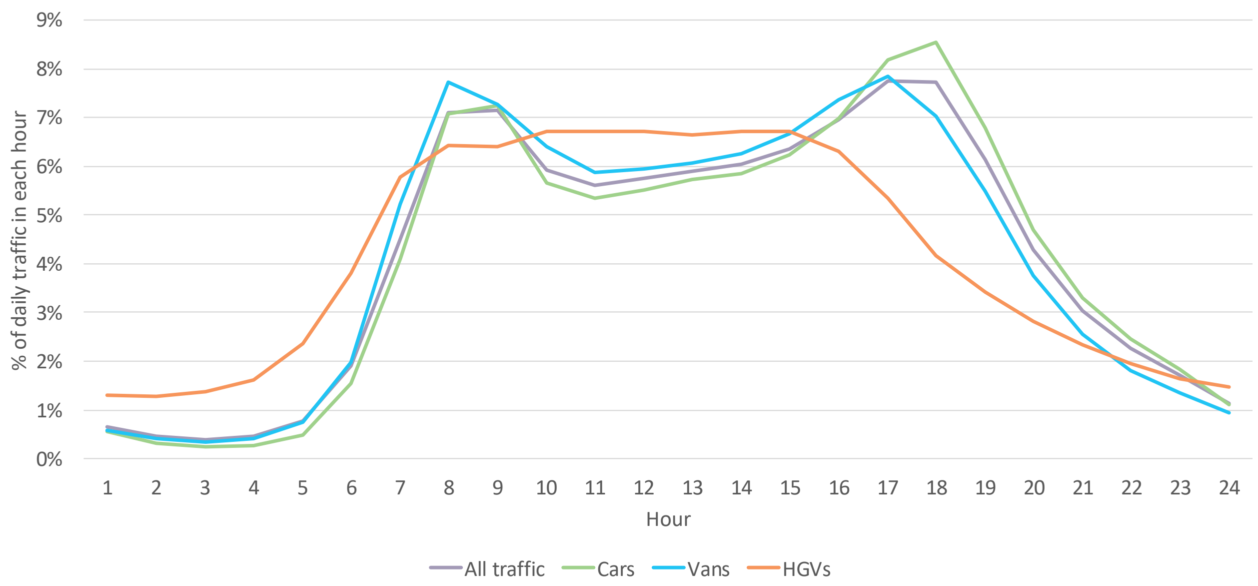
Vans contributes significantly to congestion, though their role in freight is unclear. Vans are responsible for a significant share of network use, and predominantly use more congested roads. Vans account for around a 15% of traffic on motorways, and around 30% on major and minor roads; and van transport, like cars, is concentrated around peak times; indeed, the morning peak in van traffic is more pronounced than the peak for cars.

Figure 25. **HGVs account for the minority of traffic, and predominantly use less congested roads**



Source: *Vivid Economics, Department for Transport*

Figure 26. **HGVs contribute less to peak traffic than other modes**



Source: *Vivid Economics, Department for Transport*

In passenger transport, a range of options are available to reduce congestion. In passenger transport, congestion could be reduced through some degree of shift to public transport or active travel (walking and cycling); varying travel times to avoid the most congested periods; selecting less congested routes; or selecting alternatives to travel. Analysis by the Department for Transport in 2004 based on the National Travel Survey indicated that around 20% commuters who travel by car or motorcycle in peak hours would find it relatively easy to change either mode or time of travel because alternatives to their current travel are capable of fitting in with their lifestyle needs (Department for Transport, 2004; unfortunately, more recent National Travel Survey figures are not available). There is also likely to be scope to increase car occupancy; currently 71% of cars and vans in the morning peak period in cities have a single occupant, suggesting that efforts to increase car occupancy (for example, through car-sharing) could have a material impact on congestion.

In freight transport, options to reduce congestion are more limited, but include modal shift to rail and varying travel times. The potential to shift some road freight to rail is discussed in Section 3.2. Arup/AECOM (2016) estimated that a package of measures could shift around 20% of road freight to rail, though the costs of achieving such a shift are poorly understood. In principle, there is also scope to reschedule deliveries to allow a higher level of night-time HGV traffic. Figure 26 shows that 18% of HGV travel already occurs during the least congested period between 8pm and 6am. This level reflects a significant shift in scheduling over the period 1985-2005, when the share of HGV travel occurring during this window doubled from around 9% (McKinnon, 2018). However, this share has not increased further over the last decade, suggesting that the barriers to greater shift in travel times are more significant. Barriers such as noise associated with night-time deliveries in urban areas are likely to be a limiting factor.

Utilisation of the road network is highly inefficient, leading to high levels of congestion. Road pricing could be an effective policy instrument to manage congestion. Road user charging is an economic instrument to encourage drivers to make more efficient use of the existing road network by imposing a charge that reflects the full social costs of their travel choices. Road pricing has the potential to reduce congestion by encouraging alternative travel choices; these may include a change in the time of travel, the mode of travel, the route selected or the level of vehicle occupancy. A modelling study on the impact of a road pricing scheme in the UK found that road pricing could reduce congestion by 50%, with only a 2% reduction in car travel (Department for Transport, 2006). However, empirical evidence on the impact of road pricing schemes is limited and mixed. The London Congestion Charge initially reduced congestion by 30% following its introduction in 2002, but congestion subsequently rose, and by 2006 was only 8% lower than pre-2002 levels. Other schemes have had a greater impact: Singapore's Electronic Road Pricing scheme reduced car traffic in the central business district by 73%; Stockholm's trial congestion tax reduced traffic by 22%, and was subsequently made permanent. To date, no country has a national road pricing scheme in place.

A 50% reduction in congestion could deliver over £3 billion per year in freight cost savings. Section 2.3 estimated the cost of the road freight system at around £38 billion per year, or 2% of GDP, and estimated that the costs of freight congestion could account for over £6 billion of this value (or around 0.3% of GDP). A 50% reduction in congestion could therefore reduce the cost of road freight by over £3 billion per year.

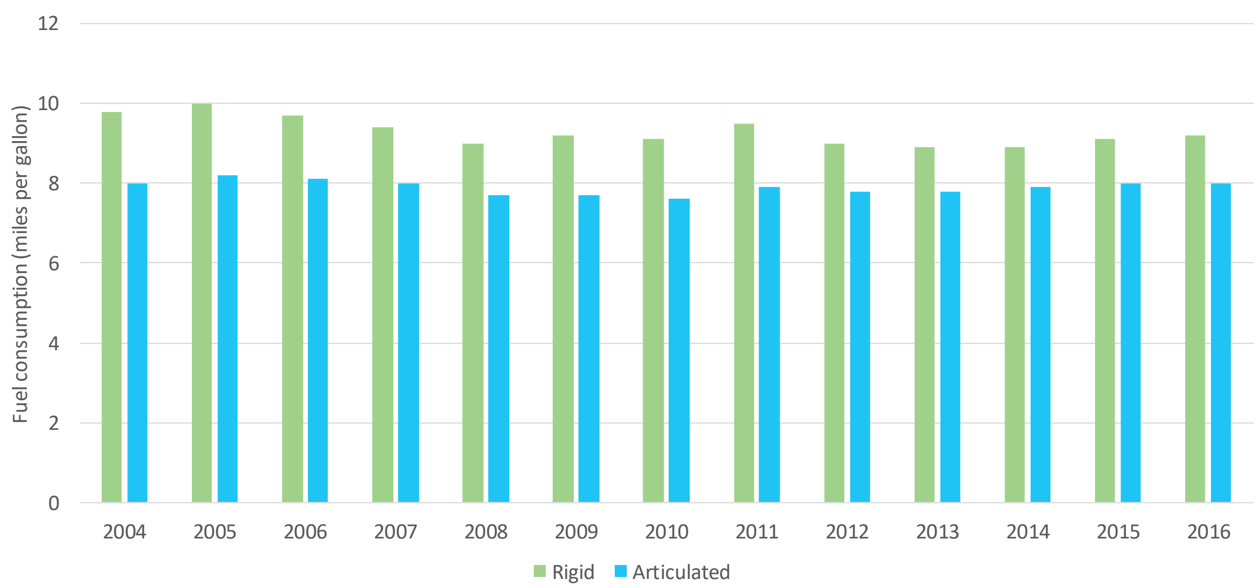
Recently, technology has begun to improve the efficiency of road network utilisation. Active traffic management is an approach to increase the effective capacity or the road network at peak times. It does this by temporarily allowing use of hard shoulders for traffic, and the use of variable speed limits to smooth traffic flows, and 'ramp metering' to regulate the entry of traffic onto congested roads. Active traffic management uses technology to monitor traffic levels and identify the speed limit that will deliver the smoothest traffic flow to reduce the severity of delays. Active traffic management has been in place in the UK since 2006 (the M42 motorway); following an evaluation of this scheme several subsequent schemes have been implemented under the 'Smart Motorway' system, and several new schemes are currently under development.

3.4.1 Transport fuel and powertrain technology

Diesel is the dominant fuel in road freight. In the UK, and in all other European countries, almost 100% of road freight vehicles are fuelled by fossil fuels. Of these, the most common vehicle type is diesel; in the UK 96% of vans and 99% of trucks are diesel vehicles.

There has been no discernible improvement in the fuel efficiency of HGVs over the last decade. Figure shows the fuel consumption of rigid and articulated and HGVs in the UK over the period 2004-2016. Fuel consumption of rigid vehicles appears to have decreased slightly over this period, while fuel consumption of articulated trucks remains unchanged.

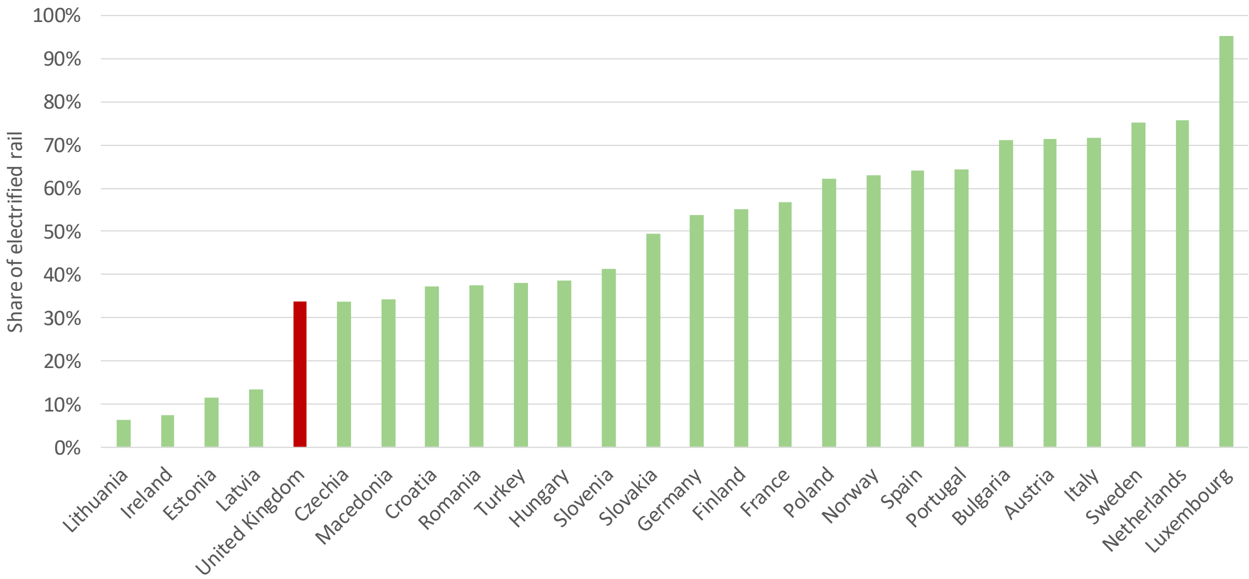
Figure 27. **There has been no discernible improvement in the fuel efficiency of HGVs over the last decade**



Source: *Vivid Economics, Department for Transport*

Diesel is also the dominant fuel in rail freight. Figure 28 demonstrates that the UK has one of the lowest shares of electrified rail among European countries: only 34% of the UK rail network is electrified, compared to 54% in Germany, 57% in France, 72% in Italy, and 95% in Luxembourg. Furthermore, the share of rail freight that is carried on electric lines appears to be significantly lower than this figure. The Office of Rail Regulation provides estimates of petrol and diesel consumption for passenger and freight rail transport; adjusting for the greater efficiency off electric locomotives relative to their diesel counterparts, the data suggest that while 64% of passenger rail transport occurs on the electrified share of the network, the equivalent share is only 9%. Other estimates are consistent with this figure (for example, AECOM/ARUP, 2016).

Figure 28. **The UK has one of the lowest shares of electrified rail among European countries**



Source: *Vivid Economics, Eurostat*

Deep decarbonisation of road and freight by shifting to alternative fuelled vehicles is an urgent priority. Section 3.3 argues that if unabated, CO2 emissions from freight transport could make up around 20% of allowed emissions in 2050, and that near- or full-decarbonization of freight transport is likely to be needed to meet the UK's Climate Change Act. In this context, a shift to alternative fuelled vehicles in both road and rail freight is an urgent priority.

3.5 Vehicle sizes

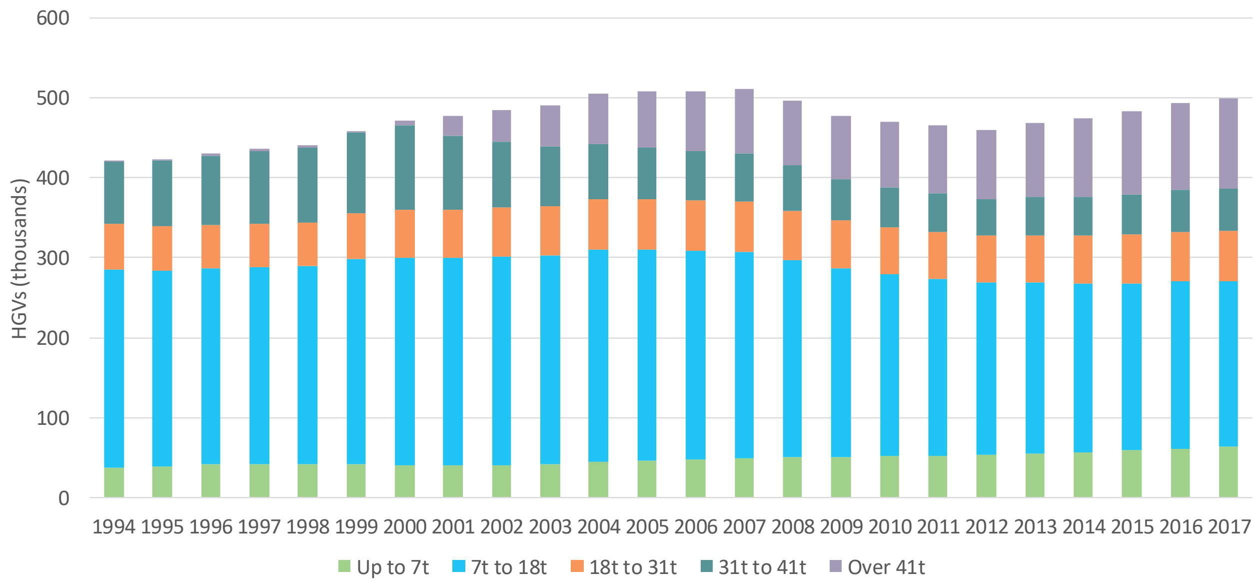
Provided they are fully utilised, larger vehicles offer cost and environmental advantages. While larger vehicles consume more fuel per kilometre, they can consume less fuel per tonne of freight carried, provided they are adequately loaded.

An overall trend in the average size of UK freight vehicles is difficult to establish. At the larger end of the fleet there is a trend towards larger HGVs. However, at the smaller end of the fleet there appears to be a trend towards vans, though this is poorly understood.

3.5.1 HGVs

The UK freight system has taken advantage of the cost and environmental benefits offered by larger vehicles. Very large HGVs (with a gross vehicle weight between 40-44t) were introduced in 2001. Figure 29 shows that these vehicles made up 22% of the vehicle fleet by 2017.

Figure 29. **By 2017 44 tonne trucks made up 22% of the HGV fleet**

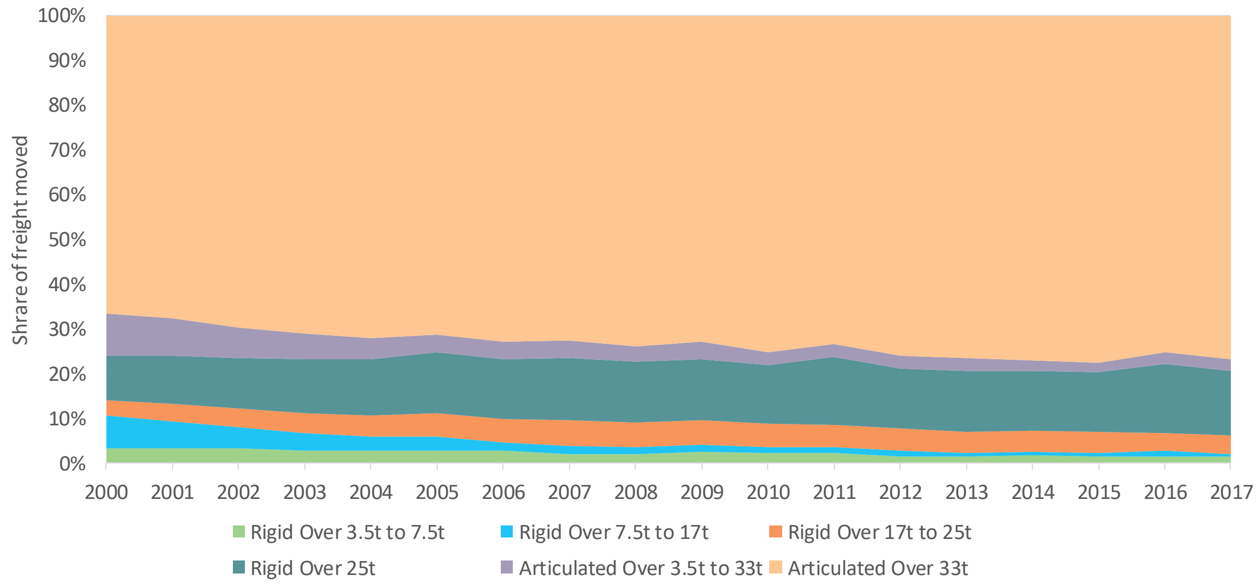


Note: *Smaller HGVs include vehicles not used for freight, such as refuse disposal, street cleaning, concrete mixing vehicles.*

Source: *Vivid Economics, Department for Transport*

As a result, freight is increasingly carried in larger HGVs. Figure 30 shows how the share of freight moved in different types of HGV has changed over the period 2000-2017. Overall, freight tends to be carried in larger vehicles. The share of freight carried in smaller rigid HGVs (under 17 tonne) decreased from 11% in 2000 to only 2% in 2017; while the share of freight carried in larger rigid HGVs increased from 13% to 18% over the same period. The share of freight carried in smaller articulated HGVs (under 33 tonne) decreased from 9% in 2000 to only 3% in 2017; while the share of freight carried in larger articulated HGVs increased from 67% to 77% over the same period. As a shift to larger HGVs can be observed across all vehicle types, this shift is not entirely due to the introduction of 44 tonne trucks. However, the largest increase in the volume of freight carried occurred in larger articulate HGVs, which includes the suggesting that the introduction of 44 tonne trucks had a significant impact on the growth of freight carried in this size class.

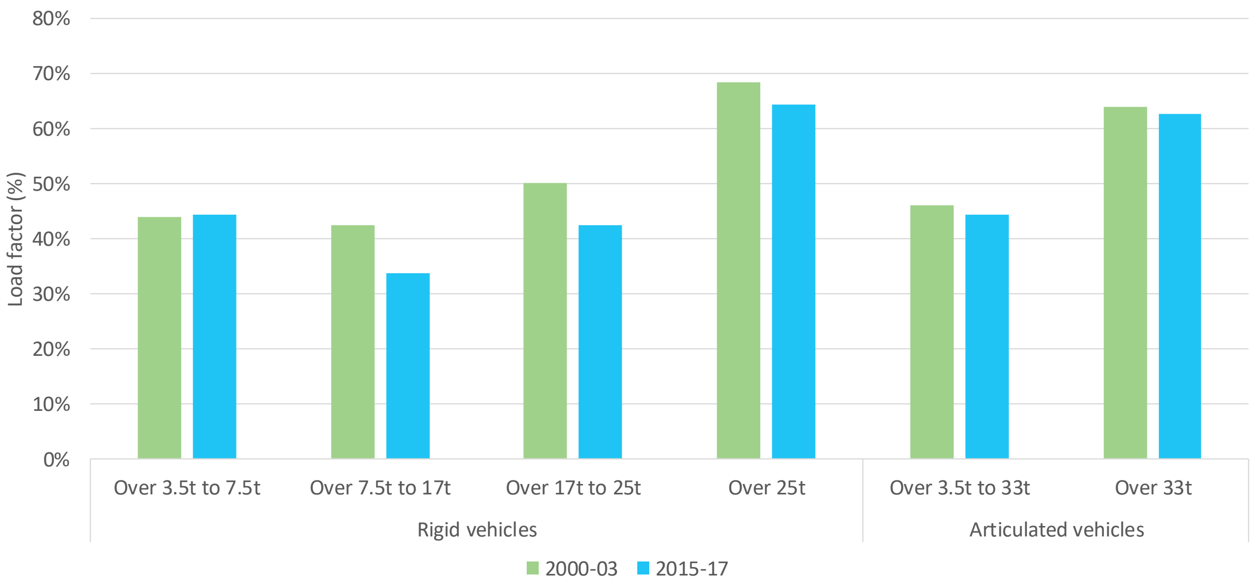
Figure 30. **The share of freight carried in large vehicles has increased significantly since 2000**



Source: *Vivid Economics, Department for Transport*

Increases in HGV size do not seem to have reduced the operational efficiency of the HGV fleet. Some commentators are concerned that increases in HGV size could actually increase energy consumption and CO2 emissions, given their greater fuel consumption, if the increase in HGV size results in higher levels of part-loading. However, analysis of the utilization of larger HGVs in the UK suggests that this has not been the case. Figure 31 shows the level of empty running and the average load factors for six types of HGV (four types of rigid HGVs, and small and large articulated HGVs). Over the period 2000-17, during which 44 tonne trucks were introduced, load factors for large articulated HGVs (including the 44 tonne trucks) did decrease around 2%. However, over the same period load factors for smaller HGVs decreased much more significantly: among rigid vehicles load factors decreased 20% in the 7.5-17t size class, 15% in the 17-25t size class, and 6% in the over 25t size class; and load factors for small (3.5-33t) articulated trucks decreased 4%. The only size class with a rise in load factors was small rigid trucks in the 3.5-7.5t size class (a 1% rise). The smaller reduction in load factors in large articulated trucks than across the majority of other size classes does not support the hypothesis that increases in HGV size has resulted in higher levels of part-loading.

Figure 31. **Load factors decreased across the majority of truck size classes over the period 2000-17**



Source: Vivid Economics, Department for Transport

Our overall assessment is that the impact of further increasing the size of HGVs is highly uncertain. There is good theoretical and empirical evidence that larger HGVs can offer cost and environmental advantages. However, beyond a certain size, or certain market share, it is likely that opportunities to consolidate loads into larger HGVs will be limited. Infrastructure constraints, such as the dimensions of tunnels, bridges and other elements of road network infrastructure, present a barrier to the widespread take up of larger HGVs. Further, it is possible that increasing the size of HGVs could result in a diversion of freight from rail to road, reducing the efficiency of rail freight and therefore the overall efficiency of the freight system. The cost and environmental advantages will depend on the extent to which freight delivery needs offer continued scope for greater load consolidation, and to which larger vehicles can be accommodated without significantly upgrading or replacing current infrastructure; and to which this can be achieved without increasing costs of rail freight.

Reducing restrictions in the size of HGVs is not an urgent policy priority. A shift to alternative fuelled vehicles is an urgent priority and this would erode the environmental benefits of larger HGVs. Current regulations on the maximum size of HGVs have been motivated by concerns about infrastructure, safety and public disapproval. The economic benefits of larger HGVs are highly uncertain and it is far from clear that the benefits would outweigh these concerns.

3.5.2 Vans

Van use is growing very rapidly in the UK. Van traffic grew 20.7% between 2007-17 compared to a 6.4% decline in HGV traffic over the same period. Over the last twenty years growth in van kilometres (71%) has outpaced growth in cars (13%) and HGVs (2%). Van traffic accounts for 15% of total motor vehicle traffic compared to 9% in 1997. Unfortunately, current statistics do not provide enough detail to estimate the contribution of vans to overall freight traffic.

Vans may disproportionately contribute to congestion. Section 3.4 describes the use of the road network by vans. Vans are responsible for a significant share of network use, and predominantly use more congested roads, and van transport is concentrated around peak times.

However, trends in the use of vans for freight are poorly understood. Data on the share of freight in van traffic is not available. DfT collected data on van use until 2008; the results of the last survey indicated that in 2008 the delivery and collection of goods accounted for only 26% of van mileage, with transport of equipment accounting for the majority (53%) of mileage and other uses (private and domestic use, and providing transportation services) accounting for the remaining 27%. While van traffic has grown around 20% since the survey was carried out, it is not known whether this growth has been driven by increasing use of vans for freight, or by other uses. While the increase in van use is commonly attributed to the growth in online retail deliveries, analysis indicates that this is not the case. The Committee on Climate Change estimated delivery of online purchases account for 8% of total van traffic; this is consistent with a study for the RAC foundation, which estimated that 8% of the total vans on the road are engaged in parcel and packet delivery (Braithwaite, 2017).

Further work is needed to understand the role of policy in driving efficient use of vans within the freight system. It is possible that the increase in van use in recent years is due to a shift in freight from HGVs to vans, and is therefore driving an unnecessary increase in vehicle km. If this is the case then there may be a role for policy to align incentives to manage van use and limit its impacts of freight costs, CO2 emissions and congestion. Further work is therefore needed to understand the drivers of van use; a new Department for Transport survey, with the results expected to be published in 2019, may improve understanding in this area (Committee on Climate Change, 2018).

3.5.3 Trains

Increasing the capacity of freight trains could also offer cost and environmental benefits. As with road vehicles, an increase in the size of freight trains can reduce the number vehicle movements and quantity of fuel needed to transport freight. KPMG suggest that the biggest rail freight efficiency gain to date has come from more efficient utilisation of the rail network driven by longer and heavier trains (Rail Delivery Group, 2009), though it is difficult to substantiate this claim. At present, limits to train capacity are driven by legal restrictions on the maximum length of trains, and maximum axle weight. For lower density products, such as containerised shipments, train length is the limiting factor. Train length is itself limited by station lengths; the Department for Transport has sets an objective that 775 metre train length should be the design standard for new freight terminal developments and enhancement of existing terminals on the Strategic Freight Network (the portion of the UK rail network comprising the most important freight routes) (Department for Transport, 2009). For dense products, such as metals, metal products and construction materials, the maximum axle weight that the track can accommodate is the limiting factor. At present, 85% of the current network is capable of accommodating axle weights of up to 22.5 tonnes. Increasing train capacity for dense products would require substantial investments in new infrastructure to accommodate greater axle weights.

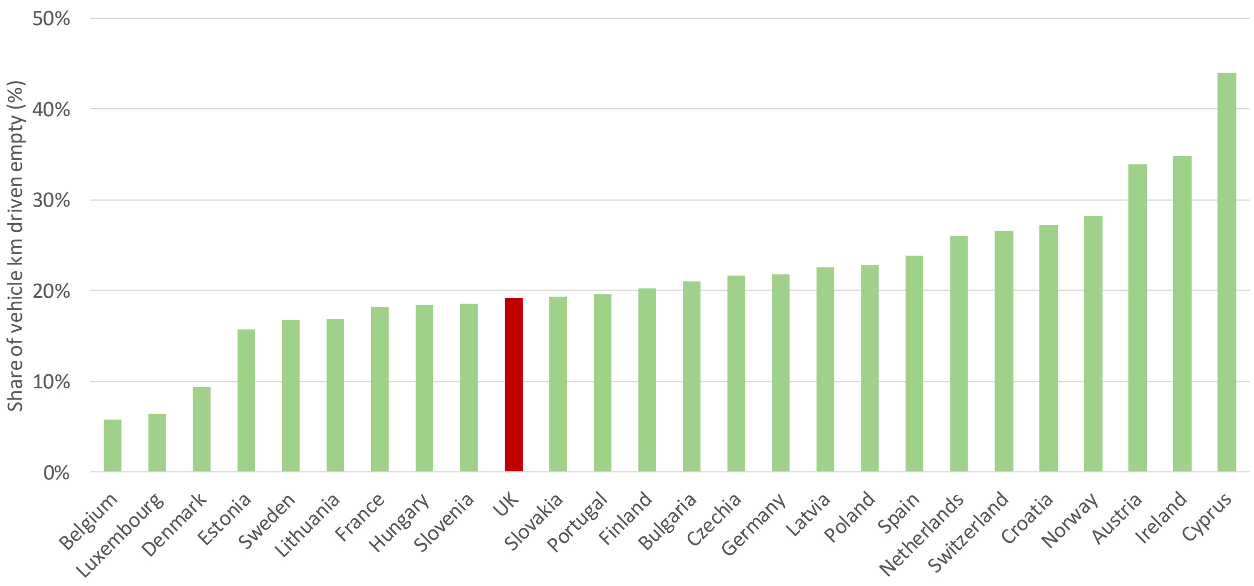
Much of the UK rail network is relatively poorly suited to freight. The Department for Transport sets an objective that the Strategic Freight Network (the portion of the UK rail network comprising the most important freight routes) should a have a loading gauge of at least W10 standard, i.e. capable of accommodating deep sea containers (Department for Transport, 2009). At present, only 16% of the current network meets this standard; and loading gauges are low by international standards (McKinnon, 2018). However, the UK network performs well with respect to axle loads:, and therefore meets the European Commission's objective Trans-European Transport Network (TEN-T) objectives that all of the Core Freight Network (the portion of the complete European rail network comprising the most important nodes for freight) should be capable of accommodating axle loads of 22.5 tonnes by 2030 (Network rail, 2017).

3.6 Operational efficiency

3.6.1 Empty running

UK levels of empty running are moderate by European standards. Figure 32 shows the level of length empty running in road freight in the UK and other European countries. The highest level of empty running is observed in Cyrpus (44%) and the lowest in Belgium (6%). While there does not seem to be a simple explanation for levels of empty running, the countries with the smallest levels tend to be small: after Belgium, Denmark, and Luxembourg have the lowest levels of empty running among European countries. Levels of empty running in the UK are around 20%; this is lower than in the majority of European countries, including Spain and Germany; but higher than some others, including France and Sweden.

Figure 32. **UK levels of empty running are moderate by European standards**



Source: Vivid Economics, Department for Transport

Empty running in the UK appears to be increasing slightly. Figure 33 shows the level of empty running in UK HGVs over the period 2000-2017. Empty running has increased slightly over this period; around 27% of HGV km were driven by empty HGVs in 2000, and 30% by 2017, though there has been significant variation in empty running over this period and there is not a clear upward trend.

Figure 33. **Empty running has increased slightly over the period 2000-2017.**

Source: *Vivid Economics, Department for Transport*

It is likely that some level of empty running is efficient, and even inevitable. Empty running occurs for a number of reasons; for example:

- **Geographical mismatch of freight supply and demand.** In some areas, such as manufacturing locations, the volume of outbound freight is greater than the volume of inbound freight, while in others (such as retail locations) the reverse is true.
- **Time constraints:** in the event that an outbound load is matched by a comparable inbound load, the delivery and pickup times of the two loads may not allow backhauling. If the pickup time of the inbound load is scheduled before the delivery time of the outbound load then the backhaul is not possible; and if the pickup time of the inbound load is scheduled significantly later than the delivery time of the inbound load then vehicle and driver must wait, and the cost of the idle vehicle and driver time may outweigh any benefits in reduced empty running.
- **'Own account' freight.** While around 70% of road freight is moved by public haulage operators, who carry goods for other companies, the remaining 30% moved is 'own account', i.e. moved by the owner of the shipment (for example, a manufacturer or retailer). The potential backhauling opportunities available to 'own account' operators are restricted to the firm's own shipments, and are therefore likely to be significantly more limited than those available to public haulage operators.

However, evidence suggests there are opportunities to reduce empty running. 'Backhauling' refers to the loading of a vehicle on the return journey to reduce empty running. Two studies of backhauling in the UK indicated that there are some small opportunities to reduce empty running:

- McKinnon and Ge (2006) analysed over 20,000 HGV trips in the grocery distribution sector, of which 9,000 were empty, to identify empty trips that were potentially suitable for backhauling. The analysis excluded journeys that were under 100km long (given evidence that backhauling opportunities on short journeys are harder to justify), journeys where the where the vehicle used for the outbound journey did not have the required weight or volume for the backhaul, or where it was a specialised vehicle not suited to the backhaul. The study concluded that of the 9,000 empty journeys analysed, around 2% could have been eliminated with backhauling.

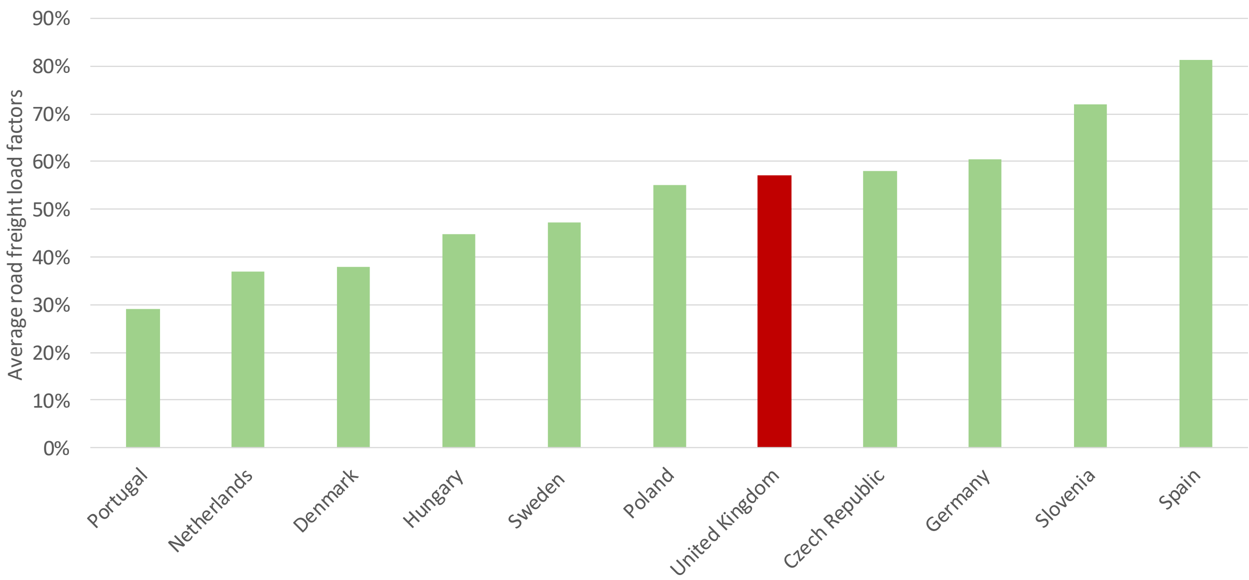
- In the ‘Starfish’ project Palmer and McKinnon (2011) analysed trips in the retail sector and identified a potential opportunity to reduce vehicle km by 8% through backhauling. However, achieving these backhauling opportunities required a relaxation of time constraints to allow coordination of delivery and pickup windows.

Our overall assessment is that efforts to reduce empty running are unlikely to deliver a step change in freight efficiency. The barriers to further reducing levels of empty running and the limited opportunities for backhauling identified to date suggest that at present it would be very challenging to reduce empty running significantly below current levels of around 30%. This assessment is consistent with a scenario developed by the Centre for Sustainable Road Freight (CfSRF) to inform the Committee on Climate Change’s advice on reducing CO2 emissions to the fifth carbon budget (2028-2032); the (CfSRF) scenario included a 5% reduction in CO2 emissions (and therefore a comparable reduction in vehicle kilometres) due to backhauling and its resulting reduction in empty running.

3.6.2 Part-loading

UK load factors appear moderate by European standards. Unfortunately, comprehensive data on load factors in European road freight is not available; the European Commission did collect data for a small number of countries, but ceased collection in 2008. The data available is therefore of poor quality, and covers 2008 for some countries, and earlier years for others. Based on this data, the lowest average load factor (highest level of part-loading) is observed in Portugal (29% load factor) and the highest load factor (lowest level of part-loading) in Spain (81%). The drivers of the variation in load factors are not clear. Load factors in the UK in 2007 were around 57%; this is lower than in Spain and Germany; but higher than others, including Netherlands and Denmark.

Figure 34. **UK load factors are moderate by European standards**



Note:	*Data is for 2008*
Source:	*Vivid Economics, Eurostat*

Load factors in the UK has been broadly constant over time. Figure 35 shows the load factors level of UK HGVs over the period 2000-2017. Load factors have remained broadly constant over this period, at around 60%; a small drop in load factors was observed in the early 2000s, but load factors were back to their 2000 level by 2011, and have remained close to this level since.

Figure 35. **Load factors have been broadly constant over time**

Source: Vivid Economics, Department for Transport

As with empty running, it is likely that some level of part-loading is efficient, and even inevitable. Part-loading occurs for several reasons; for example:

- **Information and analytical requirements.** The information gathering and analytical requirements of matching loads arising from multiple origins to freight vehicles, particularly given variation in required delivery times, are substantial. Information needed to facilitate widespread collaboration across companies includes a set of weight, volume and delivery time data, and analytical needs include the ability to calculate an set of freight journeys that could minimise the total cost of transporting the loads (and therefore reducing part-loading to more efficient levels) while maintaining reliability in deliveries.
- **Cultural barriers and competition concerns.** Evidence suggests businesses are generally averse to sharing vehicles with competitors, due to the risk of revealing intelligence about their products or operations. More broadly, businesses are simply unused to collaborating with others in freight transport, and may be unlikely to seek these opportunities without a shift in business culture, and potentially larger cost savings than the majority of collaborative opportunities present.
- **'Own account' freight.** This barrier was discussed in the context of empty running, above. The potential collaboration opportunities available to 'own account' operators is restricted to the firm's own shipments, and are therefore likely to be significantly more limited than those available to public haulage operators.
- **Just-in-time delivery.** Over time, retailers have increasingly demanded smaller deliveries with shorter lead-times and more stringent delivery times (just-in-time delivery). The impact of this trend has been to reduce loads, and therefore reduce vehicle loading. While in principle the reduction in loading could be mitigated by combining part loads into a single load ('synchronised consolidation'), in practice this can be difficult due to the stringency of delivery times, the challenge

of matching part-loads with similar delivery times, and the time taken to load and unload part-loads at multiple premises. In the context of just-in-time delivery, congestion is also a barrier to consolidation, as it increases the time taken to travel between multiple premises for loading or unloading.

- **Demand fluctuations.** In principle, a freight operator faces strong incentives to invest in vehicles that are appropriately sized for the loads it will carry, as part-loading implies greater expenditure on the vehicle and the fuel relative to carrying the same load in a smaller vehicle. However, where demand fluctuates and there is variation in the size of load that must be carried, it may not be cost-effective for a freight operator to invest in a range of vehicles to address different load sizes. In this case, the operator will invest in a vehicle stock that is most appropriate for the majority of journeys, such that there will be some spare capacity on the average journey.
- **Density of loads.** Load factors are measured by the weight of the load, rather than volume. However, there is evidence that the density of many loads is low, such that freight vehicles are more fully loaded (in terms of volume) than their load factors would suggest. According to data from the Continuing Survey of Road Goods Transport (CSRGT) on the proportion of HGV tonne-kms subject to weight and/or volume constraints in 2010, although only around 37% of freight (measured in tonne km) was carried in fully laden vehicles when measured by weight, a further 25% was carried in fully laden vehicles when measured by volume. These figures suggest that fully eliminating part-loading (i.e. increasing load factors to 100%) is physically impossible as around 25% of loads will 'cube out' before they 'weigh out'.
- **Geographical mismatch of freight supply and demand.** Even if an outbound journey is fully loaded, it may be difficult to fully load the vehicle on the backhaul.

However, evidence suggests there are some limited opportunities to reduce part-loading. 'Synchronised consolidation' refers to combining part loads moving between origin and destination zones into a single load with a higher load factor. A number of studies of synchronised consolidation in the UK indicate that there are some limited opportunities to reduce part-loading:

- A number of successful bilateral collaboration initiatives have yielded a reduction in freight transport demand; a collaboration initiative by Kimberly-Clark and Kelloggs resulted in a reduction in CO2 emissions by 270 tonnes per year; while an initiative by Nestle and United Biscuits resulted in a 250 tonne per year reduction (McKinnon, 2018).
- Palmer and McKinnon (2010) analysed transport data collected from 27 large fast-moving consumer goods (FMCG) companies to identify opportunities for collaboration. The analysis identified opportunities for collaboration to increase load factors and offer CO2 savings of up to 20%. Following the study, a number of participating companies developed collaborative arrangements, suggesting that opportunities existed to realise cost savings
- In the 'Starfish' project Palmer and McKinnon (2011) identified opportunities for synchronised consolidation capable of reducing total freight vehicle km by roughly 1%.

3.6.3 Implications for policy

Empty running and part-loading are imperfect indicators of operational efficiency. Very high levels of empty running and part-loading are indicators that operational efficiency is poor, and vice-versa. However, levels of empty running and part-loading are partly determined by geographical differences in supply and demand for freight, challenging delivery schedules and a range of other factors unrelated to operational efficiency. It is not possible to determine from today's levels of empty running and part-loading whether a significant improvement in operational efficiency is needed.

Our overall assessment is that efforts to reduce part loading are unlikely to deliver a step change in freight efficiency. As with empty-running, the barriers to further reducing part loading the limited opportunities for increased collaboration identified to date suggest that a significant improvement in improve load factors would be very challenging to achieve. This assessment is consistent with the CfSRF scenario for the Committee on Climate Change, which included a 1% reduction in CO2 emissions (and therefore a comparable reduction in vehicle kilometres) due to synchronised consolidation and its resulting reduction in part-loading.

Further, it is not clear that Government intervention is needed. There is little evidence of major market failures preventing freight operators from reorganising their operations to reduce levels of empty running and part-loading. The freight sector is subject to intense commercial pressures, and incentives to achieve high levels of operational efficiency and minimise freight costs are strong. Further, given the urgent priority a shift to alternative fuelled vehicles, the benefits of Government intervention are likely to be limited. Reducing levels of empty running and part-loading cannot achieve near- or full-decarbonization of freight transport; and a shift to alternative fuelled vehicles would erode the environmental benefits of intervention.

4 Potential step-change technologies

Key messages

- **A complete shift to alternative fuelled vehicles would eliminate tailpipe greenhouse gas and air quality pollutant emissions in road freight.**
- **Connected and autonomous vehicles could substantially reduce road freight costs by eliminating the need for a driver.**
- **Robotics and automation could substantially reduce warehousing costs by automating currently labour-intensive tasks.**
- **Unmanned aerial vehicles (drones), digitalisation and data science, delivery droids and 3D printing are less likely to deliver a step change in freight efficiency**

A range of technologies are likely to emerge in the freight system in future. This section identifies the technologies likely to emerge in the freight system, and assesses the potential for each technology to deliver 'step-change' improvements to freight efficiency. Technologies assessed comprise alternative fuelled vehicles, unmanned aerial vehicles (drones), connected and autonomous vehicles, robotics and automation, digitalisation and data science, delivery droids and 3D printing. We separately consider the potential for each technology to deliver a significant improvement in the cost, speed and reliability, environmental impact, and resilience of the freight system. We then assess the likely severity of any barriers to deploying that technology and the prospects for that technology to emerge at scale.

4.1 Alternative fuelled vehicles

Alternative fuels for freight vehicles include electricity and hydrogen. Both battery electric vehicles and hydrogen fuel cell vehicles are electric in the sense that motive power is provided by an electric motor. In battery electric vehicles, the motor is supplied with electricity by a battery. Overhead (catenary) electric wiring could also be used to provide electricity, and reduce the need for long-distance trucks to carry large batteries. In hydrogen fuel cell vehicles, the motor is supplied with electricity by a fuel cell, which converts hydrogen into electricity. Low-carbon routes to hydrogen production include electrolysis from renewables; or steam methane reforming of natural gas combined with carbon capture and storage.

Electric vehicles are beginning to emerge in passenger transport. Over the last decade, an early adopter market in electric cars and vans has emerged in passenger transport in the UK. Sales have increased from under 1,000 in 2010 to 48,000 in 2017, and electric vehicles now have a market share of almost 2% of new cars and vans. In a number of other countries, take up is stronger; in Norway, new electric cars have a market share around 40% (IEA, 2018).

While alternative fuel freight vehicles are lagging behind passenger vehicles, developments are underway. Product are being launched for both battery electric and hydrogen fuel cell vehicles, and pilot-scale fuelling infrastructure is also under development:

- **Electric vehicles.** A number of product launches are underway or planned. US electric vehicle manufacturer Tesla has announced the launch of its long-haul truck Semi in 2020, with a shorter-range (480km) and a longer-range (800km) model; UPS, PepsiCo and others have reportedly placed

340 orders to date. Germany manufacturer Mercedes-Benz launched a 200 km range electric truck in 2018; to date, at least 10 have been delivered to logistics firm Hermes. Further product launches have been announced by BYD, Freightliner, VDL Groep/DAF and Renault.

- **Catenary electric truck infrastructure.** If major roads were equipped with catenary overhead wiring, battery electric vehicles could travel long distances without the need for a very large battery. Trials of catenary electric trucks have been carried out in Germany and California. In Germany, the eHighway field trial involves 6 km of overhead catenary infrastructure supported by a €14 million subsidy from BMU, the German Federal Minister for the Environment, Nature Conservation, and Nuclear Safety. In California, the South Coast Air Quality Management District, in collaboration with Siemens and Volvo, is trialling a one-mile highway catenary system at two ports in Los Angeles and Long Beach.
- **Hydrogen fuel cell vehicles.** US truck manufacturer Nikola Motor Company has announced the launch of a large hydrogen truck on the US market in 2021; US Xpress and Budweiser have placed 800 orders to date. Nikola is also launching a hydrogen-powered semitrailer truck on the European market (Energy Transitions Commission, 2018). Hyundai has announced the launch of a large truck in 2019; Swiss retailed Coop has reportedly placed 1,000 orders to date. Demonstrator vehicles have also been trialled by Toyota and Renault.
- **Hydrogen fuelling infrastructure.** Although not targeted at freight vehicles, a hydrogen fuelling infrastructure is emerging in a number of European countries, with 52 fuelling stations deployed to date in Germany and smaller numbers elsewhere.

While currently expensive, strong cost reductions are expected strong over the long term. Electric vehicles are inherently energy-efficient, and battery costs are decreasing rapidly:

- **Efficiency.** Electric motors (used in both battery electric vehicles and hydrogen fuel cell vehicles) possess a significant efficiency advantage relative to the internal combustion engine; electric motors are around 95% efficient, while internal combustion engines are only around 40% efficient, with much of the fuel wasted in production of heat or sound.
- **Rapid battery cost reductions.** Battery costs have decreased by around 20% per year in recent years, from around $1,000/kWh in 2010 to around $200/kWh in 2020 (BNEF, 2018), as batteries are produced in ever greater volumes and new innovations in battery production reach the market. Volumes are projected to increase significantly, driven by both market uptake in the passenger section and large-scale state initiatives; China, for example, plans to deploy a million electric buses by 2025. Over US$14 billion of battery-related investments are currently targeting improved energy density, through the development of new battery chemistries such as silicon-based anodes, solid-state electrolysis and advanced-cathode chemistries. As a result of further deployment and innovation, the Energy Transitions Commission estimate that the cost of lithium ion batteries will continue to fall, decreasing below US$100/kWh by 2025.

Given the inherent efficiency advantages of electric vehicles and the strong prospects for further battery cost reductions, electric freight vehicles are expected to reach cost parity with internal combustion engine vehicles over the next decade. For example, the Energy Transitions Commission estimate that the full cost of BEV purchase and lifetime operation will be less than the cost of diesel ICEs by 2030, even if no excise duty (such as fuel duty) is imposed on the diesel fuel.

Alternative fuelled vehicles could substantially reduce the environmental impact of the freight system, and improve resilience. Improvements in cost and speed and reliability are likely to be limited.

- **Cost.** With further innovation, alternative fuelled trucks are expected to be broadly cost-neutral relative to diesel trucks.
- **Speed and reliability.** Alternative fuelled vehicles are not expected to reduce congestion.
- **Environmental impact.** A complete shift to alternative fuelled vehicles would eliminate tailpipe greenhouse gas and air quality pollutant emissions in road freight (though PM10 from tyre abrasion will remain). Such a shift could take place over a relatively short space of time. In the UK, average HGV lifetimes are around ten years. Therefore, once alternative fuelled freight vehicles have achieved mass market dominance, a shift to alternative fuelled freight vehicles for the entire HGV fleet could occur within a decade. If alternative fuel vehicles dominate the new truck market by the 2030s, a full transition could be achieved by 2040.
- **Resilience.** Alternative fuelled vehicles would reduce the exposure of the freight system to fuel supply shocks as the scope for energy self-sufficiency in electricity or hydrogen is greater than for oil products. However, this would only slightly improve resilience, given the UK’s low energy security risks.

Alternative fuelled vehicles have the potential to achieve mass market deployment. Alternative fuelled vehicles will be suited to all segments of the freight market. Current electric vehicle technology is already adequate for vans and small-trucks, and short- to medium-distance journeys. Further innovation could be needed to deliver cost-effective solutions for large trucks and long-distance journeys.

Provided cost reductions are achieved, barriers to deployment are low. Battery electric and hydrogen vehicles do not face significant operational or public acceptability barriers.

Alternative fuelled vehicles are likely to need large investments in new infrastructure. Infrastructure needs will depend on the mix of vehicle technologies, but could include fast charging infrastructure and catenary overhead wiring for electric vehicles, or hydrogen fuelling infrastructure for hydrogen fuel cell vehicles. Major upgrades to electricity networks could also be needed.

Our assessment is that alternative fuelled vehicles are could deliver a step change in the efficiency of the freight system. Alternative fuelled vehicles could improve environmental impact and resilience across the freight system. They would be suited to the mass-market, and prospects for large-scale deployment are strong given the scope for further cost reductions, and lack of public acceptability barriers.

4.2 Unmanned aerial vehicles

Drones or Unmanned Aircraft Vehicles (UAV) are aircrafts that do not need a pilot. Drones were initially used in military applications but advances in engineering and manufacturing technologies have expanded their uses. Drones are used in place of manual inspections to monitor the quality of infrastructure and equipment, or to record spatial data such as land cover, or soil or crop quality.

Small freight drones are undergoing extensive trials in a number of countries to deliver goods directly to consumers. Most trials have taken in place in rural areas or in areas with poor connectivity. Drones are delivering food in Reykjavik, Iceland, improving connectivity between two parts of the city separated by a river; and are being used to deliver goods in remote areas in China. More recently, the use of delivery drones has expanded to urban areas. Drone delivery startup Matternet transports blood and pathology samples between hospitals in Switzerland. In the UK, Amazon is testing its drone delivery technology in rural Cambridgeshire and successfully delivered its first package in 2016.

Drones could reduce costs and improve speed and reliability in some parts of the freight system. Improvements in resilience and environmental outcomes are likely to be limited.

- **Cost:** Drones could reduce costs in some market segments. First, drones could offer cost advantages relative to road freight in areas with low population or poor road infrastructure, where road freight vehicles may be unable to achieve high loading factors, or may need to take long detours to reach a customer. Second, like connected and autonomous vehicles, delivering by drone avoids incurring driver costs.
- **Speed and reliability:** Drones could offer fast deliveries, similar to courier services today. Amazon is working towards delivering small packages within 30 minutes of an order being placed (McKinnon, 2016). Drones could also contribute to reducing road congestion, if they are able to displace road vehicles in some market segments..
- **Environmental impact:** Unlike today's diesel road freight vehicles, drones are powered by electricity and produce CO2 emissions. However, drones would not offer environmental advantages relative to alternative fuelled road vehicles.
- **Resilience:** By not relying on roads and eliminating the need for drivers, drones could increase resilience against infrastructure failures and labour strikes. However, drones are likely to increase the vulnerability to other risks. Current drones do not have the capability to handle challenging weather conditions and are likely to be vulnerable to extreme weather events, for example heavy snow or storms. Drones will also make the freight system more vulnerable to failures in information systems, such as cyber attacks.

Drones are likely to add value in some segments of the freight market but are unlikely to reach mass-market deployment. The small payload capacities and lack of economies of scale are likely to limit the scope of drones to rural and high value urban deliveries.

- **Rural areas:** Drones are more likely to offer speed and cost savings when delivering goods to rural areas with relatively poor infrastructure. While the UK has good quality infrastructure, there may be certain remote areas that could benefit from drone deliveries. Drones could be a cost-effective option in rural areas where the number of parcels to be delivered are too small to justify using a delivery van.
- **Premium segment of the freight market:** 10% of the nearly 7 billion packages delivered annually in the EU are for same day delivery, and 60% of these are light enough (<2.5kg) to be carried by drone (Single European Sky ATM Research Joint Undertaking, 2016). SESAR JU (2016) estimate that around 10% of the same-day, premium lightweight parcel market has the potential to be delivered by drone.
- **Mass-market deliveries:** Drones do not offer the economies of scale of road freight. Current drones can deliver only a small number of packages at a time, with a weight of between 2-5kg, compared to a delivery van in the UK that can deliver 120 non-food items over an 8-hour shift (McKinnon,

2016). 15-16 drones would be needed to replace a single van, suggesting that drones are unlikely to offer a plausible alternative to road vehicles for mass market deliveries.

Drones face a number of technological and public acceptability barriers. Drones would require technology improvements to handle extreme weather conditions and need to overcome public acceptability barriers.

- **Technological:** Current drones have been tested under calm weather conditions. Further development of drone technology is likely to be needed to ensure they can deliver reliably and safely in challenging weather conditions, such as snow, heavy winds, or storms.
- **Public acceptability:** Public acceptability of drone deliveries is low. A poll by the Royal Aeronautical Society (2016) found that only 32% of respondents approved of the use of drones for parcel delivery. Surveys (NESTA, 2017) have shown that the public are concerned about privacy, noise and safety issues. According to the UK Airprox Board (2019), the specialist body responsible for assessing airspace conflicts, near-misses involving drones have increased from 29 in 2015 to 126 in 2018.

Infrastructure investments will be needed to support the rollout of drones, particularly in urban areas. Current trials have bene limited, and have not needed new infrastructure so far. The widespread rollout of drones would require homes and offices to have the necessary infrastructure to receive drone deliveries in a safe and secure manner. Rural deliveries could be possible without major infrastructure investments as houses tend to have driveways or gardens, and there is more open space. However, urban areas would require investments in new landing facilities. Compared to vans, drones travel shorter distances before they need to be recharged or reloaded with goods. This would require new investments to support the expansion of decentralised stockholding points that are closer to customers. Urban landing facilities and decentralised stockholding points are likely to be costly, given the high value of urban land.

Our assessment is that unmanned aerial vehicles are unlikely to deliver a step change in the efficiency of the freight system. Drones could improve cost, and speed and reliability, for a small segment of the freight market. They are unlikely to be suited to the mass-market, and prospects for large-scale deployment are poor given technological and public acceptability barriers.

4.3 Connected and autonomous vehicles

Connected and Autonomous Vehicles (CAV) are an emerging technology that could allow vehicles to function without a driver. Connected vehicles communicate with each other and the world around them, while autonomous vehicles can perform all driving functions without a driver. There are different levels of automation. The US National Highway Traffic Safety Administration (2019) defines five levels of automation: at levels 1 and 2 (‘Driver assistance’ and ‘Partial automation’) the vehicle may perform functions such as acceleration and steering without driver involvement under certain conditions; at levels 3 and 4 (‘Conditional automation’ and ‘High automation’) a driver is not needed under normal driving conditions but must be able to take control if necessary; and at level 5 (‘Full automation’) the vehicle is capable of performing all driving functions under all conditions. The Society for Motor Manufacturers and Traders, the trade association for the United Kingdom motor industry, suggests that fully autonomous vehicles (Level 5) could enter UK production in 2025, and achieve approximately 25% market penetration by 2030 (SMMT, 2017).

Some features of CAV technologies are already being deployed commercially. A number of driver assistance and partial automation technologies are in use today, including self-parking, lane control (to prevent drivers from drifting into adjacent lanes), and automatic emergency breaking. eCall (emergency call) is used to report accidents. If a car is involved in an accident, it will detect what happened, automatically connect to the call centre and use GPS to share the vehicle's location. The EU made this technology a legal requirement for all new models of cars and light vans from April 2018. It would reduce response times by 50% in rural areas and 40% in urban areas, and is estimated to save 2,500 lives a year (EU Press Release, March 2018).

Advanced CAV technologies are currently undergoing trials in several countries under a range of driving scenarios. Governments, technology firms and traditional car manufacturers have taken a strong interest in demonstrating CAV technology.

- The UK Centre for Connected and Autonomous Vehicles, a joint BEIS-DfT initiative, is currently trialling automated passenger shuttles, automated urban delivery vehicles, and remote teleoperation demonstrations where a human operator can manoeuvre or recover a fully autonomous vehicle into safe mode.
- Waymo, the company setup by Google to develop self-driving cars, has already trialled autonomous vehicles (with a driver behind the wheel) in California, Arizona and Georgia, and is currently developing a fully autonomous truck technology.
- In passenger transport, Uber has introduced CAVs with a driver ready to take control in an emergency as part of its ride-hailing fleet in Pittsburgh and Tempe, although a similar move in San Francisco faced legal challenge.

CAVs can reduce road freight costs by a third. CAVs would also reduce fuel consumptionand ease congestion.

- **Cost:** CAVs could reduce both the labour and fuel costs of road freight. CAVs could reduce labour costs by eliminating the need for a driver. As labour costs account for a third of road freight costs, CAVs could deliver very substantial cost savings. CAVs could reduce fuel costs through platooning to reduce air resistance. While conventional vehicles must drive at a significant distance from each other to account for reaction times of human drivers, in principle, CAVs would be able to drive much closer together ('platooning'). This reduces air resistance and reduces fuel consumption emissions. The New Energy and Industrial Technology Development Organisation (NEDO), Japan carried out a trial of a four-truck platoon with one human driver and three autonomous vehicles that showed a 15% reduction in fuel consumption (SAE International, 2014). A two-truck platooning trial in the Netherlands in 2014 by truck manufacturer DAF and a Dutch research institute, TNO, showed that fuel consumption improved by 8% for the first truck, and 13% for the second truck (Paris Process on Mobility and Climate Change, 2019). In the UK, a £8.1 million government funded trial is currently underway.
- **Speed and reliability:** In principle, CAVs have the potential to free up road space and reduce congestion by driving close together. Modelling for the Department for Transport suggests that the congestion benefits will increase with adoption of CAVs, with a 50% penetration of CAVs on urban

roads delivering a 17% reduction in congestion and a 100% penetration delivering a 30% reduction (Atkins, 2016). This will improve the speed and reliability of road freight.

- **Environmental impact:** CAVs could enable platooning, which would reduce fuel consumption. If CAVs technology were used in diesel trucks, platooning could offer moderate reductions in tailpipe CO2 emissions. Platooning would not reduce tailpipe CO2 emissions in alternative fuelled vehicles, but could reduce any CO2 emissions associated with electricity generation or hydrogen production.
- **Resilience:** CAVs could improve resilience by reducing its exposure to labour action. However, CAVs could reduce resilience in other areas. Connected and autonomous vehicles are more vulnerable to cyber-attacks. CAVs also require road markings, signs and signals to be maintained to a higher standard compared to manned-vehicles. This is likely to reduce their resilience to infrastructure failures, and extreme weather events that may affect road signs and markings.

CAVs would also improve safety. 94% of serious car crashes are due to human error (NHTSA, 2019). By removing the scope for human error, autonomous vehicles could in principle improve road safety. Current vehicles equipped with partial autonomous features have demonstrated the safety benefits of CAVs. For example, a study by the EU on Automated Emergency Brake Systems, found that that the technology was effective in reducing the number of casualties (Grover et al, 2008).

CAVs have the potential to achieve mass market deployment. CAVs are likely to offer significant benefits and in principle can replace the entire existing road freight fleet. In practice, deployment will depend on progress made in addressing technology and public acceptability barriers, and progress made in upgrading existing infrastructure.

CAVs face a number of technological and public acceptability barriers. The prospects for CAVs in the long-term are strong, although existing barriers suggest that adoption is likely to be gradual.

- **Technology:** CAVs have been proven under simple driving conditions but further trials are required to assess the viability and risks of fully autonomous vehicles under complex environments, such as a large number of roundabouts, rural roads or heavy snow.
- **Public acceptability:** Public acceptability of CAVs is improving but remains a barrier. A Deloitte market survey in 2016 found that 73% of UK respondents thought fully self-driving cars will not be safe, and 59% do not want the government to allow fully self-driving cars to be sold in the next five years. However, public acceptability appears to be improving; the 2018 survey found that only 49% of respondents thought that self-driving cars would not be safe. A SMMT survey showed a more positive result. 56% of participants said they felt positive about CAVs, with young people and those facing disabilities feeling the most positive.

CAVs would require a range of infrastructure upgrades to support adoption. The ability of CAVs to communicate with each other and the wider transport infrastructure is critical to realise their full benefits. This will require upgrades to transport infrastructure, as well as information communications infrastructure more widely.

- **Transport infrastructure and sensors:** Transport infrastructure would need to be redesigned to accommodate the rollout of CAVs. Sensors and other infrastructure upgrades would allow CAVs to communicate with the wider transport infrastructure, for instance traffic signals. Road markings, signs and signals would need to be maintained to a higher standard than is currently the case (RAC Foundation, 2017).

— **Information and communications infrastructure:** Investments in fast, secure and reliable wireless communication technologies will help maximise the benefits of CAVs. The UK performs poorly on infrastructure capability in KPMG's Autonomous Vehicles Readiness Index because it has one of the lowest scores for 4G coverage. In the future, 5G connectivity could significantly enhance the capabilities of CAVs by improving communication flows between vehicles and the infrastructure.

The current regulatory framework would need to be updated to support the commercial rollout of CAVs. Under the current regulatory framework, liability issues are dealt with on a case by case basis by the courts (DfT, 2015). A clearer regulatory framework is needed to deal with the liability and insurance issues associated with CAVs. In some cases, existing legislation may need to be updated, for example legislation associated with the way vehicles are used and maintained to ensure they are fit to travel on the road.

Our assessment is that connected and autonomous vehicles could deliver a step change in the efficiency of the freight system. CAVs could reduce road freight costs by a third, and contribute to reducing congestion. CAVs have the potential to achieve mass market deployment, as they could in principle replace the entire road freight fleet. Provided technological and public acceptability barriers exist at present, but could be overcome.

4.4 Robotics and automation

Robotics and automation involve the use of machines to carry out a complex series of tasks automatically. Advances in computing, software and hardware development and network technologies have created a sophisticated range of robots that can integrate information from multiple sensors and adapt their behaviour in real time. The costs of robotics and automation have fallen by half over the last thirty years, and even further when compared to labour costs (McKinsey, 2017).

The use of robotics and automation is dramatically improving the efficiency of large warehouse operations. Case study evidence has shown that robotics and automation have reduced costs, enabled faster delivery and increased the productivity of large warehouse operations. Online retailer Amazon deployed 45,000 robots across 20 warehouses, which reduced operating costs by 20% and allowed warehouses to hold 50% more inventory per square foot (Business Insider, 2017; Quartz, 2016). Retailer Uniqlo replaced 90% of their staff at a Tokyo warehouse with robots to help reduce storage costs and improve delivery times (WEF, 2018).

Several companies are developing more sophisticated robotics solutions for the freight sector. In spite of advances in robotics and automation technologies, there remain a range of tasks that existing robots are unable to perform. For example, there are some technical challenges around the ability of existing robots to handle goods of different shapes and sizes, and work out the optimal loading/unloading sequence to ensure goods are not damaged. Companies are investing in robotics and automation solutions to improve the efficiency and speed of loading and unloading items from a trailer/container, and picking items off warehouse shelves with limited human input.

Robotics and automation could substantially reduce warehousing costs, and improve the efficiency of warehousing operations.. Robotics and automation are less likely to deliver improvement in environmental outcomes or resilience.

- **Cost:** UK National Accounts indicate that labour costs account for around one third of warehousing costs. Fully automating warehouse operations could therefore reduce costs by up to one third.
- **Speed and reliability:** Existing warehouses operations, such as loading/unloading, sorting and picking items off shelves for delivery are labour-intensive and time consuming. Robotics and automation would improve the speed at which these tasks are carried out and reduce the number of errors.
- **Environment:** Robotics and automation are not expected to deliver environmental benefits.
- **Resilience:** Robotics and automation are not expected to deliver improved resilience.

In principle, robotics and automation could be deployed across all warehousing facilities, and there are no major barriers to deployment. Wide scale adoption of robotics and automation in the logistics industry has been limited; for example, 80% of current US warehouses are manually operated with no supporting automation, 15% are mechanised and only 5% are fully automated (Robo Global, 2017). The low level of deployment to date is due in part to technological challenges specific to the freight sector (efficiently loading and unloading goods of different shapes and sizes). If these challenges are addressed, robotics and automation could be deployed very widely, though high capital costs could initially restrict deployment to large firms with low borrowing costs.

Our assessment is that robotics and automation could deliver a step change in the efficiency of the freight system. Robotics and automation could reduce warehousing costs by over third, and potentially improve the speed and reliability of warehouse operations. The technology has the potential to achieve mass market deployment. Further technological improvements are needed, but there are no other significant barriers to adoption.

4.5 Digitalisation and data science

Digitalisation is the use of technologies to enhance the transfer of information either between devices or between companies. Digitalisation underpins other technologies such as connected and autonomous vehicles, and robotics and automation. In the logistics sector, digitalisation enables more detailed analysis and gathering of insights from data, sensors and connected devices to increase efficiency and reduce costs.

Data science is the analysis of data to solve problems. Data science includes the development and use of large datasets, various statistical techniques, and machine learning. Artificial intelligence, a related concept, is the ability of computer systems to perform tasks that normally require human intelligence. Progress in computing power and the generation and storage of large volumes of data has accelerated the development of data science. It is being used by the manufacturing sector to improve the efficiency of equipment and maintenance operations and to provide a more accurate forecast of the demand for goods and services (Autodesk, 2019; DHL, 2018; WEF, 2019).

Digitalisation has enabled freight exchanges, which have expanded the scope for freight operators to collaborate to and improve operational efficiency. A freight exchange is an online service which records customer delivery needs, and allows freight operators to identify deliveries that are suited to their available vehicle capacity. Freight exchanges can improve vehicle utilisation by sharing information on assets, routes and fill rates. For example, Cayote, a company recently taken over by UPS, specialises in scheduling shipments for return trips to reduce empty running. DP Schenker, a global logistics company, signed a five-year contract with an online freight exchange company, uShip, to develop a platform to connect truck drivers and shipments more efficiently.

There has been some application of digitalisation and data science in freight. Digitalisation and data science are now used to optimise routing, predict and avoid delays..

- **Intelligent Route Optimisation:** Deutsche Post DHL Group pioneered the SmartTruck optimised routing pilot in 2010 to develop routes for its fleet operators and drivers. The initiative is able to calculate the ideal sequence of shipments, and the optimal routing patterns to avoid congestion, and re-calculate these in real-time in response to new information. The pilot reduced the number of miles travelled by 15% and the length of the average route by 8% (DHL, 2011).
- **Predictive analysis:** DHL has developed a machine-learning tool to predict air freight transit time delays. The programme draws on 58 different parameters to predict transit delays up to a week in advance, and identify the reasons behind the delay.

In future, data science could deliver larger gains in operational efficiency. As set out in section 4.5, part-loading of freight vehicles occurs in part because of the challenges of efficiently matching freight vehicles to loads. Efficiently matching freight vehicles to loads would require detailed information on all delivery needs, including origins, destinations, payloads and specified delivery times; and sufficient information processing ability to calculate the optimal pattern of deliveries given delivery needs and available vehicles.In principle, it is possible that advances in digitalisation and data science could meet these information and analytical needs. If all freight loads were logged on freight exchange platforms, and systems were developed to share information across multiple platforms then a large, real-time database of all freight loads could be developed. It could then be possible to analyse the database and identify a set of vehicle journeys which could meet freight demand across multiple origins and destinations much more efficiently than can be achieved today.

Digitalisation and data science could reduce costs and congestion.
Improvements in environmental outcomes and resilience are likely to be limited.

- **Cost:** Advances in digitalisation and data science could improve the matching of loads arising from multiple origins to freight vehicles, which could reduce costs.
- **Speed and reliability:** Improved matching of loads to freight vehicles could reduce the number of vehicles needed to meet freight demand, and help ease congestion.
- **Environment:** Improved matching of loads to freight vehicles could reduce total freight vehicle travel. If diesel trucks continue to be used for freight, this reduction in vehicle travel could reduce GHG emissions. However, if a shift to alternative fuelled vehicles is achieved, reducing vehicle travel would not offer substantial environmental advantages.
- **Resilience: By reducing vehicle travel, d**igitalisation and data science could improve freight resilience by predicting and mitigating supply chain delays, and reducing exposure to infrastructure

failures and fuel supply shocks. However, increased digitalisation could increase the freight system's vulnerability to cyber attacks.

Barriers to collaboration would also need to be addressed before substantially greater collaboration could be achieved. As set out in section 4.5, barriers to collaboration include cultural barriers and competition concerns, as well as fundamental constraints such as geographical mismatches of freight supply and demand, demand fluctuations or the requirements of just-in-time delivery.

Our assessment is that digitalisation and data science are unlikely to deliver a step change in the efficiency of the freight system.

- **Impact on cost:** Digitalisation and data science could reduce costs by improving operational efficiency, though the scale of this opportunity is uncertain.
- **Impact on speed and reliability:** Digitalisation and data science could identify routing and scheduling patterns to minimise congestion, though impact on congestion could be limited if road users do not face congestion pricing.
- **Environmental impact:** By reducing the volume of freight through increased collaboration and decentralised consolidation, digitalisation and AI could reduce but not eliminate GHG emissions.
- **Impact on resilience:** Digitalisation and data science could improve freight resilience by reducing its exposure to infrastructure failures and fuel supply shocks, but could reduce resilience given vulnerability to cyber-attacks.
- **Prospects for deployment:** Cultural barriers may slow the pace of adoption but prospects remain strong.

4.6 Delivery droids

Delivery droids are autonomous, self-driving robots that currently travel on footpaths. Droids can navigate road crossings and zebra crossings using a combination of GPS, cameras, sensors and radar to avoid oncoming traffic.

Trials are currently taking place in several cities to deliver small parcels over short distances. Starship Technologies has run trials of its delivery droids in 12 countries. In 2016, the company launched a more detailed test programme in London, Dusseldorf, and Bern in partnership with local food and parcel delivery companies. In London, Starship is working with Southwark Council to operate a fleet of 10-15 delivery droids to deliver food orders, and increasingly parcels, over a distance of 2 miles. Dominos has also used droids for a small proportion of its deliveries in Germany and the Netherlands.

Delivery droids could reduce costs and reduce congestion in the urban delivery segment of the freight system. Improvements in resilience and environmental outcomes are likely to be limited.

- **Costs:** By eliminating the need for delivery drivers, droids have the potential to reduce delivery costs in urban areas.
- **Speed and reliability:** In principle, droids could reduce the impact of urban congestion on deliveries by shifting deliveries from congested roads to pedestrian routes. However, travel speeds would need to be low for safety, and a large shift towards droids could merely transfer congestion from roads to pedestrian routes.

- **Environment:** Delivery droids would not offer environmental advantages relative to alternative fuelled road vehicles.
- **Resilience:** Delivery droids are not expected to deliver improved resilience.

Delivery droids are unlikely to be deployed widely. Droids are currently used to deliver small packages over short distances in urban areas. Given the small payload capacity and the distance that droids can travel, they will not offer the economies of scale and delivery costs are likely to be higher than those of larger road vehicles. Delivery droids are likely to be restricted to delivering a small range of goods to segments of the urban freight market it is difficult to achieve high utilisation of larger vehicles .

Public and political acceptability could limit the deployment of droids. Droids currently travel on footpaths and risk displacing pedestrians or lead to overcrowding of footpaths. This could restrict the rollout of droids and limit their use to particular segments of the freight market. This concern has already led to restrictions on the use of droids. For example, the San Francisco municipal government considered banning delivery droids, before deciding to restrict their use by issuing a limited number of permits.
CAVs could reduce road freight costs by a third, and contribute to reducing congestion. CAVs have the potential to achieve mass market deployment, as they could in principle replace the entire road freight fleet. Provided technological and public acceptability barriers exist at present, but could be overcome.

Our assessment is that delivery droids are unlikely to deliver a step change in the efficiency of the freight system. Drones could improve cost, and speed and reliability, for a small segment of the freight market. They are unlikely to be suited to the mass-market, and prospects for large-scale deployment are poor given public acceptability barriers.

4.7 3D printing

3D printing or 'Additive Manufacturing' creates three-dimensional solid objects using digital files. 3D printing involves the development of model object using a computer-aided design, and the reproduction of that object by the 3D printer. The printer layers material one on top of another until the object is ready. Once the object is ready, finishing activities or secondary processing may be required, for example polishing, sanding or painting.

Advances in 3D printing have greatly expanded the range of potential applications. 3D printing technology has been under development for the last three decades. In its early stages manufacturers used 3D printing to prototype products. Technological advances, falling costs and improved accuracy have made 3D printing more widespread. Until the mid-2000s 3D printers could only use soft plastic for a limited range of applications. However, current models can use a range of materials including glass, ceramics, liquids, organic materials, cement, bituminous concrete or metal powders.

3D printing is relatively established in the manufacturing sector. A range of industries are increasingly employing 3D printing in their manufacturing processes. Aerospace firms are using 3D printed parts in aircraft production, automotive firms are using 3D printed parts to make personalised, small-batch replacement parts and the healthcare sector is using 3D printers to produce customised implants, prosthetics and medical devices.

3D printing offers some advantages over conventional manufacturing processes. 3D printing is more efficient than conventional manufacturing at producing products at small volumes; and is better suited to decentralised production.

- **Small volume production.** Many products are mass produced. Mass production offers economies of scale as manufacturing processes such as injection moulding or casting can produce of large quantities at low cost. Mass production is efficient for mass-market products with high market demand. However, manufacturers must also produce for niche products with low market demand. For example, service agreements between component suppliers and companies require spare parts to be on the inventory for several decades, even when models are no longer in production (Ernst & Young, 2016). For such products, mass production implies either low utilisation of the manufacturing plant; or over-production and increased stockholding costs. In contrast, 3D printing can produce small or variable quantities with low fixed investment costs; designs can be changed digitally and printed, without any additional investments in plant or machinery.
- **Decentralised production.** Because conventional mass production processes offer economies of scale, they are best suited to large-scale, centralised production. As centralised production increases delivery times, it is less efficient for products that are needed urgently. In contrast, 3D printing of niche products can be closer to the customer, to shorten delivery times.

In principle, 3D printing could encourage more decentralised manufacturing of some products. Products which have low market demand, but where consumers place high value on short delivery times, may be ideally suited to small volume, decentralised production using 3D printing. Such products could include spare parts for essential equipment. For example, Mercedes-Benz Trucks has started to offer 3D printed spare parts on demand, at any quantity, helping reduce lead times, and storage and shipping costs (SMMT, 2016). Another example is medical products such as customised dental implants (HBR, 2015).

In turn, decentralised manufacturing could reduce the total volume of freight moved. At present, many manufactured products are produced in bulk and stored in large central warehouses, and transported long distances to retailers and consumers. If manufacturing were more decentralised, goods could be produced closer to consumers and transported much shorter distances. The freight system could shift from transporting primarily parts and finished goods to transporting raw materials needed for 3D printing, which could be delivered in bulk with limited packaging. As the mass of raw materials transported would be comparable to the mass of final products manufactured with 3D printing, decentralised manufacturing is not expected to result in major changes to the mass (in tonnes) of freight lifted. However, by improving load factors in freight vehicles which currently carry low-density goods, decentralised manufacturing could result in a reduction in total freight moved (tonne km).

By decentralising some manufacturing, 3D printing could reduce costs and congestion, and improve resilience in some parts of the freight system. Improvements in environmental outcomes are likely to be limited.

- **Costs:** A reduction in total freight moved (tonne km), and in the volume of warehousing space used to store items with low turnover, would reduce the costs of freight.

- **Speed and reliability:** By reducing the volume of freight moved, 3D printers could reduce congestion.
- **Environment:** Decentralised manufacturing would result in production taking place closer to customers and reducing the volume of freight moved. If road vehicles continued to run on diesel, a reduction in freight moved could reduce CO2 emissions. However, a shift to decentralised manufacturing would not offer environmental advantages if a shift to alternative fuelled road vehicles is achieved.
- **Resilience: If** 3D printing were to encourage some decentralised manufacturing, it could reduce the distances over which some goods are transported, , and decrease the vulnerability of the freight system to infrastructure failures and extreme weather events.

However, a large part of the manufacturing sector is likely to continue to use conventional processes. Only a minority of products are characterised by both low market demand and consumers placing high value on short delivery times. As a result, the majority of products are likely to continue to be manufactured using large-scale, centralised processes.

Our assessment is that 3D printing is unlikely to deliver a step change in the efficiency of the freight system. 3D printing could deliver some reductions in cost and improvements in speed and reliability, but is unlikely to displace conventional production processes in the majority of manufacturing activity.

4.8 Conclusion

Table 1 summarises the assessment of the technologies considered in this section. Our assessment is that Alternative Fuelled Vehicles, Connected and Autonomous Vehicles and Robotics and Automation could deliver a step change in the efficiency of the freight system. Unmanned aerial vehicles (drones), digitalisation and data science, delivery droids and 3D are likely to play some role in the freight system, but are less likely to deliver a step change in the cost, speed and reliability, environmental impact and resilience of the freight system.

Table 1. **Impact of new technologies on freight efficiency**

Technology	Cost	Speed and reliability	Environmental impact	Resilience	Scale	Barriers	Step change
Alternative fuel vehicles	No impact	No impact	Strong impact	Moderate impact	Mass-market	Weak	Yes
Unmanned aerial vehicles (drones)	Moderate impact	Moderate impact	Moderate impact	Mixed impact	Niche	Strong barriers	No
Connected and autonomous vehicles	Strong impact	Moderate impact	Moderate impact	Mixed impact	Mass-market	Uncertain	Yes
Robotics and Automation	Strong impact	Moderate impact	No impact	No impact	Mass-market	Weak	Yes
Digitalisation and data science	Strong impact	Moderate impact	Moderate impact	Mixed impact	Mass-market	Weak	Yes

Technology	Cost	Speed and reliability	Environmental impact	Resilience	Scale	Barriers	Step change
Delivery droids	Moderate impact	Moderate impact	Moderate impact	No impact	Niche	Uncertain	No
3D Printing	Moderate impact	Moderate impact	Moderate impact	Moderate impact	Niche	Weak	No

Source: *Vivid Economics*

5 Value of freight efficiency

Key messages

- **The freight system plays a vital role in supporting economic activity.**
- **New technologies could reduce the cost of the freight system by around one third, delivering cost savings equivalent to around 1.3% of GDP.**
- **The benefits of attracting new international businesses through an improvement in UK freight efficiency are likely to be limited.**
- **Improved freight efficiency is unlikely to improve productivity by accelerating the development of industrial clusters**
- **The freight system is now extensive and regional economic benefits from integration with the wider manufacturing economy are likely to be very limited.**

There are multiple channels through which a more efficient freight system could generate economic benefits.

- **Enabling economic growth.** All economic activity depends directly or indirectly on the freight system, and failure to meet freight demand would constrain output
- **Delivering cost savings.** A reduction in freight costs directly translates into increased output
- **Encouraging inward investment.** A reduction in the cost of the UK freight system could encourage global manufacturing industries to locate production in the UK
- **Driving agglomeration.** Greater freight efficiency could encourage clustering of manufacturing, resulting in diffusion of innovations and higher productivity.
- **Integrating new regions with the wider economy.** Connecting new regions to the freight network could enable a shift to manufacturing and raise regional productivity.

This section identifies the economic benefits which improved performance of the UK freight system with respect to the drivers of freight efficiency could deliver, and assesses the magnitude of the benefits that could be realised, given appropriate regulation and innovation in the emerging technologies.

5.1 Enabling economic activity

Freight transport is needed to meet the UK's most essential needs. For example, freight is critical to maintaining food and fuel supplies. Freight supplies food to supermarkets, where the majority of consumers buy their food. Like most retailers, supermarkets hold minimal inventory, and no inventory of fresh produce; instead, food retailers order products on a daily basis for delivery within 24 hours. Freight also supplies fuel to petrol stations. Again, petrol stations hold very small inventories, sufficient for 3-4 days of sales; instead, petrol stations receive several deliveries per week to maintain sufficient supply. Other critical functions of freight include carrying medical products to hospitals, cash between banks and to ATMs, letters and parcels to homes and businesses.

The freight system plays a vital role in supporting economic activity. Freight transports raw materials and intermediate products to factories, to support manufacturing; it transports finished products to retailers, to meet consumer demand; and it transports goods to ports, to support exports. By enabling goods to be moved long distances at low cost, freight allows products to be manufactured at large scale in the most suitable locations in the UK and overseas.

The UK's exposure to freight costs is declining. Section 2.1 shows how the cost of the freight system as a share of GDP is decreasing as GDP rises faster than freight costs. As a result, the UK's exposure to freight costs is also decreasing.

However, the UK remains highly dependent on freight. While the UK economy is becoming less exposed to the cost of freight over time, its dependence on freight to support economic activity is unchanged. Section 0 describes how disruption to the freight system resulted in economic disruption during the 1979 truck drivers' strike and the 2000 fuel protests. In both cases, these crises disrupted food transportation; and the 2000 fuel protests severely disrupted fuel supply and risked the imminent shutdown of the manufacturing sector.

Maintaining a functional freight system is of primary importance. Improving the cost and reliability of the freight system will deliver economic benefits, as described in the remainder of this section. However, given the UK's low and declining exposure to freight costs, the overall economic impact of even large relative changes in cost and reliability could be limited. Nevertheless, the economic impact of a serious disruption to the freight system would be severe, and addressing the risks of such a disruption remains a policy priority.

5.2 Delivering cost savings

The cost of the UK freight system is around £80 billion, equivalent to around 4% of GDP. As described in Section 2.1, the major cost components of the freight system are the cost of freight transport, and the cost of warehousing. We estimate the cost of freight transport is around £40 billion (of which road freight makes up around £38 billion and rail freight up to £2 billion); and the cost of warehousing at around £38 billion. Rounded to the nearest £10 billion, this implies that the cost of the UK freight system is around £80 billion, equivalent to around 4% of GDP.

New technologies could offer cost savings of around £26 billion, equivalent to around 1.3% of GDP. Connected and autonomous vehicles could decrease the cost of road freight by around one third; robotics and automation could decrease the cost of warehousing by a similar amount. Together these technologies could reduce the cost of the UK freight system by £26 billion, equivalent to around 1.3% of GDP. Digitalisation and data science could offer further cost savings, though the magnitude of potential savings is very difficult to quantify.

5.3 Attracting inward investment

In principle, a more efficient freight system could attract new business investment in the UK. Large businesses serving an international market must make decisions about where to locate their operations. If the cost and quality of the freight system influences such location decisions, an improvement in the cost and quality of the UK freight system could attract new business investment in the UK.

The economic benefits of attracting international businesses to the UK could be substantial. International businesses offer access to large overseas markets. They also operate in some of the most productive sectors, such as the pharmaceutical, chemicals and petrochemicals sectors, and could therefore offer large productivity gains.

The evidence base on the importance of transport infrastructure in attracting international business is poor. A small number of studies have looked at the role of transport infrastructure in attracting international business. Kumar (2006) shows that the quality and availability of overall infrastructure, including transport infrastructure, does contribute to the relative attractiveness for investment by international businesses, though it does not consider the specific contribution of transport infrastructure within this. Survey evidence confirms that transport infrastructure is a material factor. EY's European Attractiveness Survey (2015) showed that transport infrastructure was an the third most important factor in shaping location decisions after policy and regulatory stability and domestic market characteristics. However, while such surveys demonstrate that the availability and quality of transport infrastructure does influence business location decisions in general, it is not clear that further improvements in the availability and quality of transport infrastructure will continue to influence business location decisions once a certain threshold of availability and quality has been achieved.

Improved freight efficiency is more likely to attract valuable inward investment in sectors with high exposure to freight costs, high trade intensity and high productivity. First, improved freight efficiency is more likely to influence investment decisions in sectors where dependence on freight and exposure to freight costs have a material impact on profitability. Second, an improvement in freight efficiency is more likely to attract international businesses in sectors where the goods and services produced are highly traded internationally. Third, new business investment driven by improved freight efficiency is more likely to deliver substantial economic benefits in sectors with high productivity.

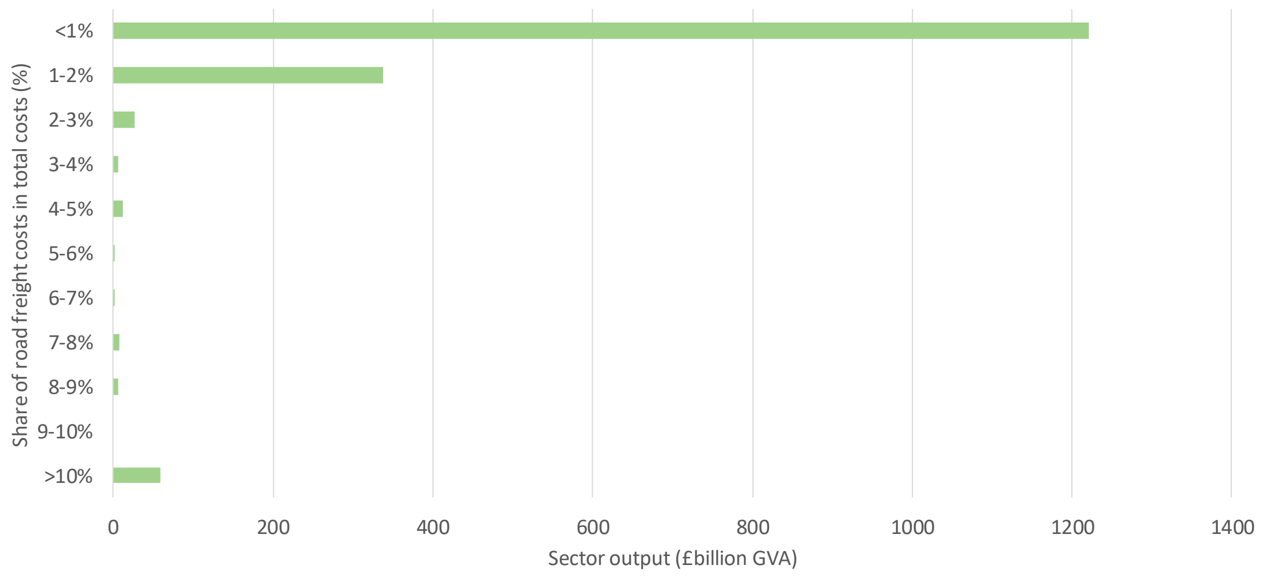
Many sectors are exposed to minimal freight costs. Figure 36 shows the economic activity of UK business sectors (expressed in GVA), organised by the share of freight cost within the total cost structure in these sectors. Much of UK economic activity is concentrated in sectors in which freight costs make up only a very small share of the total cost structure. 75% of economic activity is concentrated in sectors in which freight costs make up less than 1% of total costs; and a further 18% of activity is concentrated in sectors in which freight costs make up less than 2% of total costs. Sectors in which freight costs make up less than 2% of total costs include:

- **Almost all of the service sector.** Freight costs make up less than 2% of total costs in over 95% of the service sector (by GVA). Much of this sector consists of activities that do not make use of the freight system (for example, information and communication services, financial services, real estate), or relatively little use (hospitality, healthcare).
- **Much of the resources sector.** Freight costs make up less than 2% of total costs in around 90% of the resources sector (by GVA). Sectors with low freight costs include fishing, forestry, agriculture and petroleum. While these sectors are highly dependent on freight transport, other costs make up a far greater share of the cost structure. For example, in the agriculture sector, expenditure on animal feeds, fuel, and fertiliser is each several times greater than expenditure on freight.

- **Much of the utilities sector.** Freight costs make up less than 2% of total costs in around 85% of the utilities sector (by GVA). Sectors with low freight costs include electricity and gas supply, water supply and treatment sectors.
- **Much of the manufacturing sector.** Freight costs make up less than 2% of total costs in around 85% of the manufacturing sector (by GVA). Sectors with low freight costs include the shipbuilding, aerospace, pharmaceuticals and automotive sectors.

Only 7% of economic activity is concentrated in sectors in which freight costs make up more than 2% of total costs.

Figure 36. **Road freight costs make up a small share of UK business costs**



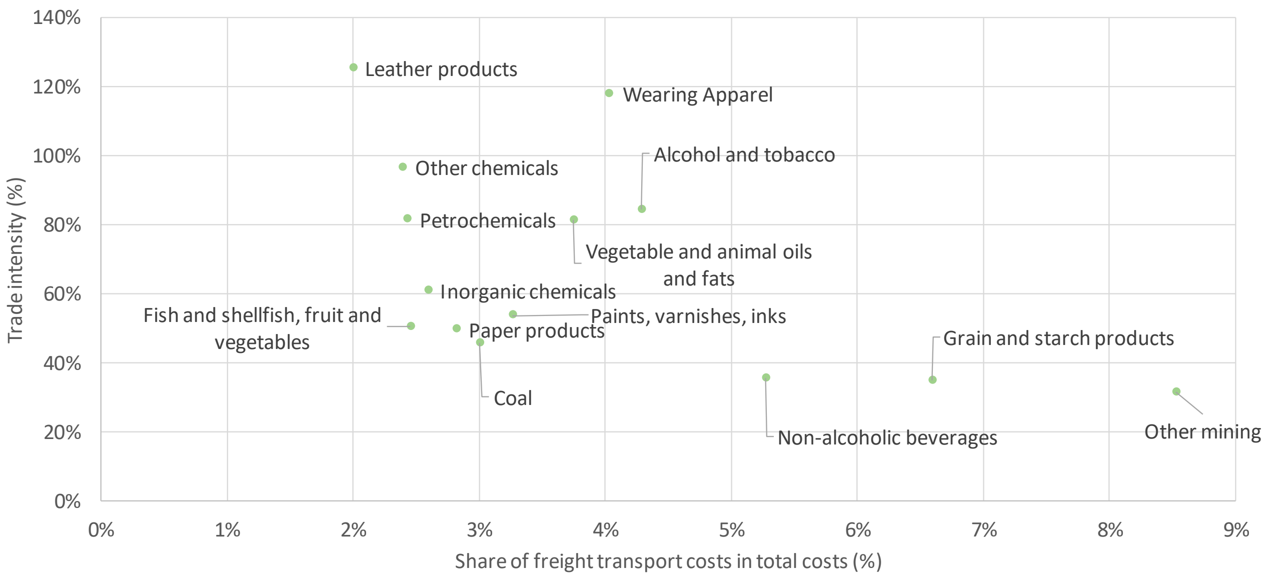
Source: Vivid Economics, Office for National Statistics

Several sectors have relatively high exposure to freight costs, but are not highly traded. Of the 7% of economic activity accounted for by sectors in which freight costs make up a moderate to high (>2%) share of the cost structure, only 3% of activity is accounted for by sectors that produce highly traded goods and services. Sectors with moderate to high freight costs that do not produce highly traded goods and services include sectors that are inherently domestic (wholesale and retail sectors, veterinary activities; remediation services, printing services); sectors that produce highly homogenous goods (such as animal feeds); and sectors that produce goods that are not suitable for international freight (such as cement and concrete; or bakery products).

Finally, a number of sectors have relatively low productivity. Sectors with moderate to high freight costs that have low productivity include some food product sectors (meat products, dairy products); commodities (wood products, glass and ceramics, iron and steel); and the waste management sector.

Only a small number of sectors offer attractive opportunities for improved freight efficiency to attract valuable inward investment. Figure 37 shows the UK business sectors which have moderate exposure to freight costs, trade intensity and labour productivity. In total, these sectors account for 2% of economic activity.

Figure 37. **A small number of sectors with moderate to high exposure to freight costs also have above average trade intensity and labour productivity**



Source: *Vivid Economics, Office for National Statistics*

5.4 Developing clusters of innovation

Agglomeration is the concentration of economic activity. The concentration of economic activity has led to the development of the UK's large cities, and its major industrial locations, such as the ceramics industry in the West Midlands; the science and technology cluster centred at Cambridge; and clustering of European headquarters along the M4 corridor.

Agglomeration has been shown to deliver significant productivity benefits. There are several ways in which agglomeration brings economic benefits. First, it increases the opportunities for firms and individuals to share knowledge and ideas. Second, it gives firms better access to skills as clusters of firms attract specialised workers from a wider area. Third, it creates economies of scale in transport infrastructure and services to key suppliers and markets. Fourth, it provides access to greater diversity of labour and materials needed to produce goods and services. Evidence suggests the impacts of agglomeration on productivity can be large. For example, larger cities are associated with higher productivity levels. Eddington and DfT (2006) found that a doubling of a city size is associated with an increase in productivity of between 3-8%, while Graham (2006) found that in the UK, a 10% increase in agglomeration is associated with a 1.25% increase in productivity.

In turn, these productivity benefits drive further agglomeration. The productivity benefits of location within agglomerations provides incentives for other firms and workers to locate there as well. Furthermore, agglomerations may attract workers for other reasons, such as the greater range of goods and services available in large agglomerations.

Improving passenger transport could deliver agglomeration benefits. Passenger transport could drive agglomeration in two ways. First improving the speed and cost of travel within an urban area could attract more workers and increase city size. Second, improving the speed and cost of travel between an urban area and its surroundings could widen its catchment area, increasing opportunities for exchange of knowledge and access to skilled labour. There is some evidence that this has improvement has occurred in practice. For example, Graham (2004) and Rice and Venables (2005) estimate that a 10% reduction in travel time has the potential to increase productivity by between 0.4% to 1.1%, respectively.

However, the scope to deliver agglomeration benefits by improving freight transport is more limited. Improving passenger transport could delivers agglomeration benefits by facilitating the movement of people. Improving freight transport to facilitate the movement of goods would not offer comparable opportunities for exchange of knowledge and access to skilled labour.

Improving freight transport in specific locations could potentially encourage clustering in manufacturing sectors, though the resulting productivity benefits are highly uncertain. It is possible that improving freight transport in some areas could encourage major freight users to cluster in those areas. Manufacturing sectors are the most likely to cluster in response to better freight transport. Agglomeration in manufacturing sectors is driven partly by proximity to suppliers and to customers (Eddington, 2006), while retailers must locate where their customers are, and other service sectors are not major freight users. Therefore, it is possible improvements to the freight system connecting industrial clusters to suppliers and customers could encourage greater agglomeration and increases in sector productivity. However, current evidence does not suggest that the agglomeration has a large impact on manufacturing sector productivity For example Graham (2007) examined impact of agglomeration on firm level productivity across eight industry groups and found that the returns to the manufacturing industry is less than half as large as those for the service sector (particularly banking finance & insurance, business services and real estate). Finally, increased clustering in manufacturing sectors could displace manufacturing activity from regions with relatively poorer freight transport, reducing employment opportunities there.

In contrast, improving freight transport overall would not encourage clustering in manufacturing sectors. While improving the freight system connecting manufacturing clusters to suppliers and customers could increase the advantages of locating in those cluster, improving the freight system overall could reduce these advantages, and limit the extent of manufacturing sector agglomeration.

5.5 Integrating new regions to the economy

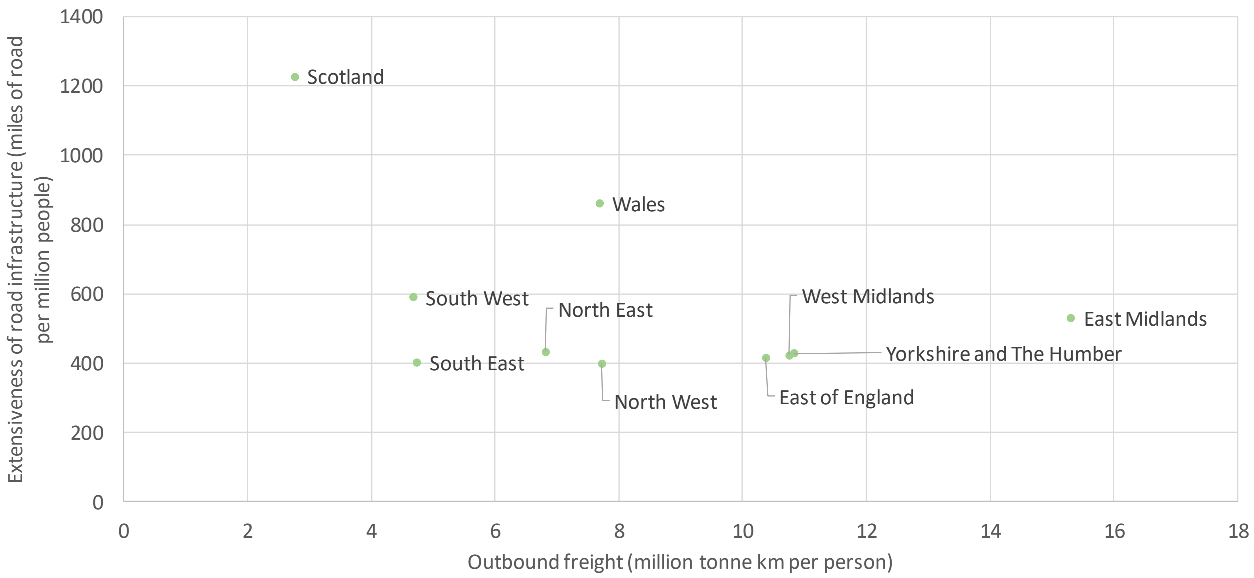
By integrating markets, the freight system benefits both producers and consumers. The freight system provides access to import markets, allowing manufactures to source low-cost raw materials and intermediate products, and consumers to purchase low-cost finished products. It also provides access to export markets, allowing manufacturers to developing efficient scale in production. A region that is poorly connected to the freight system will face constrained access to markets, and the competitiveness of its manufacturing sector and welfare of its consumers would be severely impaired.

Freight transport has driven over two centuries of regional integration. Initially limited to coastal shipping, successive development of canals, railways and the road network have integrated Britain's regions into a national market for manufactured goods.

- **Coastal shipping.** The first form of long-distance transport in the UK was coastal shipping. By the eighteenth century, coastal shipping transported goods, including coal and grain, up and down the East coast between London and coastal ports of Newcastle, Sunderland, and Scarborough (Bogart, 2013).
- **Canals.** Development of the canals began in the mid-18th century and by 1800 was largely complete, with a total length of over 2,400 miles (extending further than current motorway network). The canal system provided the freight infrastructure needed for the industrial revolution, and was an important determinant of the location of industry.
- **Railways.** Development of the railways began in the mid-19th century, as the industrial revolution was drawing to a close. Over the period 1830-1870 investment in the UK rail network averaged around 1.5 per cent of GDP per year. The railway network quickly eclipsed the canal network; by 1850 it extended for 6,000 miles of track, by 1900 was several times larger at almost 20,000 miles, and by 1920 was largely complete. While the railways opened up new possibilities for passenger transport, they had little impact on the location of industry over this time period (Crafts and Mulatu, 2005), suggesting that integration of manufacturing markets was already highly developed following the earlier development of the canals.
- **Road network.** While the UK had a road network before the 1930s, the development of the trunk road network in the 1930s and subsequent development of the motorway network in the 1960s enabled a massive expansion of motor vehicle traffic (Lowson, 1998). The road network quickly became the dominant transport choice in both passenger and freight transport. It also drove a shift in the location of industry, with the South East of England emerging as an important new manufacturing centre (Crafts and Leunig, 2005)

The freight system is extensive and connectivity is unlikely to be a major barrier to regional manufacturing activity. If improvements in freight infrastructure could improve regional integration, we would expect to see areas with less extensive road infrastructure suffering from lower freight trade. However, this is not the case. Figure 38 shows the extensiveness of major road infrastructure capacity and the volume of freight exported from eight English regions (excluding London), Wales and Scotland. As the volume of freight exported from a region could be limited by either its road capacity or the size of its population (and resulting ability to support a large manufacturing sector), both road capacity and outbound freight are expressed on a per capita basis. Figure 38 shows that areas which produce low volumes of outbound freight (Scotland, and South West and South East England) do not generally have significantly less extensive road capacity than regions which produce high volumes (the East Midlands, West Midlands and Yorkshire and the Humber). In fact, Scotland and South West England have considerably more extensive road capacity than do the East Midlands, West Midlands and Yorkshire and the Humber, suggesting that road capacity is not a barrier to producing higher volumes of outbound freight from these regions. All regions of Great Britain are therefore well connected by the road freight system, and it highly unlikely that there remain large opportunities to increase regional integration into the freight system.

Figure 38. **The English regions, Scotland and Wales are well connected by the road freight system**



Source: *Vivid Economics, Department for Transport*

6 Conclusions

The primary economic benefit of freight is supporting economic activity in other sectors. The freight system plays a vital role in supporting economic activity: it transports raw materials and intermediate products to factories, goods to ports and products to retailers, supporting manufacturing, exports and consumers. We have examined the theoretical and empirical evidence on the link between freight efficiency and economic activity, and found that wider economic benefits beyond a reduction in cost are likely to be small. Freight costs make up a small share of total costs in most highly traded and productive sectors, and are unlikely to be a material factor in attracting inward investment. While improving the quality of passenger transport facilitates the spreading of knowledge and is associated with higher levels of innovation, comparable benefits are unlikely to result in the case of freight transport. And the freight system is now extensive and regional economic benefits from integration with the wider manufacturing economy are likely to be very limited.

For freight to continue to play its vital role, it must continue to evolve. The freight system must improve outcomes in all key areas of efficiency: it must remain cost-competitive; minimise its impact on congestion; reduce its greenhouse gas emissions in line with the UK's climate targets; and remain resilient to future stresses. The conclusions of this study on these issues are set out below.

6.1 Cost

The cost of UK freight system is equivalent to around 4% of GDP. While diesel and wage costs have driven freight costs up, they have fallen as a share of GDP. We estimate that the UK spends up to £80 billion per year on road freight, rail freight and warehousing. Of this, road freight accounts for around £38 billion; rail freight for around £1 billion; and warehousing for £20-38 billion. Labour costs make up around one third of road freight and warehousing costs. As labour costs rise with incomes, road freight costs have risen over time. However, exposure to freight costs is declining and freight costs as a share of GDP have fallen over time.

New technologies - particularly, connected and autonomous vehicles, and robotics and automation - could significantly reduce freight costs. In the near-term, there may be some opportunities to reduce costs through incremental improvements in freight efficiency (for example, by reducing empty running and part-loading). The cost of freight can also be reduced by reducing congestion. In the longer-term, new technologies could deliver more significant cost reductions. Connected and autonomous vehicles could decrease the cost of road freight by around one third; robotics and automation could decrease the cost of warehousing by a similar amount. Together these technologies could reduce the cost of the UK freight system by £26 billion, equivalent to around 1.3% of GDP. Digitalisation and data science could offer further cost savings, though the magnitude of potential savings is very difficult to quantify.

A cheaper freight system will provide direct economic benefits. A reduction in the cost of freight, whether this is achieved through improving efficiency, reducing congestion or through automation, will free up resources (such as labour) for more productive uses and increase economic output. The reduced cost of freight will be reflected in lower production costs, benefiting both producers and consumers.

6.2 Speed and reliability

UK road freight suffers severe and worsening congestion problems, and addressing congestion is a high priority. Congestion could account for over 16% of the cost of road freight, equivalent to around £6 billion per year. Road congestion in the UK is among the highest across European countries, and is worsening. Congestion imposes economic costs; while estimates of the cost of congestion typically only account for lost time, congestion also increases expenditure on vehicles and fuel. The impact of congestion on of delays to freight journeys is currently poorly understood. Based on the available evidence, we estimate a range for the impact of congestion on delays. At the higher end of the range, we estimate that congestion could delay HGV journeys by around 23% today, potentially rising to 35% by 2050. Overall, we estimate that the total cost of congestion to the UK freight system today could be more than £6 billion, or 0.3% of GDP.

A number of factors contribute to congestion and its impact on the freight system. First, the UK's road and rail network capacity is strained by high levels of transport demand. Second, utilisation of the road network, particularly by passenger transport, is highly inefficient. Third, freight is typically consolidated in regional distribution centres located outside the urban areas that they serve, which increases the number of vehicle movements to retailers and other customers to, from and within urban areas. Fourth, van use is growing significantly; while the role of vans in freight transport is uncertain, growth in the use of vans to deliver freight would increase the volume of freight traffic.

The causes of congestion are complex, and a number of solutions could contribute to reducing congestion levels in future. Some infrastructure investment may be needed to mitigate congestion, though overall demand management is likely to provide a more cost-effective solution than a large-scale infrastructure investment programme. Road pricing could be an effective policy instrument to manage congestion. Location of freight distribution centres inside urban areas would reduce freight's contribution, and exposure, to congestion. Finally, further work is needed to understand the role of policy in driving efficient use of vans within the freight system.

6.3 Environmental impact

Freight transport is responsible for 6% of total greenhouse gas emissions today but if unabated, could make up around 20% of allowed emissions in 2050. Near- or full-decarbonization of freight transport is likely to be needed to meet the UK's climate targets. We estimate that freight transport as a whole emitted around 27 MtCO2 in 2016. If CO2 emissions from freight transport are not addressed, they could increase a further 20% to 2050 given increasing demand for travel. The Climate Change Act requires that greenhouse gas emissions in 2050 to decrease from 468 MtCO2e in 2016 to 160 MtCO2e in 2050. If freight transport emissions continue unabated, they would make up around 20% of this total. However, due to the challenges of reducing emissions in other sectors it is unlikely that unabated freight emissions can be accommodated over the long term.

The fundamental cause of freight transport emissions is the use of diesel fuel. However, a range of secondary factors contribute to the level of freight emissions. The highly centralised nature of the freight system increases travel distances as freight is diverted to consolidation centres between origins and destinations. The majority of freight is carried by road, which is less energy-efficient than rail. There are limitations to the size of freight vehicles, which could increase the number of vehicles and trips needed to meet freight demand. And moderate levels of empty running and part-loading might indicate a degree of inefficiency in freight operations.

A shift to alternative fuelled vehicles is urgently needed to decarbonise freight. Given such a shift, wider reforms to the freight system are less urgent. A complete shift to alternative fuelled vehicles would eliminate tailpipe greenhouse gas and air quality pollutant emissions in road freight. Prospects for deployment of alternative fuelled freight vehicles are strong: while these currently lag behind passenger vehicles, development of the technology is underway, and large cost reductions are expected in the near term. In contrast, the scope to decarbonise freight through alternative solutions such as moving to a more decentralised freight system, shifting significant freight volumes to rail, increasing the size of freight vehicles and reducing empty running and part-loading, highly uncertain and likely to be very limited. A shift to alternative fuelled vehicles is therefore an urgent policy priority.

6.4 Resilience

The risks faced by the UK freight system are changing as a result of climate change and digitalisation. A comprehensive review of freight resilience is needed to secure the freight system against future risks. A shift to alternative-fuelled vehicles will reduce the risks of fuel supply shocks, and a shift to connected and autonomous vehicles could reduce the vulnerability of the freight system to labour action. However, other risks are emerging. First, risks of infrastructure failure and extreme weather events could increase with climate change, and risks associated with information failures could increase as digitalisation increases reliance on complex information networks and exposure to failures in IT systems or cyber-attacks. Second, improvements in freight efficiency are likely to have reduced the resilience of the freight system. Firms increasingly hold fewer inventories in order to minimise the cost of warehouse space in urban areas. As a result, firms are increasingly exposed to disruptions in the reliability of the freight system. Given the new risks facing the freight system, and the need to make the right trade-off between efficiency and resilience, a comprehensive review of freight system resilience is needed to ensure that the freight system remains efficient while securing it against future risks.

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Annex: Estimating the cost of the freight system

This report presented estimates of the cost of the UK freight system (in Section 2) and how these costs are distributed among the various sectors of the economy (in Section 5). This technical annex describes the data sources and calculations Vivid Economics used to make these estimates.

Approach

As the cost of the freight system is not directly measured and reported, we use three sources of evidence to identify the possible cost and cost ranges for different elements of the freight system:

- National statistics data on turnover for firms in the various freight sectors;
- National accounts data on business expenditure on goods and services related to freight; and
- For road freight, analysis on expenditure on road freight vehicles, drivers and fuel, drawing on a range of publicly available data sources.

Turnover by firms in the freight sector.

The Office for National Statistics publishes data on turnover for firms in each sector of the UK economy. Table A1 sets out turnover by firms in the road freight, rail freight and warehousing sectors:

Table A1. **Turnover by firms in the road freight, rail freight and warehousing sectors**

Freight segment	Turnover (£ billion)
Freight transport by road	26.9
Freight rail transport	0.9
Warehousing, storage and cargo handling	20.3

Source: Annual Business Survey – 2017 Provisional Results

Turnover data from firms in the freight sector will significantly underestimate the cost of road freight and warehousing, as it will not include expenditure by businesses on their own freight and warehousing activities. Therefore, turnover data is useful in identifying a **lower bound** to the possible cost of these segments of the freight system. However, as businesses outside the rail freight sector to do not carry out their own rail freight activities, turnover should represent an accurate estimate of the cost of rail freight.

For road freight transport, it is possible to estimate total expenditure, based on turnover by firms in the road freight sector, and data from Department for Transport's Road Freight Statistics on the share of freight that businesses carry themselves. Road Freight Statistics indicates that only 70% of road freight is moved by public haulage operators, i.e. specialised firms whose turnover would be recorded in the Annual Business Survey. A further 30% of road freight is moved by 'own account operators', who carry goods only for their own trade or business. Adjusting the cost of road freight moved by public haulage companies for the share of freight moved by own account operators suggests that the total cost of road freight could be more like £38.5 billion.

For warehousing, available evidence does not provide an indication of the extent to which businesses carry out their own warehousing activities.

Business expenditure on freight services

The Office for National Statistics also publishes data on use of different goods and services by firms and households in each sector of the UK economy. Use tables are developed as part of the process compiling the UK's national accounts (estimates of economic activity). A use table shows how goods and services produced in the UK are used by businesses, households, or exported overseas. It disaggregates expenditure on goods and services produced in the UK by both the type of goods and services produced; and the sector of use. Table A2 sets out expenditure by firms on goods and services related to the road freight, rail freight and warehousing sectors:

Table A2. **Firms' use of goods and services related to road freight, rail freight and warehousing**

Type of good or service	Use of goods and services (£ billion)
Land transport services and transport services via pipelines, excluding rail transport	38
Warehousing and support services for transportation	38

Source: Office for National Statistics (2010): United Kingdom Input-Output Analytical Tables 2010

Expenditure by firms on goods and services in these sectors will likely **overestimate** the cost of freight, as these sectors include expenditure on goods and services other than freight:

- The 'Land transport services and transport services via pipelines, excluding rail transport' sector will include pipeline transport (for example, of oil and gas) and passenger road transport as well as freight transport;
- The 'Warehousing and support services for transportation' sector includes support services for transportation as well as warehousing.

Therefore, expenditure data is useful in identifying an **upper bound** to the possible cost of the freight system.

For the ‘Land transport services and transport services via pipelines, excluding rail transport’ sector, it is possible to estimate expenditure on road freight, as a share of total expenditure in this sector.

- The ‘Land transport services and transport services via pipelines, excluding rail transport’ category is made up of several sub-sectors. In addition to freight transport by road, these include Removal services, Transport via pipeline, Urban and suburban passenger land transport, Taxi Operation and Other Passenger land transport n.e.c.
- The annual business survey provides turnover in each of these sub-sectors. Turnover is set out in Table A3. Table A3 indicates that Freight transport by road accounts for 58% of turnover in the ‘*Land transport services and transport services via pipelines, excluding rail transport*’ sector, while other forms of transport account for the remaining 42%.
- However, a share of turnover in these sectors is earned through expenditure by households rather than businesses. While data on expenditure by households and businesses is not available, the Department for Transport provides data on the purpose of travel across different modes. The share of business travel in different modes is set out in Table A4. Table A4 indicates that the majority of travel in the ‘urban and suburban passenger land transport’, ‘taxi operation’ and ‘Other Passenger land transport n.e.c.’ sectors is carried out by households and not businesses. This data implies that the majority of expenditure in these sectors is similarly incurred by households and not businesses.
- Therefore, while freight transport by road accounts for only 58% of total turnover in the ‘*Land transport services and transport services via pipelines, excluding rail transport*’ sector, it accounts for a significantly higher share of the turnover in this sector from supplying businesses. Adjusting for the small share of business travel in other forms of transport, we estimate that freight transport by road could account for 90% of total turnover in the ‘*Land transport services and transport services via pipelines, excluding rail transport*’ sector from supplying businesses.
- Finally, while reported turnover in this sector reflects sales from public haulage companies, it does not reflect the cost to businesses of carrying their own goods (‘own account’ freight). Own account freight accounts for 30% of freight moved. Taking this into account we estimate that freight transport by road could account for 93% of business expenditure in the ‘*Land transport services and transport services via pipelines, excluding rail transport*’ sector.

For Warehousing and support services for transportation, available evidence does not provide an indication of the split between firms’ use of warehousing, and transportation support services.

Table A3. **Turnover in sub-sectors within the 'land excluding rail and pipeline transport' sector**

Variable	Unit	Year
Freight transport by road	26929	58%
Removal services	944	2%
Transport via pipeline	781	2%
Urban and suburban passenger land transport	12143	26%
Taxi Operation	1789	4%
Other Passenger land transport n.e.c.	3700	8%

Note: *'Urban and suburban passenger land transport' comprises: urban, suburban or metropolitan underground, bus and other passenger transport. 'Other Passenger land transport n.e.c.' comprises long-distance bus and coach transport and other suburban and extra-urban passenger transport.*

Source: *Source: Annual Business Survey – 2017 Provisional Results*

Table A4. **Share of business travel across different modes**

Mode	Share of business travel
Other private transport (mostly private hire bus including school buses)	4%
Bus in London	4%
Other local bus	2%
Non-local bus	0%
London Underground	8%
Taxi / minicab	6%

Source: *Department for Transport: Department for Transport Statistics (Average distance travelled by purpose and main mode: England, 2017; Table NTS0410)*

Analysis of road freight cost components

To supplement and verify our estimates of the cost of road freight developed using national statistics data on turnover and national accounts data on business expenditure, we also estimate expenditure on road freight vehicles, drivers and fuel, drawing on a range of publicly available data sources.

We estimate that the **ownership and maintenance of HGVs** could cost around **£10 billion per year**.

- Department for Transport's Vehicle Licensing Statistics record the number of licensed rigid and articulated goods vehicles over 3.5 tonnes, by gross vehicle weight.
- The Freight Transport Association publishes data on the average annual costs of operating freight vehicles of different types.
- Table A5 shows the number of licensed rigid and articulated goods vehicles of each weight category; the average annual costs of operating freight vehicles in that category; and total estimated expenditure on operating costs for each type of vehicle.
- As the vehicle categories used by the Department for Transport and the FTA are slightly different, judgment was used to estimate costs for each category of vehicle.
- The data suggests that total expenditure on operating costs for each type of vehicle was around £10 billion in 2017.

Table A5. **Ownership and maintenance of HGVs could cost around £10 billion per year**

Type of HGV	Number of vehicles (thousands)	Per vehicle costs (annual)	Total costs (annual)
	Rigid HGVs		
Up to 7.5t	112	12,500	1.4
Over 7.5t to 15t	31	15,000	0.5
Over 15t to 18t	60	19,500	1.2
Over 18t to 26t	53	22,000	1.2
Over 26t	39	30,000	1.2
Rigid HGV total	**294**		**5.3**
	Articulated HGVs		
Up to 26t	2	27,000	0.0
Over 26t to 34t	10	27,000	0.3
Over 34t to 38t	11	28,500	0.3
Over 38t to 40t	3	32,500	0.1
Over 40t	109	38,000	4.2
Articulated HGV total	135		4.9
	All HGVs		
All HGV total	**429**		**10.2**

Source: *Vivid Economics; Freight Transport Association (2018): Manager's Guide to Distribution Costs; Department for Transport (2018)*

We estimate that expenditure on **drivers** could cost around **£8 billion per year**.

- Office for National Statistics indicate that average weekly earnings for heavy goods vehicle drivers
- were around 556.2 per week in 2016 (data for 2017 are not available).
- Office for National Statistics employment data indicate that 302,000 people were employed as large goods vehicle drivers in 2016.
- Overall, these data suggest that the wage bill for heavy goods vehicle drivers could have been around £8.1 billion in 2017.

HMRC data indicates that expenditure on **diesel fuel** by HGVs could amount to around **£8.5 billion per year**.

- Department for Transport statistics indicate that heavy goods vehicles consumed 6.4 million tonnes, or 7.6 billion litres of diesel in 2016 (data for 2017 are not available).
- The Department for Business, Energy & Industrial Strategy estimate that the average price of diesel in 2016 was around 110 pence per litre.
- Overall, these data suggest that expenditure on diesel for heavy goods vehicles was around £8.5 billion in 2017.

Overall, we estimate that expenditure on road freight vehicles, drivers and fuel could add up to around £26.5 billion per year. This is of the same order of magnitude as the £38 billion estimated using national statistics data on turnover and national accounts data on business expenditure. The difference in estimates can be accounted for by additional costs incurred by the freight industry, such as salaries for transport managers and administration, sales, marketing and accounting personnel; costs of renting office space and running despatch offices; utilities bills such as gas, water and electricity; and other expenses such as maintaining fuel storage tanks and tachograph analysis (FTA, 2018).

Overall estimate of the cost of the freight system.

Overall, evidence suggests the cost of road freight could be around £38 billion per year.

- Our estimate based on National Statistics data on turnover is around £38 billion.
- Our estimate based on National Accounts Use Tables data is around £35 billion.
- Our estimate based on analysis on expenditure on road freight vehicles, drivers and fuel is around £30 billion.

The cost of rail freight could be around £1 billion per year.

- Our estimate based on National Statistics data on turnover is around £1 billion.

The cost of warehousing and cargo handling could be around £20-£38 billion per year

- Our estimate based on National Statistics data on turnover is around £20 billion.
- National Accounts Use Tables data indicate that the cost of warehousing and cargo handling is no more than £38 billion.

Data sources used

The following data sources were used to provide the three estimates of freight system costs outlined above:

- Department for Business, Energy & Industrial Strategy (2019): Monthly and annual prices of road fuels and petroleum products
- Department for Transport (2017): Road Freight Statistics Table RFS0107: Goods lifted and goods moved by commodity and mode of working: 2017
- Department for Transport (2018): Petroleum consumption by transport mode and fuel type: United Kingdom from 2000 (Table ENV0101/TSGB0301)
- Freight Transport Association (2018): Manager's Guide to Distribution Costs
- Office for National Statistics (2018): Annual Business Survey – 2017 Provisional Results
- Office for National Statistics (2018): Employment by occupation (Table EMP04)
- Department for Transport (2018): Goods vehicles over 3.5 tonnes licensed by gross vehicle weight (tonnes), rigid or articulated: Great Britain and United Kingdom (Table VEH0521)
- Office for National Statistics (2019): Average Weekly Earnings time series

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Company Profile

Vivid Economics is a leading strategic economics consultancy with global reach. We strive to create lasting value for our clients, both in government and the private sector, and for society at large.

We are a premier consultant in the policy-commerce interface and resource- and environment-intensive sectors, where we advise on the most critical and complex policy and commercial questions facing clients around the world. The success we bring to our clients reflects a strong partnership culture, solid foundation of skills and analytical assets, and close cooperation with a large network of contacts across key organisations.