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HIGHER CAPACITY VEHICLES (HCVs)

Briefing Report

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Higher Capacity Vehicles (HCVs) - Briefing Report

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Executive Summary

Introduction

Policy commitments to reduce greenhouse gases (GHG) in the UK and many other countries require the road freight industry to achieve major change in relation to this aspect of vehicle activity. In the UK, the road freight industry has pledged support to the government's voluntary commitment to reduce GHG emissions from heavy goods vehicles by 15% by 2025 (from 2015 levels), and will also play its part in the government's commitment bring all GHG emissions to net zero by 2050. Research for the Committee on Climate Change's Fifth Carbon Budget into the potential for logistics management measures to bring about reductions in GCG emissions in the freight industry indicated that the use of HCVs for long distance freight transport could play an increasingly important role from 2025 on if permitted by government (Greening et al., 2015). In addition, to contributing to GHG emissions reduction, the use of HCVs also has the potential to reduce road freight vehicle kilometres and air pollutant emissions.

This briefing report provides a summary of the findings from field trials and other research into the topic of Higher Capacity Vehicles (HCVs) to help inform those involved with public policy and corporate decision-making. The size and weight of goods vehicles operated varies considerably between countries. The term 'HCVs' in this report refers to vehicles that are greater in terms of volume and/or weight carrying capacity than those currently permitted.

In the majority of European Union countries (besides the UK) that have trialled or implemented HCVs this refers to a vehicle with a maximum length of 25.25 metres and weights of 60-75 tonnes (referred to as the European Modular System - EMS). In other countries, such as Australia, Finland and South Africa, HCV lengths and weights exceed these.

Current vehicle size and weight limits

Many countries have trialled and subsequently adopted HCVs in recent decades. Maximum vehicle lengths up to 25.25 metres (and weights of up to 76 tonnes) are common in EU and Scandinavian countries. HCVs operate in other countries including Australia, Brazil, Canada, Finland, and South Africa.

The maximum weight of goods vehicles in the UK was last increased in 2001 (to 44 tonnes), and the maximum length of a semi-trailer (a tractor unit towing a trailer), was last increased in 1990 (to 16.5 metres). In 2012, the UK Department for Transport (DfT) set up a 10-year longer semi-trailer (LST) field trial in which 2000 vehicles in two length categories are permitted on British roads "to test the impact of such operations on efficiency, and on emissions" (but the trial vehicles having to remain within the existing 44 tonnes weight limit). The trial has now been extended to 2027.

Potential impacts of HCV use

Four major review studies into the effects of HCVs have been carried out in recent years, one for the European Commission published in 2009, two by the OECD/ITF in 2011 and 2019, and another for the European Parliament in 2013 (Christidis and Leduc, 2009; OECD/ITF, 2011 and 2019; Steer et al., 2013). All four are deemed 'globally positive' towards HCVs with statements such as the introduction of HCVs "would be beneficial for the EU economy and, under certain conditions, environment and society as a whole" (Christidis and Leduc, 2009, p.24), HCVs, "would be unlikely to work against the EU's objective of reducing road deaths by 50% from 2010 levels by 2020" and "could help with the EU's objective of reducing greenhouse gas emissions by 20% from 1990 levels by 2020" (Steer et al., p.10), and HCVs "can contribute to improving the efficiency and safety of road transport operations and reduce transport costs and energy demand" (OECD/ITF, 2019, p.5).

The use of HCVs has several potential impacts, some of which are beneficial and some not. These potential impacts can be divided into five main categories:

1. *Freight transport vehicle activity*
   a) HCVs can facilitate the consolidation of loads into fewer vehicles (and hence a reduction in total truck kms).
   b) Possible modal shift of freight from rail and intermodal operations to HCVs to take advantage of lower operating costs they provide.
   c) Possible impacts on traffic flow (by potentially increasing or reducing it).
   d) Possible generation of increased demand for freight transport if companies respond to the reduction in freight costs by making their logistics operations more transport-intensive (e.g. more distant sourcing, more centralised stockholding, or more frequent deliveries). This is often referred to as a 'rebound effect'.
2. *Environmental impact of freight transport*
   a) Possible change in road vehicle emissions and noise due to changes in vehicle size/weight and total vehicles kilometres (kms).
   b) Possible environmental impacts of mode shift from rail and intermodal to HCVs (which can alter the environmental benefits of HCV load consolidation).
3. *Freight transport operating costs*
   a) Possible changes in the cost per unit of goods transported.
4. *Road freight traffic collisions and casualties*
   a) Possible change in the incidence of road traffic collisions from using HCVs.
   b) Possible change in the frequency and severity of casualties from using HCVs.
5. *Road infrastructure costs*
   a) Possible changes in road maintenance costs due to HCV use.
   b) Possible expenditure on road infrastructure modifications for HCVs (including bridge strengthening).

A review was carried out of HCV field trials, post-implementation analyses and theoretical modelling studies that have assessed the above impacts of HCVs in recent years. Table 1 provides a summary of the type and number of field trials and desk studies that have investigated HCV impacts in relation to each topic and sub-topic outlined above, the countries in which these have taken place, a summary of the research findings, and an indication of whether HCV use is likely to result in a positive (+) or negative impact or (-) or no change (0) (based on these findings). A fuller version of Table 1 which provides references to all the field trials, post-implementation analyses and modelling studies reviewed is provided in Appendix 1.

Table 1. Review of results of trials and desk studies into impacts of HCV use

Impact topic and sub-topic	Number and type of studies	Countries	HCV impact	Impact
1. Freight transport vehicle activity				
a) Consolidation of loads onto fewer vehicles	5 field trials & 2 post-implementation analyses	Australia, Finland, Germany, Norway, South Africa, Sweden, UK	South Africa: average 22% reduction in vehicle km per vehicle. UK: average 7% reduction in vehicle km per operator (LST trial of vehicles with greater length but unchanged weight, so less scope to reduce vehicle kms).	+
	2 theoretical modelling studies	Spain, UK	Spain: 1-3% reduction in national road freight kms (taking account of modal shift)	+
b) Modal shift from rail to HCVs	3 field trials & 2 post-implementation analyses	Netherlands, Sweden, UK	No discernible effect on modal shift.	0
	6 theoretical modelling studies	UK, Germany, EU-wide	Very marginal to 18% reduction in rail freight activity.	-
c) Traffic flow	1 field trial and 1 post implementation analysis	Norway, EU	Norway: Marginal worsening in traffic flow. EU: no significant effect on traffic flow found.	0/-
d) Increased demand for freight transport ('rebound effect')	1 post-implementation analysis	UK	Little evidence of additional demand for freight transport.	0
	1 theoretical modelling study	Sweden	1-17% increase in road freight depending on assumed HCV weight/length.	-
2. Environmental impact on freight transport				
a) Road vehicle emissions and noise pollution from HCV use	7 field trials	Australia, Denmark, Netherlands, Germany, Norway, South Africa, UK	Reductions in fuel consumption and CO_2 emissions per tonne-km and in total operations reported in several trials. Denmark and Netherlands: No impact on vehicle noise.	+
	2 desk study	UK, Germany	Reductions in emissions per unit of goods transported.	+
b) Modal shift from rail to road	1 desk study	Germany	Estimated 0.01% increase compared to total GHG emissions from rail freight in 2010.	0/-
3. Freight transport operating costs				
a) Changes in vehicle operating costs	2 field trials	Australia, Germany	HCVs have lower operating costs than conventional non-HCVs (if additional volume and/or weight capacity is utilised.	+
4. Road freight traffic collisions and casualties				

a) Collisions with HCV use	3 field trials	Australia, Germany, South Africa	Australia/SA: HCVs have lower collision rates per million km than non-HCVs. Germany: No measureable impact on road safety at motorway sites.	
b) Casualties with HCV use	2 field trials & 1 post-implementation analysis	Australia, Sweden, UK	Australia: HCVs have lower fatality rate per million km than non-HCVs. Sweden: Longer vehicles (18.75 m) have lower fatal and serious casualty rate per billion km than shorter vehicles. UK: HCVs have lower rate of injury incidents than non-HCV articulated vehicles.	+
5. Road infrastructure costs				
a) Road and bridge maintenance costs due to HCV use	3 field trials	Australia, Norway, South Africa	South Africa & Australia: estimated reduction in road wear and road maintenance costs. Norway: Impact of HCVs on roads compared to conventional vehicles varied from marginally better to marginally worse.	0/+
	2 desk studies	UK and EU	UK: HCVs pose no greater risk to bridge damage than conventional vehicles as axles load are not increased. EU: Bridge loading - HCVs no more aggressive than conventional vehicles. Road wear - conventional drawbar combination more aggressive to the pavements than most of the LHVs studied.	0
b) Expenditure on road and bridge modifications for HCVs	1 field trial and 1 actual implementation	Denmark, Norway, Sweden	Denmark/Norway: little expenditure on road infrastructure adjustments for trials. Sweden: Sizeable expenditure for load bearing when increasing permissible vehicle weights from 51.4 to 60 tonnes.	0/-

Conclusions

The results of field trials and desk studies, together with the everyday use of HCVs in some countries, indicate that concerns expressed by some about their economic, safety and environmental impacts have been overstated. This review has found a growing consensus among the research community that a well-loaded HCV will, through its greater load capacity, result in a reduction in vehicle journeys and hence vehicle kilometres and that this in turn will lead to lower greenhouse gas (GHG) emissions and air pollutants than conventional road vehicles per unit of goods carried. The reduction in vehicle kilometres will result in reductions in total vehicle collisions and injuries, and this road safety improvement can be further assisted by the application of Performance Based Standards (PBS) to HCVs to reduce collision and injury rates per vehicle kilometre travelled. Also, the review work carried out does not support the notion that HCV use will lead to worse outcomes in terms of road infrastructure wear and tear, which will be dependent on the vehicle size and weight combinations and axle loads permitted.

Some of the evidence reviewed suggests that HCVs can lead to modal shift from rail to road, and that the lower operating cost of HCVs can result in a greater total demand for freight transport. However, the evidence indicating that HCVs could lead to these negative impacts is from theoretical modelling work that makes use of assumptions concerning the relationship between freight operating costs and the demand for freight transport (i.e. elasticity values) and vehicle load factors. There is limited evidence and consensus about the appropriate elasticity values to use in such modelling. It should be noted that real-world field trials and actual implementations of HCVs have provided no evidence of modal shift towards HCVs, or increased total demand for freight transport.

Other important factors in the extent to which the use of HCVs in the UK would alter total truck kms include: i) the road network over which their use is permitted, ii) the vehicle size/weight limits permitted, iii) the perceived financial costs and benefits of HCV use by freight operators, iv) the type of product carried and transport service provided, and v) the extent to which collection and delivery locations are updated to facilitate handling HCVs. The sectors in which HCVs are most likely to be used include: the Fast Moving Consumer Goods (FMCG) sector (for movements between factories, distribution centres and retail sites), trunk routes in pallet-load networks, , raw material and industrial product distribution, mail and parcels transport (to and from national sortation hubs), container transport to and from deep-sea ports, and the forestry sector (Knight et al., 2008; Risk Solutions, 2018).

The reduction in total goods vehicle kilometres as a result of permitting the operation of HCVs depends on several factors including: i) the HCV regulations implemented (i.e. the maximum vehicle length and weight permitted), ii) the operating conditions imposed on these HCVs (such as route restrictions), and iii) the applicability of HCVs to prevailing freight transport sectors and their operations (which will depend on factors including types of products carried, journey types made, vehicle costs, and the ease with which HCVs can accommodated at existing delivery and collection facilities).

The authors of this briefing report are of the opinion that HCV use is suited to long-distance freight movements on trunk roads, and not for operations in built-up urban areas or villages.

It is also important to note that the use of HCVs would not result in increases in the weight carried per axle. Instead, in field trials and implementations in other countries, HCVs have lower weights per axle through the use of an increased total number of axles, thereby better spreading the weight of the load. As a result, HCVs would not be expected to increase road infrastructure wear and tear, and can reduce it.

Long-distance road freight vehicles are likely to become autonomous (driverless) in future. Experimenting with and implementing HCVs in advance of this will permit countries to utilise greater vehicle capacity when such autonomous vehicles are available.

A 2008 desk study estimated that if the maximum number of trips that were applicable to HCVs were transferred to them then the reduction in kilometres travelled by goods vehicles of 32 tonnes and heavier in the UK would be considerable (a 13-52% reduction in vehicle kilometres travelled if there were no road restrictions on HCVs, and a 3-13% reduction in vehicle kilometres travelled if HCVs were allowed on motorways and other roads within 20 km of a motorway only (depending on the size/weight configuration of HCV) (Knight et al., 2008). This same UK study indicated that the actual transfer from conventional articulated trucks to HCVs would be far less than the maximum theoretically possible. Preliminary analysis from the current UK longer semi-trailer (LST) field trial indicates that, depending on the sector the vehicles are used in and whether or not collection and delivery locations are updated in future to facilitate the handling of longer vehicles, operators in the trial state they would like to replace 9-30% of their current trailer fleet with longer vehicles. The UK LST trial results estimate an average vehicle kilometre saving of 7% per operator, which varies by operator from 1% to 14% (Risk Solutions, 2018). It should be noted that the maximum potential distance travelled savings per vehicle in the LST trial are lower than those possible for HCVs which accommodate greater weight capacities as well as greater vehicle length. The findings of this

2008 UK study are still considered to be applicable, and together with the results to date from the on-going UK LST field trial, indicate that if policy makers should decide to permit the use of HCVs in the UK this would be expected to result in a reduction in vehicle kilometres travelled.

The reduction in total vehicle kilometres required to transport the same quantity of goods (compared to using conventional non-HCVs) that HCVs can result in has an important benefit in terms of lowering total vehicle collision and injury rates. In addition, evidence suggests that the application of PBS to HCVs including better inherent vehicle dynamic performance, improved driver training and vehicle maintenance, together with route selection/compliance and overloading controls can result in lower collision and injury rates per vehicle kilometre travelled than for non-HCVs. Experiences running HCVs utilising such best protocol methods have yielded significant safety benefits with much reduced collision and injury rates.

When combined with the productivity benefits, substantially lower fuel consumption and carbon emissions per unit of goods transported compared with conventional vehicles that these vehicles have demonstrated in practical trials, it seems clear that the UK government should reconsider its policy regarding adoption of HCVs.

Recommendations

Given the evidence available from field trials and implementations reviewed in this report about the contribution that HCVs can make to reducing goods vehicle traffic, GHGs and air pollutant emissions, we recommend that the UK government reconsider its policy regarding the adoption of HCVs.

HCVs operate should take place only on suitable routes on the UK road network. While HCVs may need to use a limited road network other than trunk roads in order to collect and deliver product to distribution centres and other facilities, it is not recommended that general use of HCVs in urban areas or rural roads be considered. We recommend that the government commence work into the consideration of suitable roads and routes for HCV operation in the UK.

HCVs are likely to be best suited to trunking operations on motorways and dual carriageways in the movement of products between factories and distribution centres in various sectors including manufacturing and retail supply chains, pallet-load networks, parcel and mail transportation to and from national sortation hubs, transport to and from deep-sea ports, and in the forestry industry.

In considering the configuration and operating conditions of HCVs in the UK, it is important to make use of HCV best practice that has been developed in other countries where vehicles that are longer and/or heavier than those currently permitted in the UK have been trialled and implemented. There is a wealth of international knowledge and experience that can be drawn on.

This report has summarised findings from HCV field trials and implementations in many other countries. Some of these countries, such as Australia and South Africa, have very different conditions to the UK in terms of factors such as traffic levels, geographical scales and population densities. In these countries the size and weight of HCVs is not necessarily practical in a UK context. HCV trials and implementations in European countries with factors that are broadly comparable to the UK, and which have trialled or implemented HCVs up 25.25 metres and 60 tonnes, are likely to provide the greatest relevance to considerations about HCVs in the UK (such as Denmark, Germany, the Netherlands and Spain). We recommend that the government gives consideration to the lengths and weights of HCVs appropriate for use in the UK.

Evidence from HCV trials and implementations in other countries indicates that in planning for the role of HCVs in the UK, the government should consider their introduction in conjunction with the adoption of Performance Based Standards (PBS) for vehicle design and associated management and monitoring techniques for these vehicles to help ensure their achievement of established road safety, road infrastructure wear and tear targets, and route compliance. We recommend that the government gives consideration to the performance targets for HCVs in the UK.

We recommend that the government commission a detailed study to gain insight into HCV implementation issues appropriate for the UK including driver training, vehicle maintenance, vehicle performance (in terms of road safety, and road wear and tear), designated routes, infrastructure modifications necessary, vehicle and load monitoring.

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1. Introduction

Increasing the maximum permissible size or weight limits of goods vehicle (also referred to as higher capacity vehicles (HCVs), and longer and/or heavier goods vehicles (LHVs)) is a much-contested topic. It has been referred to as, "a lethal cocktail of empirical evidence, sectional interests, political lobbying and emotion" (McKinnon, 2014). Supporters argue that allowing longer and/or heavier vehicles facilitates a reduction in road freight transport activity and operating costs through the consolidation of goods onto fewer vehicles, which in turn provides traffic and environmental benefits. While many research reports and academic studies support these benefits, according to the European Transport Safety Council (ETSC) there are approximately 200 organisations from more than 20 European countries that oppose HCVs (ETSC, 2011). Those against, argue that HCVs lead to the transfer of goods to road from less environmentally-damaging modes, can stimulate increases in the total demand for freight transport and associated environmental impacts, can lead to an increase in the severity of vehicle collisions, and that operators already underuse their available vehicle capacities.

This briefing report presents a summary of the findings from field trials and other research into HCVs to help inform those involved with public policy and corporate decision-making. It has been produced as part of the Centre for Sustainable Road Freight (SRF – EPSRC grant number EP/R035148/1). Further details about the SRF project are available at: http://www.csrf.ac.uk/

The use of the term 'LHV' implies that the vehicle under consideration is longer and/or heavier than some comparison baseline vehicle. However, there is no agreed definition of a suitable baseline vehicle, and LHV could imply either greater size, weight or both. Therefore the term 'HCVs' is becoming more commonly used as it encompasses changes in vehicle weight and volume capacity, and is used in this briefing report. There are many different possible and actual types of HCV in terms of weight, length and volume. In terms of length, in the European context HCVs are likely to refer to various possible combinations of vehicle units that comprise the European Modular System (EMS) at 25.25 metres in length.

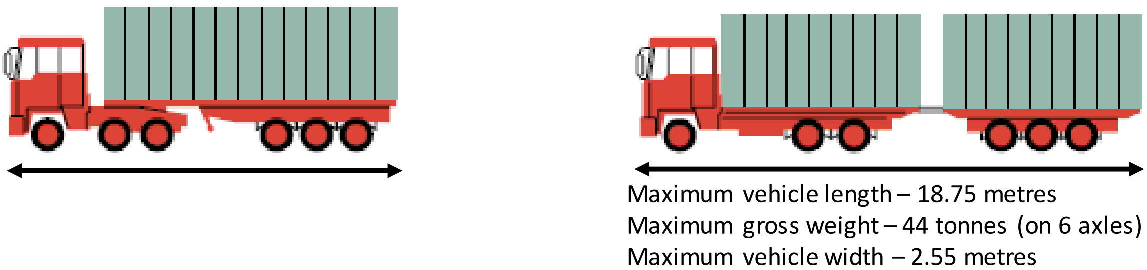
2. Policy developments in the UK

In the UK increases in maximum vehicle weights have come about since the inception of the road goods vehicle in the early 20th century as a result of developments in: (i) road and vehicle technology, and (ii) campaigning and lobbying by the road freight industry (Boyes, 2003). Both of these have factors have persuaded policy makers to increase maximum gross vehicle weights on various occasions. The maximum permissible weight for a goods vehicle was 20 tons (20.3 tonnes) in 1905, and was increased to 22 tons (22.4 tonnes) in 1922, 32 tons (32.5 tonnes) tons in 1947, 38 tonnes in 1983, 41 tonnes in 1999 and 44 tonnes in 2001 (Boyes, 2003).

By contrast, maximum permissible axle weight has increased relatively little over the history of the goods vehicle due to the rapidly increasing road damage that occurs as axle weights are raised, in proportion to the fourth power of the axle load. When axle weights have been increased this has mainly been as a result of wheel and vehicle suspension improvements. In the UK, the 8 ton (8.1 tonnes) maximum axle load for goods vehicles in 1904, was increased to 9 tons (9.1 tonnes) in 1955 after the virtual disappearance of solid tyres, and then to 10 tonnes on 1966 for vehicles with twin or wide tyres, to 11 tonnes in 1983 for 4-wheeled axles, and to 11.5 tonnes in 1999 for vehicles with only one driving axle and 'road-friendly' suspensions (Boyes, 2003). Over the same time period, maximum vehicle weights have been increased by a far greater proportion, mainly by increasing the number of axles on the vehicle.

Permissible maximum vehicle widths and lengths have also increased in the UK over time (lengths more so than widths due to road width constraints). The maximum permissible length of a semi trailer (a tractor unit towing a trailer) has increased from 33 feet (10.1 metres) in 1922, to 35 feet in (10.7 metres) 1955, to 13 metres (42 feet 7 inches) in 1964, to 15 metres (49 feet 2.5 inches) in 1968, to 15.5 metres in 1983, and to 16.5 metres in 1990. The maximum length of a drawbar combination is currently 18.75 metres . Maximum vehicle widths were 7 feet 2 inches (2.18 metres) in 1904, 7 feet 6 inches (2.29 metres) in 1931, 8 feet in 1955 (2.44 metres), 2.5 metres (8 feet 2.5 inches) in 1964 and 2.55 metres since 1996 (Boyes, 2003). With the exception of the period 1983 to 1995, there has been no specified height limit for goods vehicles or their loads (but is limited to 4.0 metres for international journeys within the EU). This means that UK trucks are some of the tallest in the world with some trailer heights over 5 metres. It gives the option of running very productive ‘double-deck' trailers. The current maximum permitted size and weight of goods vehicles permitted in the UK are shown in Figure 1.

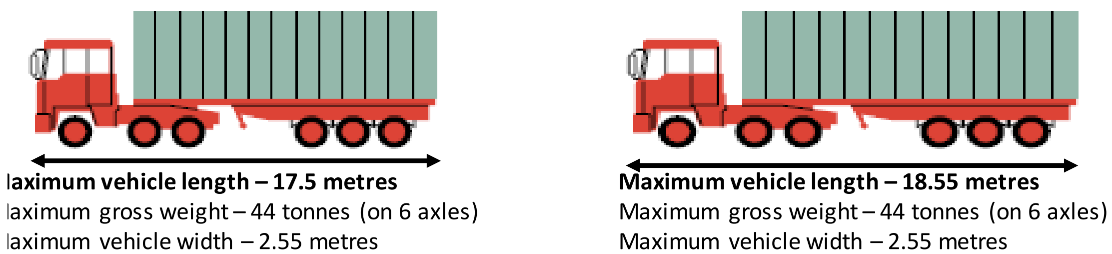
Figure 1. Current maximum goods size and weight in the UK



Source: Vehicle images from DfT, 2013.

Research studies into possible HCV options was carried out for the UK Department for Transport (DfT) in 2008 (Knight et al., 2008; Knight et al., 2010, Knight et al., 2011). The DfT decided not to implement any of the options studied and to rule out vehicles “significantly beyond the existing limits of 18.75 metres length and 44 tonnes gross vehicle weight” as impractical in the UK (DfT, 2011). Instead, the DfT set up a 10-year longer vehicle trial in 2012 (referred to as the Longer Semi-Trailer (LST) field trial) in which 2000 semi-trailers in two length categories (maximum trailer lengths up to 14.6 metres and 15.65 metres, and maximum vehicle lengths up to 17.5 metres and 18.55 metres) were permitted on British roads “to test the impact of such operations on efficiency, and on emissions” (Risk Solutions, 2013) (see Figure 2). The trial only concerns vehicle length - the trial vehicles have to remain within the existing 44 tonnes weight limit. Given that there is no legal vehicle height limit in the UK, only a practical one concerning height clearance at bridges and tunnels) some of the trailers in the LST trial have been very tall as well as longer than usually permitted. Companies participating in the trial range from the very small to the very large (with 27% of companies having 50 or fewer drivers, and 11% of companies having more than 250 drivers) (Risk Solutions, 2018). The trial has now been extended to 2027 and is expected to increase the number of vehicles in the trial to 2800.

Figure 2. Longer semi-trailers trialled in the UK since 2012



Source: Vehicle images from DfT, 2013.

3. Policy development in European Union countries and the rest of Europe

Maximum dimensions and gross weights of goods vehicles vary between countries. Vehicles of up to 24 metres were permitted in Sweden in 1968, and by 1974 these were allowed to operate at gross weights of up to 51.4 tonnes (Vierth, 2018). More recent increases in vehicle lengths and weights in EU countries have come about following: i) evaluated national vehicle trials that have persuaded governments to implement change (such as in Finland, Sweden, the Netherlands, and Germany), and ii) the accession of Finland and Sweden to the EU in 1995, which led in 1996 to them being granted permission to allow national vehicle weights and sizes in excess of other member states to remain in national use. To achieve this EU Directive 96/53/EC was implemented to allow all member states to permit the operation of HCVs if they conformed to the European Modular System (EMS) (European Council, 1996; McKinnon, 2012). The EMS facilitates the combination of existing loading units (modules) that are permissible under EU Directive 96/53 into longer and heavier combinations up to 25.25 metres in length that can be used on some parts of the road network. Other EU member states only chose to permit HCVs more recently (Conference of European Directors of Roads, 2017).

In addition, in efforts to promote sustainable freight transport, Directive (EU) 2015/719 grants derogations from the maximum dimensions of vehicles set out in the 1996 directive for the: (i) inclusion of aerodynamic devices to the rear of vehicles or to redefine the geometry of tractor to improve drivers' field of vision, as well as their safety and comfort; (ii) a weight increase of one tonne for vehicles with an electric or hybrid propulsion, to take account of the weight of batteries or the dual motorisation, without prejudice to the load capacity of the vehicle; and (iii) facilitation of the development of intermodal transport by allowing a derogation of 15 cm in the length of trucks carrying 45 foot containers, which are used in intercontinental and European transport (European Council, 2015; European Parliament, 2019).

Most notable in terms of maximum lengths within the EU is Finland which in January 2019 extended the maximum length of a vehicle combination to 34.5 metres. In Sweden (since 1996), Germany (since 2017), the Netherlands (since 2011) and Spain (since 2016 with prior authorisation) road trains up 25.25 metres (and semi-trailers of up to 24 metres in the case of Sweden) have been permitted (Gutberlet et al., 2017; EMS, 2011; EMS, 2019; Ministerio De La Presidencia, 2015; Vierth et al., 2018). These vehicles are usually restricted to an authorised route network for reasons including their size relative to the local roads and their traffic effects on overtaking by other vehicles (Conference of European Directors of Roads, 2017). The so-called LANG-Lkw trials of a 17.8 metre articulated vehicle with a 14.9 metre semi-trailer in Germany were extended for seven years on a dedicated road network in 2017 (Conference of European Directors of Roads, 2017). Outside the EU, semi-trailers of up to 24 metres are permitted in Belarus, 22 metres in Ukraine, and 20 metres in Armenia, Georgia and Russia (ITF, 2015a and 2015b).

In terms of maximum weights several EU member states permit vehicles above 44 tonnes. Finland, Sweden, Spain, Denmark, the Netherlands and the Czech Republic permit road trains with gross weights up to 76, 64, 60, 56, 50 and 48 tonnes respectively. In Sweden, 74 tonne vehicles are permitted on some dedicated forest roads. Several EU member states also permit semi-trailers to operate at above 44 tonnes, these are Finland (48), Sweden (64 tonnes), Denmark (56 tonnes), the Netherlands (50 tonnes) and the Czech Republic (48 tonnes) (Conference of European Directors of Roads, 2017; ITF, 2015a and 2015b; Ministerio De La Presidencia, 2015). Maximum permissible weights were increased from 40 to 44 tonnes by 15 of the 16 German federal states in 2017 (Gutberlet et al., 2017; OECD/ITF, 2019).

Maximum permissible vehicle heights increased in Ireland in 2013 (from 4.2 to 4.65 metres) (Irish Department of Transport, Tourism & Sport, 2013).

4. Policy developments in the rest of the world

Maximum vehicle dimensions and gross weights vary across other countries worldwide. For instance, maximum width varies from 2.5 metres in South Africa, Australia, New Zealand, many Asian countries and some countries in Africa to 2.59 metres (102 inches) in the United States, and 2.60 metres in Canada. Maximum vehicle length also varies, being as long as 26 metres for a road train (a rigid vehicle coupled to one or more trailers, or a tractor coupled to two or more trailers) in most Australian states (and road trains of up to 53.5 metres that operate in remote regions). In Canada vehicle height is usually limited to 4.15 metres, in Australia to 4.3 metres (4.6 metres in specific operations), some African countries permit vehicle heights of up to 4.6 metres, while in some countries no height limit is specified (as in the UK and is determined by practical road infrastructure limits and safe loading). The maximum gross vehicle weight varies from just 36.3 tonnes (80,000 lbs) on Interstate highways in the US to 45–56 tonnes in Mexico, South Africa and Canada (up to 63.5 tonnes in Canada for some road trains), and up to 68 tonnes for road trains and 130 tonnes for quad road trains (i.e. a road train comprising four trailers) in Australia. Larger and/or heavier vehicles are also permitted to operate in many countries in specific circumstances and subject to vehicle routing restrictions. (OECD/ITF, 2011; National Heavy Vehicle Regulator, 2016; Task Force on Vehicle Weights and Dimensions Policy, 2016; South African National Roads Agency Limited, 2018; United States Department of Transportation Federal Highway Administration, 2015).

In several countries outside Europe a 'performance-based standards' (PBS) approach is taken to vehicle size and weight regulation for HCVs (see section 5 for further details).

Examples of the maximum goods vehicle sizes and weights introduced in selected countries since 2013 are shown in Table 2.

Table 2. Maximum goods vehicle size and weights in selected countries

Country	Regulation *(Tonnes/Metres)*	Year established
The Netherlands	60 t / 25.25 m	2013
Finland	76 t / 25.25 m	2013
Denmark	60 t / 25.25 m (long-term trial)	2014
Norway	60 t / 25.25 m	2014
Sweden	64 t / 25.25 m	2015
Spain	60 t / 25.25 m (special permits)	2016
Germany	40/44 t / 25.25 m	2017
Brazil	91 / 74 t; 91 t, max 60 km/h	2017
Argentina	75 t / 25.25 m	2018
Sweden	74 t / 25.25 m	2018
Finland	76 t / 34.5 m	2019

Source: OECD/ITF, 2019.

5. Performance-Based Standards and related management practices

In several countries outside Europe (including South Africa, Canada, Australia and New Zealand) a 'performance-based standards' (PBS) approach is taken to vehicle size and weight regulation for HCVs to ensure that they are suitable for the roads on which they will operate (ACEA, 2019; Conference of European Directors of Roads, 2017; Moore et al., 2014). PBS "are a set of defined manoeuvres designed to evaluate vehicle dynamic and kinematic response characteristics. The performance metrics are normally evaluated through computer simulation however in most cases they can also be measured on full-scale test tracks" (OECD/ITF, 2019). PBS metrics set a required level of vehicle performance that designers must meet to ensure that the vehicles "behave in predictable ways and that they can successfully manoeuvre in constrained space" (OECD/ITF, 2019).

Alongside PBS for vehicle design, regulators can impose a range of operational management and monitoring requirements for HCVs. These can help further ensure that HCVs meet the desired operational performance on the road network with respect to factors such as road safety and road infrastructure wear and tear. Such measures can include specific vehicle maintenance requirements, prescribed driver training programmes including driver fatigue management, permissible routes over which HCVs are permitted to operate and the times at which they may do so, speed limitations, overtaking and lane adherence rules, and operator requirements concerning issues such as accreditation, insurance and financial standing. Compliance with the required measures can be achieved through manual enforcement or through the use of technology to monitor vehicle locations and speeds, and real-time telematics monitoring of the vehicle and axle weights of loaded HCVs (Moore et al., 2014).

PBS with associated operational management commenced in Australia in 2007. The Australian scheme is an alternative regulatory system for heavy goods vehicles, which replaces the prescriptive method of specifying weight and dimension limits. It is intended "to make freight transport safer and more productive, and to reduce impact of freight movement on the environment and society" (National Transport Commission, 2017). The scheme provides flexibility in vehicle design and allows higher weight limits on vehicles that comply with the PBS standards. The vehicle design standards cover four topics: i) 'powertrain' which specifies engine and acceleration requirements, ii) 'high speed' which specifies stability, roll over and rearward amplification, iii) 'low speed' which specifies swept path, frontal and rear swing requirements, and iv) 'infrastructure which specifies bridge and pavement requirements, and maximum axle group weight limits. The performance standards applied are at least equivalent to corresponding prescriptive schemes. Between 2007 and 2016 approximately 5000 vehicles were approved under the scheme (National Transport Commission, 2017). The scheme uses vehicle technology to monitor that vehicles are on the permitted roads at the correct times (called the 'Intelligent Access Programme' - IAP), travelling within the permitted speed (called 'Intelligent Speed Compliance'), and within the permitted weight (called 'On-Board Mass Monitoring' - OBM) (OECD/ITF, 2019).

An adapted version of the Australian PBS and management system has been implemented in South Africa. In this scheme, "the requirement for PBS demonstration vehicles is that the road wear per tonne of payload of the PBS vehicle must be less than the equivalent road wear of the baseline vehicle" (Nordengen et al., 2018). The scheme was introduced to address challenges in the road freight sector including vehicle overloading, poor vehicle maintenance, unsatisfactory driver behaviour and fitness, and inadequate road maintenance. These problems were associated with poor road safety, road infrastructure damage, high level of vehicle emissions, and high road freight transport costs. The management system used alongside PBS vehicle design involves real-time on-board vehicle monitoring and tracking of speed, route and weight compliance, together with driver education and training (OECD/ITF, 2019). PBS demonstration vehicles were first operated of South African roads in 2007, and by 2017 there were 245 PBS vehicles operating on the roads (Nordengen et al., 2018).

HCV trials in Finland have also investigated the use of technology to improve road safety, road wear, and environmental performance. In Sweden a similar system to the IAP scheme for vehicle monitoring and tracking is being developed (OECD/ITF, 2019).

The FALCON project ("Freight and Logistics in a Multimodal Context"), which was funded by the Conference of European Directors of Roads (CEDR), has studied and defined a potential PBS framework for cross-border road freight transport in Europe, which could be used for

HCVs. In the project a “representative fleet of European vehicle combinations was defined and simulated against a wide range of potential performance standards. Findings from these results were used to guide the choice of applicable European performance standards” (REF). The PBS framework proposed is based on the Australian PBS scheme, with modifications and additions to take account of the European fleet, existing European road regulations, the icy conditions that occur in some parts of Europe, and European-specific approaches to infrastructure protection. The project has provided a list of recommended performance measures for inclusion in a European PBS programme, as well as recommendations for how the pass/fail criteria for each should be reviewed for European conditions. The authors recommend that criteria for some performance standards should be reviewed on an individual jurisdiction level. The project also provides methodologies for assessing the impact of HCVs on roads and bridges, and proposes a four-level road access classification system for individual jurisdictions to set their own performance requirements for vehicle categories based on local conditions. The four-level road access classification system is as follows: Level 0 (city transport), Level 1 (existing truck routes, minor roads), Level 2 (inter urban arterial main express roads) and Level 3 (motorways). Level 0 (for vehicles accessing city centres) could potentially be applied to urban operations such as waste collection vehicles but these vehicles were not included in the project so would require further investigation. The next and final stage of the FALCON project will validate the proposed PBS framework against its impact on modal split, road damage, and congestion (de Saxe et al., 2019).

Results of the impacts of the PBS and associated operational management and monitoring programmes in Australia and South Africa are presented along with other HCV trials and studies in section 8.

6. The potential impacts of HCVs

Several potential impacts of HCV use have been identified by researchers in relation to their impact on freight transport vehicle activity, road freight transport operating costs, environmental impact, road freight traffic safety and road infrastructure wear and tear. Some of these potential impacts are positive while others are negative. Table 3 summarises these possible positive and negative impacts of HCVs are summarised in Table 3.

Table 3. Potential positive and negative impacts of HCV use

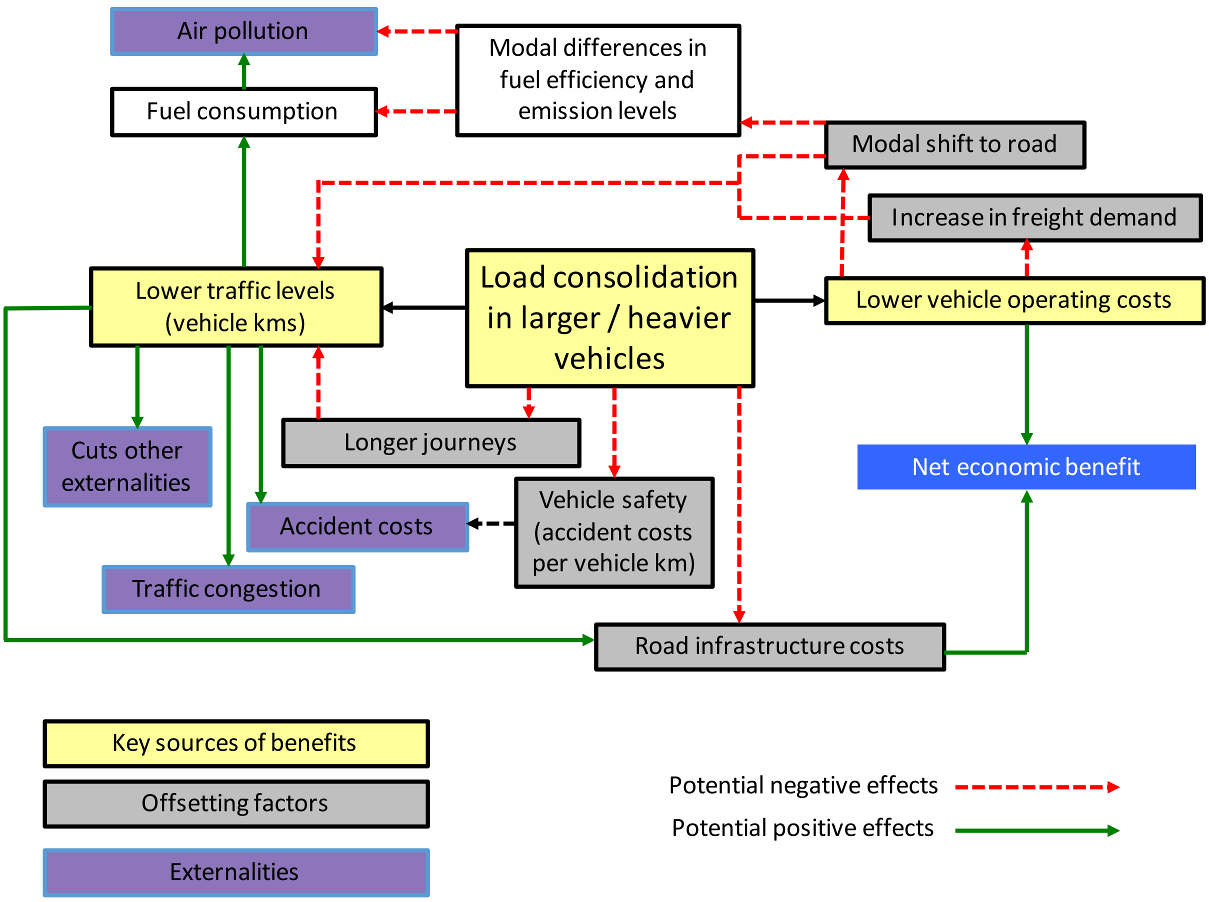
Potential positive impacts	Potential negative impacts
Freight transport vehicle activity	
The additional volume and/or weight capacity of HCVs facilitates the consolidation of loads into fewer road vehicles (and hence a reduction in total vehicle kilometres).	Shift of freight from modes perceived as less-environmentally-damaging (rail and intermodal) to HCVs to take advantage of lower operating costs they provide. Longer routes per journey by HCVs if their greater size limits these vehicles to a more restricted primary route network. Possible impacts of HCVs on traffic flow (by increasing or reducing it). Generation of increased demand for freight transport if companies respond to any reduction in freight costs by making their logistics operations more transport-intensive (e.g. more distant sourcing, more centralised stockholding, or more frequent deliveries). This is often referred to as a ‘rebound effect’.

Environmental impact of freight transport	
Reduced total vehicle kilometres lead to an alleviation of environmental impacts and congestion (cutting the external costs of road transport borne by the community).	Given HCVs have higher external costs per tonne-km than rail and water, mode shift to HCVs could reduce the environmental benefits from load consolidation that HCVs provides. Shifts from conventional road vehicles to HCVs may reduce environmental impacts per tonne-km / m^3 carried.
Freight transport operating costs	
Reduction in vehicle operating costs per unit of goods transported from using HCVs due to the ability to carry more goods on each vehicle load.	As noted above, if HCV use reduces vehicle operating costs per unit of goods transported, this may lead to mode shift from rail and intermodal.
Road freight traffic collisions and casualties	
A reduction in road freight vehicle kilometres from using HCVs may reduce traffic collisions and casualties per unit of goods transported.	Possible increase in the severity of collisions due to the greater weight and size of HCVs. In such a situation, casualty costs per vehicle-km may rise, despite the reduction in total vehicle-kilometres.
Road infrastructure costs	
As it is normally assumed that maximum axle weights will remain unchanged with HCV use and that any additional payload weight will be spread across more axles, 'wear and tear' on the road pavement is unlikely to increase and may decrease. A reduction in road freight vehicle kilometres due to HCV use may therefore reduce road maintenance costs per unit of goods moved.	Increase in capital expenditure on road infrastructure modifications (road layouts and bridge strengthening) to accommodate HCVs.

Source: based on McKinnon, 2012; 2018

Figure 3 presents in diagrammatic form the relationship between the potential advantages and disadvantages of HCVs, and the likely net effect on freight transport externalities. It is adapted from a diagram produced by a leading logistics researcher who, having reviewed the available evidence from many countries, is an advocate of the overall benefits of HCVs. As he notes, “most of these studies and long experience of LHV (i.e. HCV) use in countries such as Sweden, Canada, and Australia confirm that relaxing truck size and weight limits yields a combination of environmental, economic and safety benefits” (McKinnon, 2015). As he also notes, “the ‘real-world’ evidence that HCVs significantly reduce the carbon intensity of trucking has been steadily accumulating” (McKinnon, 2018).

Figure 3. Inter-relationships in the cost-benefit analysis of HCVs



Source: adapted from McKinnon, 2012 and 2014

7. Approaches to researching HCVs

There has been much research into the impacts of HCVs over the last forty years. This has involved research in many individual countries as well as at an international level in the case of EU-wide studies. A list of HCV research publications identified and made use of in the literature review is provided in the References section of this report. The review was limited to documents written in English.

Six main research topics have been identified in the review work carried out: (i) load consolidation achievable with HCVs and its effect on road freight vehicle kilometres travelled, (ii) road freight demand induced by lower HCV operating costs, (iii) modal shift from rail/water and conventional trucks to HCVs (iv) environmental impacts of HCVs, (v) road safety impacts of HCVs as reflected by collisions and casualties, and (vi) road infrastructure impacts of HCVs.

Some of the literature reviewed has been based on actual HCV field trials and analysis of full-scale implementations, while others have been based on theoretical studies using modelling techniques. The review includes results from nine field trials, five post-implementation analyses, and eight desk-based modelling studies.

Vehicle field trials provide the good insight into the effects of HCV use. However, such trials usually involve limited number of vehicles, and may therefore not necessarily be representative of all road freight sectors and geographical regions. The scale of such trials can also affect their ability to analyse potential impacts such as modal shift and demand for road freight transport resulting from lower vehicle operating costs. In addition, the many permutations of HCVs (in terms of size and weight configuration) can make it difficult to generalise results from a specific field trial. Post-implementation analysis of schemes in which HCVs have been introduced on an-going basis can be useful in reflecting on the actual impacts that have taken place. However, relatively few such post-implementation studies were identified in the literature review, and in studying topics such as modal shift and induced demand for road freight transport, such studies face the difficulty of isolating the effects of HCV introduction from other economic and social factors.

Desk-based theoretical modelling of the potential effects of HCV implementation on road freight transport activity is subject to various HCV operating assumptions which can sometimes be difficult to support with a strong evidence base. In investigating the substitution of conventional vehicles for HCVs official national datasets typically contain little if any data about the volume of goods carried (only the weight), insufficient disaggregation of goods by type and handling units used, and few contain information about whether loads are currently constrained by weight, volume or both (the UK being one of the exceptions to the latter).

Desk-based theoretical economic analysis and modelling of the uptake of HCVs and the potential extent of modal shift and induced demand for road freight transport that they could potentially result in is often hampered by the lack of availability of accurate and reliable price elasticity values for (i) road freight transport (i.e. the demand for road freight transport depending on the price of that service), and (ii) for modal cross-elasticity (i.e. the demand for alternative freight modes as the price of another such mode changes). Such values are likely to vary between sectors and countries. Elasticity values that do exist have a substantial range (Christidis and Leduc, 2009; De Jong, 2010; McKinnon, 2018). The lack of reliable price elasticity data makes it difficult to carry out analysis of the impact of HCV provision on road freight demand due to cost and hence price decreases, and the counter effect of HCV provision on the demand for rail freight services (McKinnon, 2012). Such theoretical modelling analysis of the modal shift from rail to road due to HCVs relies on a range of data assumptions for which is little availability and consensus (including price elasticities, modal cross-elasticities, reductions in road freight operating costs, and vehicle load factors) (De Jong, 2010; McKinnon, 2018; Steer et al., 2013; Vierth et al., 2018).

8. HCV study findings

This section presents finding from research into HCV uptake, operational performance and impacts. Four major review studies into the effects of HCVs have been carried out, one for the European Commission published in 2009, two for the OECD/ITF in 2011 and 2019, and another for the European Parliament in 2013 (Christidis and Leduc, 2009; OECD/ITF, 2011; OECD/ITF, 2019; Steer et al., 2013).

The 2009 study was commissioned as the European Commission was considering the implications of allowing the use of HCVs measuring up to 25.25 m and weighing up to 60 tonnes, in the EU. The study was intended to compare the results of three HCV studies published in 2008. In addition a further nine studies published between 2006 and 2008 were reviewed, four of which the results were deemed ‘globally positive’ towards HCVs, one ‘globally neutral’ and four ‘globally negative’. In terms of the three main 2008 studies reviewed these all forecast a decrease in rail freight due to HCVs but these varied substantially from ‘1% of rail freight’ up to ‘55% of intermodal shipments’. The three main studies varied in terms of the forecast impact on total vehicle kilometres, with two of the studies expecting a decrease with associated environmental impacts, and one predicting that induced demand through lower road freight costs would result in no net change in total road vehicle km. The majority of the twelve studies that considered road safety expected improvements due to reduced total vehicle kilometres, but two reported greater risks associated with HCVs. In terms of road infrastructure, several expected less road wear due to vehicle km reductions, while others noted that this would be HCV configuration dependent, and that HCVs would require major expenditure on bridge improvements. This 2009 study then presented its own analysis of HCV use. The simulation approach used indicated that HCVs reduce costs for operators, and would result in a 2.1% decrease in rail freight compared to its expected traffic in year 2020. It concluded that, “the introduction of LHVs (i.e. HCVs) would be beneficial for the EU economy and, under certain conditions, environment and society as a whole” (Christidis and Leduc, 2009, p.24).

The OECD/ITF 2011 research project, carried out by an international group of experts representing 15 countries and the European Commission, studied potential goods vehicle improvements in safety and efficiency including a benchmarking study of 39 vehicle configuration including HCVs (OECD/ITF, 2011). It reviewed relevant studies and concluded that, “all studies have found that increased road transport productivity would be likely if weight and dimensions limits were to be relaxed” (p.253). It stated that the shift of goods from rail to HCVs would be “limited by the fact that many freight transport markets are not contestable between modes” (p.24) and concluding that, “these effects are often small but vary greatly between commodities and markets” (p.254-5). In terms of HCV use inducing greater demand for freight transport it stated that, “induced demand effects are likely to be small” (p.15). On the environmental impacts of HCVs it reported that, “in principle, the operation of higher capacity vehicles should lead to a reduction in the number of truck miles travelled and thus overall fuel consumption per unit of freight transported” (p.254). In relation to safety, it noted that most studies have assumed that the crash risk of HCVs per vehicle km is the same as for conventional heavy vehicles, so given predicted reductions in total vehicle kilometres will lead to proportionate safety benefits. It concludes on this topic by noting that the modelling “suggests that HCVs can perform at least as safely as the workhorse vehicles they may replace” (p. 256). In terms of the impact of HCVs on road infrastructure, it stated that, “in all known applications to date, operation of HCVs have been restricted to elements of the network with suitable infrastructure characteristics” (p.253).

The 2013 study consisted of “a literature review of prominent research in this field, as well as case studies looking into the experiences of HCVs in the five Member States in which they are either allowed or tested” (Steer et al., 2013). The literature review focused on eight studies published between 2008 and 2010 (including the OECD/ITF report), The eight studies were reviewed, the majority of which indicated that HCVs would lead to positive economic and environmental outcomes. The report notes that there is “widespread agreement that HCT (i.e. HCVs) would reduce operating costs for road freight and greenhouse gas emissions per tonne-km of goods transported as less vehicles would be used to transport the same amount of goods” (p.38) and that this is estimated to be 20-30%. It reports that most of the studies predict some degree of modal shift from rail to HCVs but that “there is a significant divergence of opinions about the extent of this modal shift” (p.40). On road infrastructure wear and tear due to HCVs, it reports that an impact is likely, but that while some studies predict significant negative impacts, others report an expected reduction in road wear due to reduced weight-per-axle of some HCVs. In terms of road safety the review reported, “we have not found evidence that there would be an inherent increase in road safety risks because of LHVs (i.e. HCVs)” (p.59). It goes on to state that the expected reduction in total vehicle kilometres from HCV use “and this positive effect is thought to completely balance or even outweigh the increased risk factor per individual vehicle” (p.59). Of the studies reviewed, most “predict that GHG emissions per tonne-km of road freight will fall even though emissions per vehicle increase, due to efficiency gains associated with LHVs (i.e. HCVs)” (p.59). It reviewed the limited evidence on the impacts of HCVs on traffic flow (namely: (i) potential increased time for HCVs to clear intersections and junctions, (ii) potential impact of overtaking manoeuvres by other motorists, and (iii) potential impact on traffic flow due to fewer goods vehicle movements). The relative lack of evidence available on these aspects of HCV and traffic flow was noted, and cited as being due to “the difficulty of measuring such impact in real traffic situations” (p.50). The report summed up the impact of HCVs on traffic flow as follows: “where road traffic flow has been discussed with stakeholders in Member States which permit HCVs or which have permitted them in trials, no significant effect has been found or studied” (p.52). The report concluded that HCVs, “would be unlikely to work against the EU’s objective of reducing road deaths by 50% from 2010 levels by 2020” and “could help with the EU’s objective of reducing greenhouse gas emissions by 20% from 1990 levels by 2020” (p.10).

The OECD/ITF 2019 report “examines international experience with HCVs and aims to provide evidence to support policy-making in jurisdictions considering the deployment of HCVs. It examines approaches to implementing pilots and full-scale programmes to deploy HCVs, reviews potential impacts on road infrastructure and assesses consequences for other transport modes, industry and society” (OECD/ITF, 2019, p.5). The report reviews available research and examines existing pilot projects into HCVs from around the world, and provides evidence from this work into: the economic impacts of HCVs, the impact of HCV on decarbonisation, the modal shift associated with HCVs away from rail and intermodal, the infrastructure impacts of HCVs, and the road safety impacts of HCVs. The report then provides lessons for developing regulatory approaches for HCVs including vehicle design standards, and the monitoring and enforcement of HCV operations. The use of ‘performance based standards’ (PBS), to ensure that the design of HCVs and their manoeuvrability is suited to the road infrastructure on which they will operate is explained, together with the use of information and communications technology (ICT) to monitor and enforce the operations of HCVs on the road network. Policy options for HCV implementation are also provided. The report states that the use of HCVs “reduces the number of trucks required by “by one-third to two-fifths” and reduces CO_2 emissions per unit of freight by 15-40% (p.82). It goes on that “in most cases there is little evidence to suggest that HCVs cause significant modal shift from rail to road” (p.82), that trials and research “over many years and from many countries show that the safety risk of well-regulated HCVs is lower than standard trucks” (p.82), and that HCVs can be designed to operate on existing roads with little or no need for additional infrastructure investment (p.5). The report concludes that HCVs “can contribute to improving the efficiency and safety of road transport operations and reduce transport costs and energy demand” (p.5).

Below is a summary of findings from the field trials, post-implementation analyses and theoretical modelling studies of HCV use in relation to the key topics previously identified. The focus of this literature review was on material published since the three review studies up to 2013 discussed above, together with other noteworthy studies. The information provided below is also presented in a more summarised table form in Appendix 1.

8.1 Load consolidation achievable with HCVs and its impact on road freight vehicle kilometres travelled

Interviews carried out with six German road freight operators participating in HCV field trials transport operators found that three expected their total level of vehicle activity to fall as a result of the greater vehicle capacity while the other three road estimated that during the trial they experienced a 33% reduction in commercial vehicle traffic (Sanchez Rodrigues et al., 2015).

Research associated with the German LANG-Lkw mid-term field trials of 25.25 metre vehicles from 2012-2014 indicated that one HCV could theoretically replace 1.56 conventional vehicles and had a 16% lower operating cost compared to conventional vehicles, if an utilization rate of more than 83% could be achieved (Irzik et al., 2014 reported in Limbeck et al., 2017).

Norwegian field trials of EMS indicates that each vehicle replaces 1.2-1.5 regular vehicles. An EMS vehicle was found to result in traffic flow being “marginally worsened” compared to a regular truck but that “these challenges are small as long EMS stick to roads that are suited for them" and were outweighed by the reduction in total vehicle activity they result in (Brevik Wangsness et al., 2014).

Desk-based modelling of the impact of 60 tonne vehicles (rather than the limit of 44 tonnes) in Spain using road freight data has estimated national road freight activity savings of 360 to 816 million vehicle kilometres using 2008 data (which is equivalent to 1-3% of national road freight vehicle kilometres), when taking into account assumed modal shift scenarios from rail to road of 3-9% and induced demand (Pérez-Martínez and Miranda, 2016).

A study of heavier goods vehicle implementation in Sweden (from 51.4 tonnes to 56 tonnes in 1990 and to 60 tonnes in 1993, with vehicle length remaining constant at 24 metres throughout) has shown an increase in road freight efficiency after the weight increases, implying that fewer vehicle-km were needed for a given amount of tonne-km, especially by vehicles of the highest capacity. This indicates that the additional weight capacity of these HCVs was being utilized (Vierth et al., 2018).

Surveys carried out in 2014 and 2017 of operators in the long-running field trials (since 1997) of HCVs using PBS in Australia, who were responsible for 23% of the total HCV vehicles operated from 2009-2016 (approximately 1,500 vehicles), found that the respondents had good knowledge of their vehicle kilometres savings over this period. Weighted averages of vehicle kilometre savings in both surveys were calculated to provide results for the entire period 2009-2016 (survey 1 covered the period 2009-2012, and survey 2 the period from 2013-2016). The so-called 'productivity saving' showed that "many of the articulated (i.e. HCV) combinations are achieving around 33% kilometre reductions". Vehicle kilometre reductions varied depending on comparable conventional vehicle configuration, ranging from 12.2% for a rigid truck and 3-axle trailer configuration, up to 41.3% for a quad road train (Hassall, 2018; Industrial Logistics Institute, 2017). It has been calculated that the vehicle km savings by the 4,600 HCVs using PBS (the fleet at the time of the calculation in 2014) was equivalent to a saving of 1.6% of total tonne-kms performed nationally by all vehicles over 4.5 tonnes, and a saving of 6.2% if comparable conventional non-HCVs without PBS vehicles had carried out this activity (Industrial Logistics Institute, 2017). Analysis of the vehicle kilometre savings derived from HCV use together with the higher operating costs of HCVs forecast that the use of HCVs will result in operating cost savings of $9.6-22.2 billion (Australian dollars) over the period 2014-2034 (Industrial Logistics Institute, 2017).

The South African field trials of HCVs using PBS includes approximately 20 operators with a total fleet of 245 vehicles. Vehicles included in the trial must achieve road wear per tonne of payload that is less than the equivalent road wear of the baseline vehicle. Operators provide data on kilometres travelled, fuel consumed, emissions, incidents and crashes on a monthly basis for all participating PBS and baseline vehicles. Since the start of the trial in 2007 to the end of June 2017, the vehicles included travelled a total of 102 million vehicle kms. The 245 PBS vehicles have saved a total of 8.7 million kilometres per year which is equivalent to a 22% saving (Nordengen et al., 2018).

A study of Finnish forestry transport was carried out a year after the maximum weight limit had been increased from 60 to 76 tonnes in 2013. Data was collected through survey work with 56 operators for 11,530 vehicle loads in which roundwood was transported by 60, 64, 68 and 76 tonne vehicles from forests to pulp mills, including details of whether loads were subject to weight- and/or volume-constraints. Data was also collected about vehicle configurations and the on-board handling equipment. The analysis estimated that the increase in weight limit had resulted in a 12.5% reduction in vehicle kilometres (Palander and Kärhä, 2017).

An analysis of increases in the maximum permissible vehicle weight and size in the UK between 1983 and 2002 (during which time payload volume increased by 10-12%, and maximum payload weight by approximately 45%) found that the average weight payload of articulated goods vehicles had fallen considerably since 1983, while at the same time the number of articulated vehicles registered and their total vehicle kilometres had increased. It surmised that this was due to operators buying the biggest available vehicle even if they do not utilise it efficiently (Buchan, 2007). However, there are many factors that can contribute to the utilisation of goods vehicles.

A UK desk study of HCVs in 2008 indicated that sectors most likely to make use of HCVs include: trunk routes in pallet-load networks, movements between factories and distribution centres in the Fast Moving Consumer Goods (FMCG) sector, container transport to and from deep-sea ports, and the forestry sector. Smaller operators would be less likely to make use of HCVs than larger companies due to the capital costs of the vehicles (Knight et al., 2008). This 2008 study assessed the potential impact of the uptake of HCVs on truck kms in the UK based on the application of various scenarios to existing truck transport operating data (these scenarios included a range of HCV weight and size combinations from a 44 tonne / 18.75 metre semi-trailer HCV to an 82 tonne / 34 metre HCV). The calculations assumed that the maximum number of trips that were applicable to HCVs would be transferred. The results indicated that if there were no road restrictions then there would be a 13-52% reduction in kilometres travelled by goods vehicle of 32 tonnes or heavier (depending on the size/weight configuration of HCV). If HCVs were allowed on motorways and other roads within 20 km of them only then there would be a 3-13% reduction in vehicle kilometres travelled (depending on the size/weight configuration of HCV) (Knight et al., 2008).

In this same 2008 study, focus group work with industry indicated that the transfer from conventional articulated truck to HCVs would be far less than the maximum theoretically possible. It was assumed that in the UK the proportion of total articulated vehicle tonne-kms that would actually transfer from conventional trucks to HCVs would be (Knight et al., 2008):

- 5-10% of articulated vehicle tonne-kms for 60 tonne / 25.25 metre HCVs
- 2.75-5% of articulated vehicle tonne-kms for 44 tonne / 25.25 metre HCVs
- 1.38-2.75% of articulated vehicle tonne-kms for 44 tonne / 18.75 metre HCVs

The UK field trial of longer semi-trailers (up to 2.05 metres longer than standard permissible trailers but the trial vehicles having to remain within the existing 44 tonnes weight limit) currently involves approximately 2000 vehicles, operated by companies ranging from very small to very large. The vehicles in the trial are carrying a wide range of products. In terms of total vehicle kilometres travelled: Fast-Moving Consumer Goods (FMCG) and pallets account for 53%, raw materials, industrial products and fuel account for 11%, mail and parcels for 7%, and waste packaging and empty journeys for 24%. Analysis of the sites that the vehicles in the trial travel between shows that 67% of the total kilometres travelled by the vehicles involve carrying goods between industrial sites (including factories, distribution centres and other industrial sites), 13% of kilometres involve carrying goods to and from retail sites, 2% of kilometres involve carrying goods between other types of site, and 17% of kilometres involve the vehicles travelling empty.

The UK LST trial results estimate an average distance saving of 7% per operator, which varies by operator from 1% to 14% (distance savings are not measured directly in the trial but are calculated from vehicle fill and journey data). In validating these estimates with the operators, 90% of operators considered the estimates of percentage distance saved for their operations to concur with their own experiences. Of those operators achieving few distance saving benefits from the trial, the two main causes are complex logistics operations that involve empty running on the return leg, and those operators that only make infrequent use of the additional trailer length (Risk Solutions, 2018). Given that the trial is of longer, not heavier vehicles, and is therefore of value to operators transporting large quantities of low-density products, only 2.6% of journey legs are weight limited. In terms of deck utilisation (i.e. trailer area used) the vehicles in the trial have been 100% full for 37% of their total distance travelled (and 91-99%

full for a further 18% of their distance travelled), with the additional length in use for approximately 55% of the total distance covered. In terms of volume utilisation (i.e. including trailer height), the vehicles in the trial were 100% full for 23% of their total distance travelled and 91-99% full for a further 15% of their distance travelled. In this trial operators record the operators record a trailer as 100% full if they could not load another 'unit' of goods (i.e. one more cage, one more pallet etc.) (Risk Solutions, 2018). It should be noted that the maximum potential distance travelled savings per vehicle in the LST trial are lower than those possible for HCVs which accommodate greater weight capacities as well as greater vehicle length. The actual 'real-world' distance travelled savings depend on the HCV regulations implemented (i.e. the maximum vehicle length and weight permitted), the operating conditions imposed on these HCVs (such as route restrictions), and the applicability of HCVs to prevailing freight transport sectors and their operations (which will depend on factors including types of products carried, journey types made, vehicle costs, and the ease with which HCVs can accommodated at existing delivery and collection facilities)

Vehicles in the UK LST trial are not subject to regulatory road or route restrictions or any requirement to have routes approved (this differs from many HCV trials and implementation in other EU countries and in Australia in which vehicles operated on pre-agreed routes or are subject to permitted routes). Analysis of an entire year of UK LST vehicle journey data (830,000 legs for a total of 56,000 journeys in total) using a routing algorithm to produce a credible route for each journey (and then validating this routing algorithm with actual vehicle tracking data from eight operators' vehicles) indicate that in 2017 these vehicles performed 13.1% of their total distance travelled on roads classified as being in urban areas. However, 5.6% of total kilometres are on the Strategic Route Network where it passes through urban areas, 4.6% is on the Primary Route Network in urban areas, and 2.9% is on other urban roads (A roads, B roads, C roads and unclassified roads). Analysis indicated that "there is a very small group of routes used by trial LSTs that have a disproportionately significant contribution to vehicle km and other characteristics of LST operation, such as rural/urban split" (Risk Solutions and WSP, 2018a).

In producing an estimate of the potential national take-up of LSTs, a survey of UK operators in the trial was carried out asking how many of their current trailer fleet they might choose to replace with LSTs if the general use of these vehicles was implemented by government. The preliminary results of this survey show that, assuming the infrastructure for handling LSTs at delivery and collection locations remained unchanged from today, operators primarily engaged in journeys between suppliers and DCs, DCs to other DCs, and palletised trunking stated they would like to replace 17-19% of their existing fleet for LSTs, those engaged in journeys to or from industrial sites would like to replace 12% of their fleet, and those engaged in journeys to or from retail sites would like to replace 9% of their fleet. The survey results also show that these same operators would like to replace greater proportions of their current fleet with LSTs if the infrastructure at collection and delivery locations served was updated with LST handling in mind. In this situation, the proportion of their fleet that operators would like to replace was as follows: those primarily making journeys between two DCs (30% of fleet), palletised trunking (28% of fleet), journeys between suppliers and DCs (24% of fleet), to or from industrial sites (21% of fleet), to or from retail sites (10% of fleet) (Risk Solutions, 2018). Potential uptake of the vehicles in the existing LST trial is likely to exceed that of longer, heavier HCVs trialled and implemented elsewhere given the trial specification (with no route restrictions) and the greater ease with which this length of vehicle can be accommodated in existing operations compared with HCVs that are longer and heavier vehicles.

8.2 Modal shift from rail and intermodal operations to HCVs

Analysis of the implementation of heavier goods vehicle in Sweden in the 1990s (from 51.4 tonnes to 56 tonnes in 1990 and to 60 tonnes in 1993, with vehicle length remaining constant at 24 metres throughout) has shown that the share of work carried out by road increased steadily before, during, and after the maximum vehicle weight changes. These weight reforms did not lead to a break in trends in road and rail modal split, instead they continued on their long-term trajectories (Vierth et al., 2018).

Two theoretical studies carried out into the use of for 60 tonne / 25 metre HCVs in the EU in 2008 reported markedly different estimates of the expected decline in rail freight volumes, with one estimating a 3.8% reduction and the other an 11.6-12.9% reduction (Transport and Mobility Leuven et al., 2008; Doll et al., 2008). The difference in findings is due to the cross-modal demand elasticity values used (McKinnon, 2018).

Surveys of operators and shippers during field trials in the Netherlands in the 2000s using vehicles with gross weights of 60 tonnes indicated that the trial had no effect on modal split (Kindt et al., 2011).

In its arguments against HCVs, Transport and Environment quotes modelling work by CE Delft in 2010 showing that if the cost of goods vehicles reduce by 20%, demand for road freight would increase by 18% with one-third of this demand coming from modal shift from rail freight. It also cites a further CE Delft desk study in 2012 indicating that the introduction of HCVs in the EU would lead to a fall in demand for rail freight services would fall by approximately 10% (Transport and Environment, 2013).

An assessment of the impact of the increase in maximum truck weight in the UK from 41 to 44 tonnes in 2001 (which had been forecast to reduce road haulage costs per tonne-km by approximately 11% for weight-constrained loads prior to its implementation (Commission for Integrated Transport, 2000) showed that, at the time of the work, there was little evidence that the weight increase had generated much additional demand for road freight movement. Increases in road freight tonne-kms did increase by 0.7% per annum over the period 2001-2003 but this compared with an average growth rate of 2.7% between 1980 and 2001. Similarly, tonnes-km carried by goods vehicles of 38 tonnes and above increased by 2% per annum, which was also below the average growth rate of 3.2% between 1980 and 2001 (McKinnon, 2005)

A UK desk study in 2008 estimated that the introduction of HCVs would capture 5–10% of the tonne-kilometres carried by conventional articulated vehicles, and 8–18% of all rail freight tonne-kms in the UK (Knight et al., 2008).

The 2011 UK LST pre-trial impact assessment forecast that, “rail would lose over 50% of its forecast domestic intermodal freight by 2026 if rail did not adapt to carry LST units”. If rail did adapt, it was forecast that its domestic volume would be 10% higher than in a 2013 rail freight market study by Network Rail. These forecasts were sensitive to various assumptions used, including the take-up rate of longer semi-trailers and rail freight operators’ likelihood of investing in new LST-compatible wagons and equipment (Risk Solutions, 2018; WSP, 2018a). Desk research showed that the LST field trial will not directly affect deep sea intermodal rail freight, that it is unlikely to directly affect the small Channel Tunnel intermodal freight market, and that the only rail freight market it could affect is domestic intermodal rail freight. Stakeholder interviews carried out in 2017 as part of the UK LST field trial found that operators interviewed have not changed their decision-making in relation to use of road or rail as a consequence of the LST trial. Interviewees also explained that “for price to become a dominant factor, such that freight will move from rail to road, the additional load per vehicle would need to be much more than the saving of 15% or less offered by LSTs, especially when a joint LST+Rail solution exists, offering the best of both worlds (i.e. the research found no evidence that the trial was having any effect on their choice of mode). It is reported that “few, if any, of the factors affecting decisions to move to or away from rail freight as part of an intermodal operation are affected by the availability of LSTs” (Risk Solutions, 2018).

Modelling carried out as part of the five-year German longer vehicle field trials (of up to 25.25 metres) from 2012-2016 showed “hardly any intermodal shifts from the railways and inland waterways” (Irzik et al., 2016).

McKinnon (2012) has noted that to overcome the problem of the widely diverging, reliable and up-to-date modal cross-elasticity values available to analyse the shift from rail to HCVs these values “should be derived for those sectors of the freight market within which rail and LHVs (i.e. HCVs) would be in direct competition”. He goes on to caution against using modal shift estimates from HCV studies for different HCV specifications or in other countries given their freight market differences. He also notes that freight mode choice depends on other factors in addition to cost. Such factors include the type of product, the quantity and frequency of product flows, the service levels necessary (such as speed, reliability, regularity, flexibility and traceability), the origin and destination locations in relation to modal network infrastructure, the availability of modal infrastructure capacity, corporate policies, and human factors including personal perceptions and knowledge (AECOM and ITS Leeds, 2010).

The OECD/ITF (2019) review report concludes that “there is no ex-post evidence that HCVs are having a negative effect on rail volumes. Potential positive effects have been identified. New research could go into a better understanding of this balance” (p.32).

8.3 Road freight demand induced by lower HCV operating costs

A modelling study of the potential impact of 74 tonne / 25.25 metre and 74 tonne / 34 metre HCVs in Sweden (compared with the existing 64 tonne / 25.25 metres limit) the used detailed data on transport costs and logistics systems, together with interviews, and cross-price elasticity values from other studies. Two scenarios without HCVs were included: one based on increasing GDP, population, urbanisation, e-commerce, imports/exports and average transport distances, and the other based on a more climate efficient transport system with greater modal shift from road to rail and water, and the uptake of more transport-efficient logistics systems. Three HCV implementation strategies were then included in these scenarios: HCVs (i) permitted on all roads, (ii) a designated road network, and (iii) a designated road network with a kilometre-based truck charge. Results indicated an increase in road freight tonne-kilometres by 2030 (due to induced demand for road transport and to lower operating costs of HCVs and modal shift from rail and water) of 9-17% if HCVs were permitted on all roads, 8-16% if HCVs were only permitted on a designated road network, and 1-5% if HCVs were limited to a designated road network together with a kilometre-based truck charge. The results indicate that induced demand due to lower road vehicle operating costs was more important than modal shift in this predicted increase in road freight transport. Overall, the study showed that HCVs had the potential to improve the economic and environmental efficiency of freight transport and that counter measures could potentially be implemented to limit modal shift and increased demand for road transport (Pålsson et al., 2017).

An assessment of the impact of the increase in maximum truck weight in the UK from 41 to 44 tonnes in 2001 reported that over the period 2000 - 2003 rail freight activity in the UK tonne-kms had fluctuated around 18–19 billion and its share of the road-rail freight market had remained fairly stable at 11% (McKinnon, 2005). There was therefore no evidence of a reduction in rail freight activity as a result of the introduction of heavier vehicles. However, as noted in the paper, the UK government had also halved infrastructure charges paid by rail freight operators and implemented an investment programme to support rail freight making it “very difficult to isolate the effect of this measure from all the other influences on rail’s competitive position and even harder to determine the counterfactual” (McKinnon, 2005).

Logistics managers in discussion groups in a UK HCV desk study did not expect that reductions in road freight transport costs would lead to the restructuring of logistics systems and an additional demand for transport activity in the supply chain (Knight et al., 2008).

8.4 Environmental impacts of HCVs

Evaluation of Norwegian field trials from 2008-2013 indicated that “EMS has lower emissions per tonne-km and/or m^3-km compared to regular trucks. For a given amount of transport work, EMS vehicles will lead to reductions in CO_2, NO_X and PM” (Brevik Wangsness et al., 2014). Meanwhile Danish and Dutch field trials have shown that EMS vehicles have no noticeable impacts on vehicle noise levels (Brevik Wangsness et al., 2014).

In an online questionnaire survey of German road freight operators participating in HCV field trials 70% of respondents reported significant reductions in fuel consumption and CO_2 emissions from their transport fleets. Six companies interviewed in detailed case studies each recorded a reduction in fuel consumption (Sanchez Rodrigues et al., 2015)

Field trials in Sweden running since 2012 indicate that the use of 32 metre double trailers can lead up to a 27% reduction in CO_2 emissions per unit of cargo carried (Cider and Larsson, 2019).

Analysis of HCVs using PBS in Australian field trials has estimated that in 2016, as a result of vehicle km savings, these 4,624 vehicles resulted in a fuel saving of 94 million litres, and a CO_2 emissions saving of approximately 250,000 tonnes (National Transport Commission, 2017).

Data from the South African field trial of HCVs using PBS shows that the 245 vehicles saved a total of 6,246 tons of CO_2 emissions per year compared to their benchmark non-PBS vehicles. This is equivalent to a 12% reduction in CO_2 emissions (Nordengen et al., 2018).

A UK desk study reported that while 60 and 82 tonne HCVs would be expected to result in greater CO_2 and other emissions per vehicle km than conventional vehicles, they would lead to reductions in emissions on a per tonne carried basis (Knight et al., 2008).

Emissions modelling in the UK LST field trial of 2,000 vehicles indicates overall savings for all vehicles operating in the trial (compared to if they had been using 13.6 metre trailers) of 7.4% of CO_{2e}, 7.2% of CO, 7.3% of NO_x and 7.4% of PM exhaust emissions and 7.2% of VOC in 2017. These savings are similar to the 7% average vehicle kilometres savings in 2017. The modelling work uses the actual journey leg data of vehicles in the trial together with parameters to reflect the Euro engine standard of the tractor vehicles, the vehicle unladen weight, the vehicle load, and the vehicle speed. The modelling results estimate total NO_x emission savings of 32.6 tonnes in 2017 (which is equivalent to 0.2% of the total NO_x emissions by articulated goods vehicles in the UK in 2016 and CO_{2e} emissions savings of 6,494 tonnes in 2017 (equivalent to 0.05% of total CO_{2e} emissions by articulated goods vehicles in the UK in 2016 (Risk Solutions, 2018; WSP, 2018b).

A desk study estimated that the introduction of longer 25.25 metre HCVs in Germany would be likely to result in a 17% reduction in fuel consumption per unit of goods transported for goods shifted from conventional non-HCVs. The potential road and rail freight traffic that could switch to these longer HCVs was assessed using a cross-price elasticity approach. It was estimated that the road goods switching to HCVs would have reduced total greenhouse gas emissions by road goods vehicles in Germany by 0.06%, and that the goods traffic shifting from rail to HCVs would have resulted in a 0.01% increase compared with the total greenhouse gas emissions from rail freight in Germany. The estimated net effect is equivalent to a 0.05% reduction in total greenhouse gas emissions from road and rail freight in Germany. A 2030 scenario, by which time it is expected that the need for lengthy road detours by these HCVs due to the incorporation of a greater proportion of roads into the HCV network and thereby encouraging greater shift of goods to HCV, is forecast to result in a 0.22% reduction in total greenhouse gas emissions from road and rail freight in the country (Gutberlet et al, 2017).

8.5 Road safety impacts of HCVs as reflected by traffic collisions and casualties

Over the period of the five-year German field trial of longer trucks of 25.25 metres (from the start of 2012 to the end of 2016) a total of 13 collisions were reported to police, which resulted in one personal injury, and four instances of serious vehicle damage; the longer truck was not the main cause of the collision in any of these cases. All other collisions only involved slight vehicle damage (Irzik, 2017). Although the scale of the German trial was relatively small, it shows that “no measurable impact from longer trucks on traffic safety and traffic flow at work sites on motorways can be expected” (Limbeck et al., 2017).

In the UK LST field trial, 22 public personal injury incidents involving one of the vehicles have occurred between 2012-2017, none of which were fatalities in 443 million km of vehicle activity. Of these 22 public personal injury incidents, 3 injury incidents (all of which were slight) were found to be longer semi-trailer-related, equivalent to one LST-related injury incident in a public place for every 148 million km travelled (compared with one for every 6 million vehicle kilometres for all articulated vehicles operated in the country). Analysis has shown that trial vehicles were operated with a lower rate of injury incidents in public locations than the average for conventional articulated vehicles on urban roads, minor roads and major roads (Risk Solutions, 2017). The trial also reported that in the case of two operators the LSTs in their fleet had a higher damage incident rate than the non-LSTs in the same fleet (mostly in terms of contact with other road vehicles). In-depth conversations with these operators indicate that this was due to driver ‘equipment awareness’ and both operators were considering adopting visual cues to prevent this (Risk Solutions, 2018).

A Swedish study considered whether longer vehicles (18.76 – 25.25 metres) operating in the period 2003-2012 had higher fatal or severe casualty rates per vehicle kilometre than goods vehicles of up to 18.75 metres (i.e. within the European Union length norm). The findings showed that vehicles with lengths over 18.75 metres were involved in less fatal or severe crashes per billion vehicle kilometres than vehicles with lengths of 18.75 metres or less. regular EU vehicle combinations. For the period from 2003 to 2012, the rates for ‘short’ (≤12 metres), ‘medium’ (12.01–18.75 metres) and ‘long’ (18.76–25.25 metres) vehicles were 137, 56 and 44 fatal or severe crashes per billion vehicle kilometres travelled respectively. (Bálint et al., 2014).

A Danish study of EMS HCVs in 2009-10 in which 47 million vehicle km were driven on a restricted road network resulted in only four accidents, an accident rate of 0.085 million vehicle kilometres (Danish Road Directorate, 2011).

Insurance data concerning vehicle collision claims was used in conjunction with survey work about vehicle kilometres travelled among operators participating in the field trials of HCVs using PBS in Australia to investigate the road safety of HCVs. This data has shown that over the period 2009-2016 across all HCV configurations the observed performance in terms of major collisions (those with a vehicle and property claim value of at least $50,000, not including claims for injuries to people) (Australia dollars) per 100 million vehicle kms was 46% better than among the comparable conventional (non-HCV) fleet. HCVs had a major collision rate per 100 million kms that was 59% lower than their conventional counterparts, while total road train HCVs had a rate that was 18% lower. Results varied by HCV configuration; seven HCV configurations performed better than their conventional comparator, while two HCV configurations performed significantly worse than their benchmark conventional vehicle

(Hassall, 2018; Industrial Logistics Institute, 2017). The analysis has also shown that fatal collisions involving HCVs between 2009 and 2016 are also below that of conventional vehicles (0.49 fatalities for HCVs and no fatalities for road train HCVs per 100 million vehicle km compared with 1.30 fatalities and 0.8 fatalities per 100 million vehicle km respectively for comparable non-HCV vehicles (Industrial Logistics Institute, 2017; National Transport Commission, 2017). It has been suggested that some of this improved safety performance could be due to the remote locations in which these HCVs often operate and the enforcement regime that they have to comply with (Koniditsiotis, 2018).

The 245 HCVs using PBS in the South African field trials have had crash rates that are 39% lower than their comparable baseline vehicles up to June 2017 (1.37 crashes per million km compared with 2.24 crashes per million km) (Nordengen et al., 2018).

Longer vehicles take longer to overtake. Experimental Swedish studies indicate “a slight trend for 24-metre vehicles to result in more risky overtaking manoeuvres than 18-metre vehicles” (the time gap to oncoming vehicles in overtaking manoeuvres estimated at 4.3 seconds for shorter vehicles and 4.5 seconds for longer ones) (Hammarström, 1976; Hanley and Forkenbrock, 2005 both quoted in Vierth et al., 2008). However, this research does not suggest that overtaking-related collisions are more common for longer vehicles (Vierth et al., 2008).

The results from trials and implementations reviewed above indicate that HCVs can result in lower collision and injury rates per vehicle kilometre travelled than for non-HCVs. The evidence suggests that the application of PBS to HCVs including better inherent vehicle dynamic performance, improved driver training and vehicle maintenance, together with route selection/compliance and overloading controls are beneficial in this respect. In addition, when thinking about the safety impacts of HCVs it is important to also take account of the reduction in total vehicle kilometres required to transport the same quantity of goods (compared to using conventional non-HCVs) that HCV use can result in, which are not taken account of in the results provided above (see Section 8.1). In combination, these two factors indicate that HCVs have the potential to result in substantially fewer total collisions and injuries than comparable non-HCVs).

8.6 Road infrastructure impacts of HCVs

The Norwegian EMS vehicle field trials did not require any public expenditure on road infrastructure adjustments, and the evaluation indicated few differences in the impact EMS vehicles have on road infrastructure compared to regular trucks. Where there were differences these were small, and varied from marginally better, to marginally worse (Brevik Wangsness et al., 2014).

In Denmark approximately €18 million was spent improving the road infrastructure for its HCV field trial, while in Sweden approximately €2.7 billion was spent increasing the load bearing capacity of its road and bridge network to allow for implementation of an increase from 51.4 tonne to 60 tonne HCVs. The infrastructure costs associated with HCVs is likely to relate to the extent of the HCV network, the HCV configurations permitted, and the current standards of road and bridge infrastructure in any given country (Steer et al., 2013).

Using results from the Australian field trials of 4,600 HCVs using PBS over the period 2014-16, it has been estimated that the resulting vehicle km reduction of 440 million km reduced the total maintenance expenditure requirement in 2015-16 by approximately $65 million (Australia dollars). This estimate is based on the 1.6 per cent reduction in national tonne-kms resulting from this level of HCV use and assumes 100 per cent maintenance cost allocation to heavy vehicle use (National Transport Commission, 2017).

It has been estimated that the HCVs using PBS in the South African field trials have imposed road wear costs that are 13% less than their conventional non-PBS counterparts (an average saving of $2,000 (South African dollars) per vehicle per year) (Nordengen et al., 2018).

A desk study in the UK indicated that for the six length and weight combinations of HCV examined, four would increase road wear and two decrease it on a per vehicle basis. The ability of bridges to carry HCV depends on axles load and spacing, and therefore most of the HCV types investigated posed no greater risk than conventional articulated goods vehicles (Knight et al., 2008). However, it reported that 'a conservative analysis of bridge loading has identified some risks than 82 tonne vehicles (82 tonnes on 11 axles with a length of 34 metres - the longest, heaviest HCV type investigated) could overload a relatively small proportion of medium-span trunk road bridges and a larger proportion of such bridges away from the trunk road network' (Knight et al., 2008, p.111)

A 25.25 metre EMS road train with a 50-60 tonne gross weight operating on 7-9 axles (i.e. with axles loads of less than 9 tonnes) has been shown to impose less impact on the road than a 40 tonne semi-trailer operating on 5 axles with one axle weighing 11.5 tonnes (Jacob, 2013).

As part of the FALCON project ("Freight and Logistics in a Multimodal Context"), which was funded by the Conference of European Directors of Roads (CEDR), simulation work was carried out to study the impact of HCVs on bridge loading for 27 representative heavy goods vehicles including both conventional vehicles and HCVs. These vehicles ranged from 16.2 metres and 29.7 tonnes, up to 36.5 m and 73.8 tonnes. The impact of the representative fleet on bridges was assessed by IFSTTAR France. Vehicle impacts were studied for different types of bridge including simply-supported single span bridges, two-span continuous bridges, and spans of 10, 20, 35, 50 and 100 metres. The metrics considered "were the bending moment at the mid-span, shear force at the supports, used for both extreme loading and fatigue calculations. Dynamic effects were not considered nor were dynamic load factors" (de Saxe. 2019, p.44). This simulation work found that, "when normalised by loading capacity both in terms of volume (or loading length) or mass (total mass or cargo mass), high capacity vehicles are not more aggressive than more conventional vehicles. Indeed, the European semi-trailer is generally more aggressive when compared to the loading possibilities" (de Saxe. 2019, p.64).

The FALCON project also carried out a road wear impact assessment of six of the vehicles in this representative fleet of 27 conventional vehicles and HCVs on a selection of representative road structures. In this approach, "stresses and strains were computed using the software Alizé-LCPC, modelling the road structures with a linear elastic multi-layer model. Material properties were obtained from the Alizé-LCPC database. A standard axle of 10kN was modelled and used as a reference. From the stresses and strains, the number of repetitions of the loads applied by the axle groups before failure of the pavement were calculated. The vehicle combinations were then ranked according to aggressiveness" (de Saxe. 2019, p.65). Seven types of pavement structures were considered in this analysis which were selected to represent the most common European road structures. This assessment was carried out by BRRC in Belgium. This analysis found that a conventional drawbar combination with a length of 19.3 metres and a gross weight of up to 44 tonnes which is currently in use throughout Europe, is more aggressive to the pavements than a conventional semi-trailer with a length of 16.4 metres and a gross weight of up to 38 tonnes, "and also more than most of the LHVs, at least under the assumptions made in this document" (de Saxe. 2019, p.86).

Three approaches can be used to manage any impacts of HCVs on road infrastructure: i) the use of performance based standards (PBS) to design vehicles that are suited to the infrastructure especially bridges, ii) the greater number of axles on HCVs ensure that the road loading per axle is less than on standard vehicles, and iii) the use of information and communication technologies (ICT) can monitor and ensure high-levels of regulatory compliance with axle and vehicle weight limits in HCV operations (OECD/ITF, 2019).

9. Conclusions

The review of the existing research indicates that there is growing agreement that well-loaded HCVs will, through their greater load capacity, result in a reduction in vehicle journeys and hence vehicle kilometres. This in turn will lead to lower greenhouse emissions and air pollutants than conventional road vehicles per unit of goods carried. The reduction in vehicle kilometres will result in reductions in total vehicle collisions and injuries, and this road safety improvement can be further assisted by the application of Performance Based Standards (PBS) to HCVs to reduce collision and injury rates per vehicle kilometre travelled. Also, research does not support the notion that HCV use results in worse outcomes in terms of road infrastructure wear and tear.

Some of the evidence reviewed suggests that HCVs can lead to modal shift from rail to road, and that the lower operating cost of HCVs can result in a greater total demand for freight transport. However, the evidence indicating that HCVs could lead to these negative impacts is from theoretical modelling work that makes use of assumptions concerning the relationship between freight operating costs and the demand for freight transport (i.e. elasticity values) and vehicle load factors. There is limited evidence and consensus about the appropriate elasticity values to use in such modelling. It should be noted that real-world field trials and actual implementations of HCVs have provided no evidence of modal shift towards HCVs, or increased total demand for freight transport.

Other key factors in the extent to which the use of HCVs in the UK would affect total truck kms include: i) the road network over which their use is permitted, ii) the vehicle size/weight limits permitted, iii) the perceived financial costs and benefits of HCV use by freight operators, iv) the type of product carried and transport service provided, and v) the extent to which collection and delivery locations are updated to facilitate handling HCVs. The sectors in which HCVs are most likely to be used include: the Fast Moving Consumer Goods (FMCG) sector (for movements between factories, distribution centres and retail sites), trunk routes in pallet-load networks, , raw material and industrial product distribution, mail and parcels transport (to and from national sortation hubs), container transport to and from deep-sea ports, and the forestry sector (Knight et al., 2008; Risk Solutions, 2018).

The reduction in total goods vehicle kilometres as a result of permitting the operation of HCVs depends on several factors including: i) the HCV regulations implemented (i.e. the maximum vehicle length and weight permitted), ii) the operating conditions imposed on these HCVs (such as route restrictions), and iii) the applicability of HCVs to prevailing freight transport sectors and their operations (which will depend on factors including types of products carried, journey types made, vehicle costs, and the ease with which HCVs can accommodated at existing delivery and collection facilities).

The authors of this briefing report are of the opinion that HCV use is suited to long-distance freight movements on trunk roads, and not for operations in built-up urban areas or villages.

It is also important to note that the use of HCVs would not result in increases in the weight carried per axle. Instead, in field trials and implementations in other countries, HCVs have lower weights per axle through the use of an increased total number of axles, thereby better spreading the weight of the load. As a result, HCVs would not be expected to increase road infrastructure wear and tear, and can reduce it.

Long-distance road freight vehicles are likely to become autonomous (driverless) in future. Experimenting with and implementing HCVs in advance of this will permit countries to utilise greater vehicle capacity when such autonomous vehicles are available.

A 2008 desk study estimated that if the maximum number of trips that were applicable to HCVs were transferred to them then the reduction in kilometres travelled by goods vehicles of 32 tonnes and heavier in the UK would be considerable (a 13-52% reduction in vehicle kilometres travelled if there were no road restrictions on HCVs , and a 3-13% reduction in vehicle kilometres travelled if HCVs were allowed on motorways and other roads within 20 km of a motorway only (depending on the size/weight configuration of HCV) (Knight et al., 2008). This same UK study indicated that the actual transfer from conventional articulated trucks to HCVs would be far less than the maximum theoretically possible. Preliminary analysis from the current UK longer semi-trailer (LST) field trial indicates that, depending on the sector the vehicles are used in and whether or not collection and delivery locations are updated in future to facilitate the handling of longer vehicles, operators in the trial state they would like to replace 9-30% of their current trailer fleet with longer vehicles. The UK LST trial results estimate an average vehicle kilometre saving of 7% per operator, which varies by operator from 1% to 14% (Risk Solutions, 2018). It should be noted that the maximum potential distance travelled savings per vehicle in the LST trial are lower than those possible for HCVs which accommodate greater weight capacities as well as greater vehicle length.

The findings of this 2008 UK study are still considered to be applicable, and together with the results to date from the on-going LST field trial, indicate that if policy makers should decide to permit the use of HCVs in the UK this would be expected to result in a reduction in vehicle kilometres travelled.

The reduction in total vehicle kilometres required to transport the same quantity of goods (compared to using conventional non-HCVs) that HCVs can result in has an important benefit in terms of lowering total vehicle collision and injury rates. In addition, evidence suggests that the application of PBS to HCVs including better inherent vehicle dynamic performance, improved driver training and vehicle maintenance, together with route selection/compliance and overloading controls can result in lower collision and injury rates per vehicle kilometre travelled than for non-HCVs. Experiences running HCVs utilising such best protocol methods have yielded significant safety benefits with much reduced collision and injury rates.

When combined with the productivity benefits, substantially lower fuel consumption and carbon emissions per unit of goods transported compared with conventional vehicles that these vehicles have demonstrated in practical trials, it seems clear that the UK government should reconsider its policy regarding adoption of HCVs.

10. Recommendations

Given the evidence available from field trials and implementations reviewed in this report about the contribution that HCVs can make to reducing goods vehicle traffic, GHGs and air pollutant emissions, we recommend that the UK government reconsider its policy regarding the adoption of HCVs.

HCVs operate should take place only on suitable routes on the UK road network. While HCVs may need to use a limited road network other than trunk roads in order to collect and deliver product to distribution centres and other facilities, it is not recommended that general use of HCVs in urban areas or rural roads be considered. We recommend that the government commence work into the consideration of suitable roads and routes for HCV operation in the UK.

HCVs are likely to be best suited to trunking operations on motorways and dual carriageways in the movement of products between factories and distribution centres in various sectors including manufacturing and retail supply chains, pallet-load networks, parcel and mail transportation to and from national sortation hubs, transport to and from deep-sea ports, and in the forestry industry.

In considering the configuration and operating conditions of HCVs in the UK, it is important to make use of HCV best practice that has been developed in other countries where vehicles that are longer and/or heavier than those currently permitted in the UK have been trialled and implemented. There is a wealth of international knowledge and experience that can be drawn on.

This report has summarised findings from HCV field trials and implementations in many other countries. Some of these countries, such as Australia and South Africa, have very different conditions to the UK in terms of factors such as traffic levels, geographical scales and population densities. In these countries the size and weight of HCVs is not necessarily practical in a UK context. HCV trials and implementations in European countries with factors that are broadly comparable to the UK, and which have trialled or implemented HCVs up 25.25 metres and 60 tonnes, are likely to provide the greatest relevance to considerations about HCVs in the UK (such as Denmark, Germany, the Netherlands and Spain). We recommend that the government gives consideration to the lengths and weights of HCVs appropriate for use in the UK.

Evidence from HCV trials and implementations in other countries indicates that in planning for the role of HCVs in the UK, the government should consider their introduction in conjunction with the adoption of Performance Based Standards (PBS) for vehicle design and associated management and monitoring techniques for these vehicles to help ensure their achievement of established road safety, road infrastructure wear and tear targets, and route compliance. We recommend that the government gives consideration to the performance targets for HCVs in the UK.

We recommend that the government commission a detailed study to gain insight into HCV implementation issues appropriate for the UK including driver training, vehicle maintenance, vehicle performance (in terms of road safety, and road wear and tear), designated routes, infrastructure modifications necessary, vehicle and load monitoring.

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Appendix 1

Table A.1 provides a summary of the review of HCV trials and desk studies that have assessed the impacts of HCVs in recent years. It is subdivided into the topics on which HCV use have an impact. As well as summarising the findings of each HCV trial and desk study, an indication is provided of whether the findings suggest an improvement (+), worsening (-), or no change (0) in the impact in relation to HCV use for each topic/study.

Table A.1. Summary of the results of trials and desk studies into impacts of HCV use

Potential HCV impact by topic and sub-topic	HCV impact
Road freight transport activity	
Consolidation of loads into fewer vehicles (and hence reduction in total vehicle kms).	
Germany: Road freight operators participating in HCV field trials reported up to 33% reduction in commercial vehicle traffic (Sanchez Rodrigues et al., 2015). Analysis of trial results showed that one HCV (of 25.25 metres) could replace 1.56 conventional vehicles (Irzek et al., 2014 reported in Limbeck et al., 2017).	+
Norway: Field trials of European Modular System (EMS) indicated that each vehicle replaces 1.2-1.5 regular vehicles (Brevik-Wangsness et al., 2014).	+
Spain: Desk study estimated a potential 1-3% reduction of national road freight vehicle kms, also taking into account assumed intermodal shift scenarios from rail to road of 3-9% and induced demand (Pérez-Martínez and Miranda, 2016).	+
Sweden: Study of the actual implementation of heavier goods vehicles (from 51.4 tonnes to 56 tonnes in 1990 and to 60 tonnes in 1993, with vehicle length remaining constant at 24 metres throughout) showed that the additional weight capacity of these HCVs was being utilized (Vierth et al., 2018).	+
South Africa: The vehicles in the South African field trials of 245 HCVs using PBS have saved a total of 8.7 million kilometres per year which is equivalent to a 22% reduction (Nordengen et al., 2018).	+
Australia: Surveys of operators in the field trials of HCVs using PBS showed that over the period 2009-2016 many of the articulated combinations were achieving approximately 33% savings in vehicle kilometres compared with the comparable conventional vehicles. Vehicle kilometre reductions varied depending on vehicle configuration, ranging from 12.2% to 41.3% (Hassall, 2018).	+
Finland: A study of Finnish forestry transport carried out a year after the maximum weight limit had been increased from 60 to 76 tonnes in 2013estimated that the increase in weight limit had resulted in a 12.5% reduction in vehicle kilometres (Palander and Kärhä, 2017).	+
UK: Desk study estimated that if the maximum number of trips that were applicable to HCVs transferred from conventional road vehicles, then if there were no road restrictions there would be a 13-52% reduction in articulated vehicle kms (depending on size/weight of HCV), while if HCVs were allowed on motorways only then there would be a 3-13% reduction in articulated vehicle kms (Knight et al., 2008).	+
UK: Results of longer semi-trailer field trial estimated an average distance saving of 7% per operator (varying by operator from 1% to 14%) (Risk Solutions, 2018).	+
Possible shift of freight from rail and intermodal operations to HCVs to take advantage of lower operating costs they provide.	

EU: Two desk studies carried out into the use of 60 tonne 25 metre HCVs in the EU in 2008 reported different estimates of the expected decline in rail freight volumes, with one suggesting a 3.8% reduction and the other an 11.6-12.9% reduction (Transport and Mobility Leuven et al., 2008; Doll et al., 2008). The difference in findings was due to the assumptions about cross-modal demand elasticity values used in the models (McKinnon, 2018).	**-**
EU: In a desk study CE Delft (2010) estimated that if goods vehicle operating costs reduced by 20%, demand for road freight would increase by 18%, with one-third of this demand coming from modal shift from rail freight.	**-**
EU: In a desk study CE Delft (2012) indicated that the introduction of HCVs in the EU would lead to a fall in demand for rail freight services of approximately 10% (Transport and Environment, 2013).	**-**
EU: A desk study using a modelling-based simulation approach estimated that HCVs would result in a 2.1% decrease in rail freight compared to its expected traffic in year 2020. However, the overall work carried out indicated that "the introduction of LHVs (i.e. HCVs) would be beneficial for the EU economy and, under certain conditions, environment and society as a whole" (Christidis and Leduc, 2009).	**-**
Netherlands: Field trials in the 2000s using vehicles with gross weights of 60 tonnes had no effect on modal split (Kindt et al., 2011).	**0**
Sweden: A study of the actual implementation of heavier goods vehicles (from 51.4 tonnes to 56 tonnes in 1990 and to 60 tonnes in 1993, with vehicle length remaining constant at 24 metres throughout) showed that this did not lead to a break in trends in modal split, instead they continued on their long-term trajectories (Vierth et al., 2018).	**0**
Germany: Modelling carried out as part of the five-year German longer vehicle field trials (of up to 25.25 metres) from 2012-2016 showed "hardly any intermodal shifts from the railways and inland waterways" (Irzik et al., 2016).	**0**
UK: An assessment of the impact of the increase in maximum truck weight in the UK from 41 to 44 tonnes in 2001 reported that over the period 2000 - 2003 rail freight activity in the UK tonne-kms found no evidence of a reduction in rail freight activity. However, a reduction in charges to rail freight operators and a rail freight investment programme make it difficult to isolate the effect to the increase in truck weight from all other influences on the demand for rail freight (McKinnon, 2005).	**0**
UK: Stakeholder interviews carried out in 2017 as part of the UK longer semi-trailer field trial found no evidence that the trial was having any effect on rail and road mode choice, with interviewees explaining that "for price to become a dominant factor, such that freight will move from rail to road, the additional load per vehicle would need to be much more than the saving of 15% or less offered by LSTs (Risk Solutions, 2018).	**0**
UK: A desk study in 2008 estimated that the introduction of HCVs would capture 5–10% of the tonne-kms carried by conventional articulated vehicles, and 8–18% of all rail freight tonne-kms in the UK (Knight et al., 2008).	**-**
Possible impact on HCVs on traffic flow	
EU: An EU-wide study reported that "where road traffic flow has been discussed with stakeholders in Member States which permit HCVs or which have permitted them in trials, no significant effect has been found or studied" (Steer et al., 2013).	**0**
Norway: An EMS vehicle was found to result in traffic flow being "marginally worsened" compared to a regular truck but that "these challenges are small as long as EMS vehicles stick to roads that are suited for them" and were outweighed by the reduction in total vehicle activity they result in (Brevik-Wangsness et al., 2014).	**0/-**

Sweden: Research does not suggest that overtaking-related collisions are more common for longer vehicles (Vierth et al., 2008).	**0**
Possible generation of increased demand for freight transport if companies respond to any reduction in freight costs by making their logistics operations more transport-intensive (e.g. more distant sourcing, more centralised stockholding, or more frequent deliveries). This is often referred to as a 'rebound effect'.	
Sweden: A desk study of the potential impact of 74 tonne 25.25 metre and 74 tonne 34 metre HCVs indicated an increase in road freight by 2030 (due to induced transport and modal shift) of 9-17% if HCVs were permitted on all roads, 8-16% if HCVs were only permitted on a designated road network, and 1-5% if HCVs were limited to a designated road network together with a kilometre-based truck charge. (Pålsson et al., 2017).	**-**
UK: A post-implementation assessment of the impact of the increase in maximum truck weight in the UK from 41 to 44 tonnes in 2001 (which reduced road haulage costs per tonne-km by 11% for weight-constrained loads) showed that there was little evidence that the weight increase had generated additional demand for road freight movement (McKinnon, 2005). In a subsequent HCV study, logistics managers in the UK did not expect that reductions in road freight transport costs would lead to the restructuring of logistics systems and an additional demand for freight transport (Knight et al., 2008).	**0**
Environmental impact of freight transport	
Possible change in vehicle emissions and noise due to changes in vehicle size/weight and vehicle kms.	
Denmark and Netherlands: EMS vehicles showed no noticeable impacts on vehicle noise levels in field trials (Brevik-Wangsness et al., 2014).	**0**
Germany: 70% of respondents participating in HCV field trials reported significant reductions in fuel consumption and CO_2 emissions from their transport fleets (Sanchez Rodrigues et al., 2015).	**+**
Germany: Desk study using 2010 goods traffic data estimated that the introduction of longer 25.25 metre HCVs in Germany would be likely to result in a 17% reduction in fuel consumption per unit of goods transported for goods shifted from conventional non-HCVs. Taking account of the road goods traffic predicted to switch vehicle type, it was estimated that this would have reduced total greenhouse gas emissions by heavy goods vehicles in Germany by 0.06% (Gutberlet et al, 2017).	**+**
Norway: Evaluation of Norwegian field trials indicated that "EMS has lower emissions per tonne-km and/or m^3-km compared to regular trucks, and will lead to reductions in CO_2, NO_X and PM" (Brevik-Wangsness et al., 2014).	**+**
Australia: Analysis of HCVs using PBS in Australian field trials has estimated that in 2016, as a result of vehicle km savings, these 4,624 vehicles resulted in a fuel saving of 94 million litres, and CO_2 emissions reduction of approximately 250,000 tonnes (National Transport Commission, 2017).	**+**
South Africa: The 245 vehicles in the South African field trial of HCVs using PBS saved a total of 6,246 tons of CO_2 emissions per year compared to their benchmark non-PBS vehicles, which is equivalent to a 12% reduction in CO_2 emissions (Nordengen et al., 2018).	**+**
UK: Desk study reported that while 60 and 82 tonne HCVs would be expected to result in greater CO_2 and other emissions per vehicle km than conventional goods vehicles, they would lead to reductions in emissions on a per tonne carried basis (Knight et al., 2008).	**+**
UK: Emissions modelling in the UK longer semi-trailer field trial of 1,800 vehicles indicates overall savings for all those vehicles operating in the trial (compared to if they had been using 13.6 metre trailers) of 7.4% of CO_{2e}, 7.2% of CO, 7.3% of NO_x and 7.4% of PM exhaust emissions and 7.2% of VOC.	

These savings are similar to the 7% average vehicle kilometres savings in 2017 (Risk Solutions, 2018).	
Environmental impacts of mode shift from rail and intermodal operations to HCVs (which can alter the environmental benefits of HCV load consolidation).	
Germany: Desk study mentioned above using 2010 goods traffic data also estimated that the introduction of longer 25.25 metre HCVs on modal shift from rail and its impact on fuel consumption. It was estimated that the goods traffic shifting from rail to HCVs would have resulted in a 0.01% increase compared with the total greenhouse gas emissions from rail freight in Germany (Gutberlet et al, 2017).	**0/-**
Freight transport operating costs	
HCV has potential to reduce vehicle operating costs per unit of goods transported.	
Germany: Analysis of field trial results showed that HCVs had a 16% lower operating cost compared to conventional vehicles, if an utilization rate of more than 83% could be achieved (Irzek et al., 2014 reported in Limbeck et al., 2017).	**+**
Australia: Analysis of the vehicle kilometre savings derived from HCV use together with the higher operating costs of HCVs forecast that the use of HCVs will result in operating cost savings of $9.6-22.2 billion (Australian dollars) over the period 2014-2034 (Industrial Logistics Institute, 2017).	**+**
Road freight traffic collisions and casualties	
Possible change in likelihood of road traffic collisions and casualties from using HCVs.	
Germany: Field trials of 2012-2014 of 25.25 metre HCVs show that "no measurable impact from longer trucks on traffic safety and traffic flow at work sites on motorways can be expected" (Limbeck et al., 2017).	**0**
Sweden: Study of longer vehicles operating in the period 2003-2012 showed they were involved in less fatal or severe crashes per vehicle km than those up to 18.75m (i.e. the European Union length norm). The rates for 'short' (≤12 metres), 'medium' (12.01–18.75 metres) and 'long' (18.76–25.25 metres) vehicles were 137, 56 and 44 fatal or severe crashes per billion vehicle kilometres travelled respectively (Bálint et al., 2014).	**+**
South Africa: HCVs using PBS in the South African field trials have crash rates that are 39% lower than their comparable baseline vehicles (1.37 crashes per million km compared with 2.24 crashes per million km) (Nordengen et al., 2018).	**+**
Australia: Over the period 2009-2016 across all HCV configurations using PBS the observed performance in terms of major collisions per 100 million vehicle kms was 46% better than among the comparable conventional (non-HCV) fleet. Results varied by HCV configuration. Analysis has also shown that fatal collisions involving HCVs between 2009 and 2016 are also below that of conventional vehicles (Industrial Logistics Institute, 2017).	**+**
UK: In the longer semi-trailer field trial, analysis has shown that trial vehicles were operated with a lower rate of injury incidents in public locations than the average for British articulated non-HCVs on urban roads, minor roads and major roads, with an equivalent to one longer semi trailer-related injury incident in a public place for every 148 million km travelled, compared with one for every 6 million vehicle kilometres for all articulated vehicles operated in the country (Risk Solutions, 2017).	**+**
UK: Two operators in the longer semi-trailer field trial had a higher damage incident rate than the non-LSTs in the same fleet (mostly in terms of contact with other road vehicles). This was likely due to driver 'equipment awareness'	**+**

and both operators were considering adopting visual cues to prevent this (Risk Solutions, 2017).	
Road infrastructure costs	
Possible changes in road maintenance and road infrastructure modification (including bridge strengthening).	
Norway: EMS vehicle field trials did not require any public expenditure on road infrastructure adjustments, and the evaluation indicated few differences in the impact EMS vehicles have on road infrastructure compared to regular trucks. Where there were differences these were small, and varied from marginally better, to marginally worse (Brevik-Wangsness et al., 2014).	**0**
EU: Expenditure to improve the road infrastructure for HCVs was extremely different in Denmark for a trial (€18 million) and Sweden (€2.7 billion for load bearing when increasing permissible vehicle weights from 51.4 to 60 tonnes). The infrastructure improvement costs associated with HCVs is likely to relate to the extent of the HCV network, the HCV configurations permitted, and the current standards of road and bridge infrastructure in any given country (Steer et al., 2013).	**0/-**
Australia: Using results from the Australian HCV field trials it has been estimated that the resulting reduction in vehicle km reduced the total maintenance expenditure requirement in 2015-16 by approximately $65 million (Australia dollars) (National Transport Commission, 2017).	**+**
South Africa: It has been estimated that the HCVs using PBS in the South African field trials have imposed road wear costs that are 13% less than their conventional non-PBS counterparts (an average saving of $2,000 (South African dollars) per vehicle per year) (Nordengen et al., 2018).	**+**
UK: Of 6 HCV types studied in a desk study, 4 would theoretically increase road wear and 2 decrease it. The ability of bridges to carry HCVs depends on axles load and spacing, so most HCVs pose no greater risk than conventional vehicles (Knight et al., 2008).	**0**
EU: The FALCON project ("Freight and Logistics in a Multimodal Context") carried out simulation work to study the impact of HCVs on bridge loading and road wear. This simulation work found that, when normalised by loading capacity both in terms of volume (or loading length) or mass (total mass or cargo mass), HCVs are not more aggressive in terms of bridge loading than conventional vehicles. In terms of road wear the analysis found that a conventional drawbar combination currently in use throughout Europe is more aggressive to the pavements than most of the LHVs studied (de Saxe. 2019).	**0**

The Centre for Sustainable Road Freight (SRF)

SRF was founded in 2012 to help industry and Government minimise carbon emissions from the road freight sector.

SRF brings together three of the UK's leading academic groups: the Cambridge University Engineering Department, the Logistics Research Centre of Heriot Watt University and the Freight and Logistics Research Group at the University of Westminster, along with industry and government partners; to make road freight environmentally, economically and socially sustainable.

The overall aims of the SRF are to:

1. perform a comprehensive programme of research on the opportunities for improving the environmental sustainability of road freight transport;

2. develop innovative technical and operational solutions to road freight transport challenges;

3. assess solutions to meet Government emissions reduction targets for the road freight sector;

4. bring together organisations from across the road freight industry in a cooperative group: to develop innovative solutions to reduce fuel consumption and test them in practice.

SRF receives funding from various UK Government and European sources, particularly EPSRC, ETI and InnovateUK, as well as from industry members. Industry members include: Chevron, Denby Transport, Freight Transport Association, Goodyear Tires, John Lewis Partnership, Optrak, SDC Trailers, Tesco, Transdek, Turners Transport, Sainsbury's, Value Chain Lab and Volvo Trucks.