International Transport Forum

High Capacity Transport

Towards Efficient, Safe and Sustainable Road Freight

Case-Specific Policy Analysis

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The International Transport Forum

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Case-Specific Policy Analysis Reports

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Executive Summary

What we did

Road freight traffic is forecast to grow substantially in most countries. The anticipated increase in infrastructure capacity will not, on its own, be sufficient to accommodate projected traffic levels. Using bigger trucks, or high capacity vehicles (HCVs), is one of the most practical options for accommodating some of this growth.

This study 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.

What we found

A number of countries have introduced HCVs or are testing them. Such vehicles can be designed to operate on existing roadways with limited or no additional infrastructure investment to accommodate them. They can contribute to improving the efficiency and safety of road transport operations and reduce transport costs and energy demand. Advances in information and communication technologies (ICT) ease the introduction of HCVs by allowing better monitoring of vehicles and thus enforcement of conditions of access to the road network.

Despite the benefits, there is often opposition to the introduction of HCVs. In many cases an evidence-based approach to policy making is eclipsed by fears that increasing the weight and dimensions of trucks might increase risks for other road users. It is also argued that larger freight vehicles could take business away from small trucking firms or from railways and waterborne transport. Risk to infrastructure is also discussed.

HCVs contribute to decarbonising transport. They lower fuel consumption and emissions per unit of cargo transported and reduce the number of trips required to move the same amount of freight. They also reduce costs. Other things equal, this will tend to result in additional freight demand, yet the effect is likely to offset only a small part of environmental gains. Where there is head-to-head competition, HCVs will enjoy a greater advantage over competing modes than standard trucks. However, positive impacts on rail freight have also been observed in intermodal markets, as HCVs can extend the reach of rail services. Additional research on intermodal freight, where trucks are an essential component, is needed.

The impacts of HCVs on road transport infrastructure can be efficiently managed using three approaches. First, the vehicles can be designed using performance-based standards (PBS). This ensures their performance meets pre-defined characteristics suited to the existing or planned road infrastructure, most notably to bridges. Second, HCVs have more axles than standard vehicles to ensure that road loading per axle is less than current norms. Third, the use of ICT can ensure high-levels of regulatory compliance in the operation of the vehicles. This applies even in regions where compliance is not the norm in the trucking industry.

The safety performance of HCVs is actually better than that of the conventional freight truck fleet, as review of existing HCV programmes and data from Australia, Canada, South Africa and several European countries reveal. The good performance of HCVs also depends on how they are managed. This includes training to improve driver skills, additional on-board safety systems and limiting the operation of HCVs to certain routes. As HCVs are typically more expensive than standard trucks, operators have strong incentives to use them in an efficient and safe manner.

Several policy options exist for allowing HCVs onto roads. They include PBS and flexible policies on size and weight. Australia and Canada provide examples for very different approaches to PBS, which demonstrate the degree of flexibility that exists for delivering significantly improved road freight transport in terms of efficiency, safety and environmental performance.

What we recommend

Use the potential of High Capacity Vehicles to increase transport efficiency, reduce traffic volumes, lower emissions and achieve better safety outcomes

High Capacity Vehicles provide an opportunity to improve transport efficiency by increasing the cargo capacity of the vehicle, carrying higher mass, volume or both. Fewer truck trips are required per freight task, which reduces truck travel, lowers carbon dioxide and NOx emissions, cuts fuel use and lowers shipping costs.

Use well-monitored trials to introduce High Capacity Vehicles on a road network

The most effective way to introduce HCVs is through trials coupled with a well-structured, independent evaluation. Investing in reliable data provides an objective means of assessing the value of HCVs to policy objectives. Good data also provides a way to determine if modifications to access conditions for HCVs are required. This approach delivers the objective evidence policy makers require for determining whether to deploy HCVs on a continuing basis, and weigh advantages in relation to global, national, regional and local interests. Some level of data collection activity should continue after completion of the trial period to provide policy makers with objective data to support future decisions.

Configure High Capacity Vehicles for the specific area in which they will operate

HCVs are not necessarily a one-size-fits-all solution. They are sophisticated vehicles designed to optimise freight transport. To ensure HCVs provide full societal value they should be configured to provide maximum benefit for the region in which they will operate. Coupled with ICT solutions, compliance with the specific regulations of that region can be improved. ICT can also help ensure that HCVs can be allowed with confidence on infrastructure, including bridges, designed to prevailing specifications.

Introduction

Trade and freight traffic levels will continue to grow in all countries, according to current projections. Freight transport demand across all modes is expected to increase by a factor of three by 2050. Most growth is expected in Africa, Asia and South America, where transport infrastructure is poor and funding for new infrastructure limited (ITF, 2017a). Increasing the capacity to accommodate that growth by investment in new infrastructure alone will not be possible.

High Capacity Vehicles (HCVs) are a potential answer to this problem, as their use in a growing number of countries demonstrates. HCVs – sometimes referred to as HPV (High Productivity Vehicles) or LHV (Longer and/or Heavier Vehicles) – are freight trucks that are heavier or longer (or both) than vehicles currently permitted on the general road network. Such vehicles would normally only be allowed on certain parts of the road network. Special requirements also apply on both the vehicles and their operation.

HCVs allow better utilisation of existing infrastructure, without additional pavement wear and, where required, affordable investments in bridge strengthening. At the same time, they require less energy per unit of transported cargo and thus offer reduced emissions and less impact on our climate. They are also safer. Overall, HCVs can reduce the cost of road freight transport for operators, users and society as a whole. With smarter, greener and safer transport and a more efficient use of infrastructure as a necessity, High Capacity Transport (HCT) has enormous potential to save money and reduce CO_2 emissions. Public acceptance of longer and heavier vehicles on roads has made significant progress during the past few years not least because of this realisation.

The most important development that has facilitated the use of HCVs is the wider adoption of the Performance Based Standards (PBS) approach for heavy vehicle design and operation. The PBS allows a better matching of the vehicle to the road by differentiating the road network into several classes depending on the mass and length of vehicle combinations.

At the same time, the rapid advances in Information and Communication Technologies (ICT) have made it more cost effective to advise, monitor and enforce compliance of HCVs with access conditions and traffic regulations. The Australian National Telematics Framework with the applications IAP (Intelligent Access Program) and EWD (Electronic Work Diary) are good examples.

The aim of this study is to take stock of the current state of play with respect to HCVs and provide guidance for policy makers seeking to create appropriate regulatory frameworks for them. It also aspires to take discussions in previous work further, building particularly on the 2011 report "Moving Freight with Better Trucks" (ITF, 2011). It presents a broad, global picture of the use of HCT, looking at the types of transport operation and vehicle combinations, the trends in engineering and logistics, as well as the development of new regulatory frameworks, strategies and road maps for HCVs in different countries.

The report develops an inventory of regulatory measures and enforcement practices relating to HCVs. This inventory is based on the examination of the safety, environmental and productivity impacts of HCVs. It also takes into account the impacts of changes in heavy vehicle weight and dimensions, operational policies and technology and their compatibility with the road infrastructure and other road users. Not least, the study provides a view on HCVs and freight transport in general from logistical, market and policy perspectives.

Based on these insights, the study outlines how the needs of society and industry for increased road transport productivity can be achieved while at the same time offering significant environmental and safety benefits, along with manageable impacts on the road network.

The discussions on HCT cover a wide range of issues. This report focusses on seven aspects, for which available research was reviewed and existing pilot projects studied:

- Market and impact assessment (potential, business cases)
- Modal shift
- Infrastructure (impact on roads and bridges, network access)
- Traffic safety
- Compliance (monitoring and enforcement, ITS and telematics)
- Performance Based Standards
- ITS as an enabler for the use of HCVs.

The package for policy makers which concludes the report contains a set of policy options, technical material and public communication points. It incorporates a set of internationally vetted performance measures, metrics and protocols that can be used in the formulation of policy as well as the development, implementation and monitoring of High Capacity Transport.

Economic and political developments in transport

The 2011 report "Moving Freight with Better Trucks", (ITF, 2011) examined logistical, infrastructure and regulatory challenges as well as the environmental and safety performance of HCVs and gave a good snapshot of the situation in the immediate aftermath of the 2008 global financial crisis, which constrained economic activity, reduced transport demand and deflated energy prices.

Countries have since recovered from the economic shock, albeit to varying degrees (ECB, 2017), and demand for transport is again growing. Instead, transport's adverse environmental impacts have moved up high on the political agenda and a strong international mandate for tackling those was promulgated with the signing of the 2015 Paris Climate Agreement.

Technological innovation has also had a major impact on freight transport sector since the publication of the 2011 ITF report. One continuing trend here is the increasing shift from driver assistance functionalities to higher levels of automation, which in the road freight transport sector can enable platooning or even full autonomy of vehicles. In addition to significantly reduced operational costs for logistics operators increased automation also holds the promise for increased vehicle safety. Other trends that have emerged over the past decade include the mainstreaming of load-matching platforms and the introduction of the sharing economy to road freight, with potentially disruptive consequences.

Developments in more generic Intelligent Transport Systems (ITS) and technologies have also progressed. Highlights include an increase in road-side and in-vehicle sensors, which allow real-time and fine-grained tracking when combined with less-structured Big Data and state-of-the-art data analytics capabilities, control, and management of vehicles and loads. A clear opportunity exists for a data and tech-driven approach for the regulation and management of larger and heavier freight vehicles; thus guaranteeing safe operation in the right parts of the network at the right times.

Economic developments

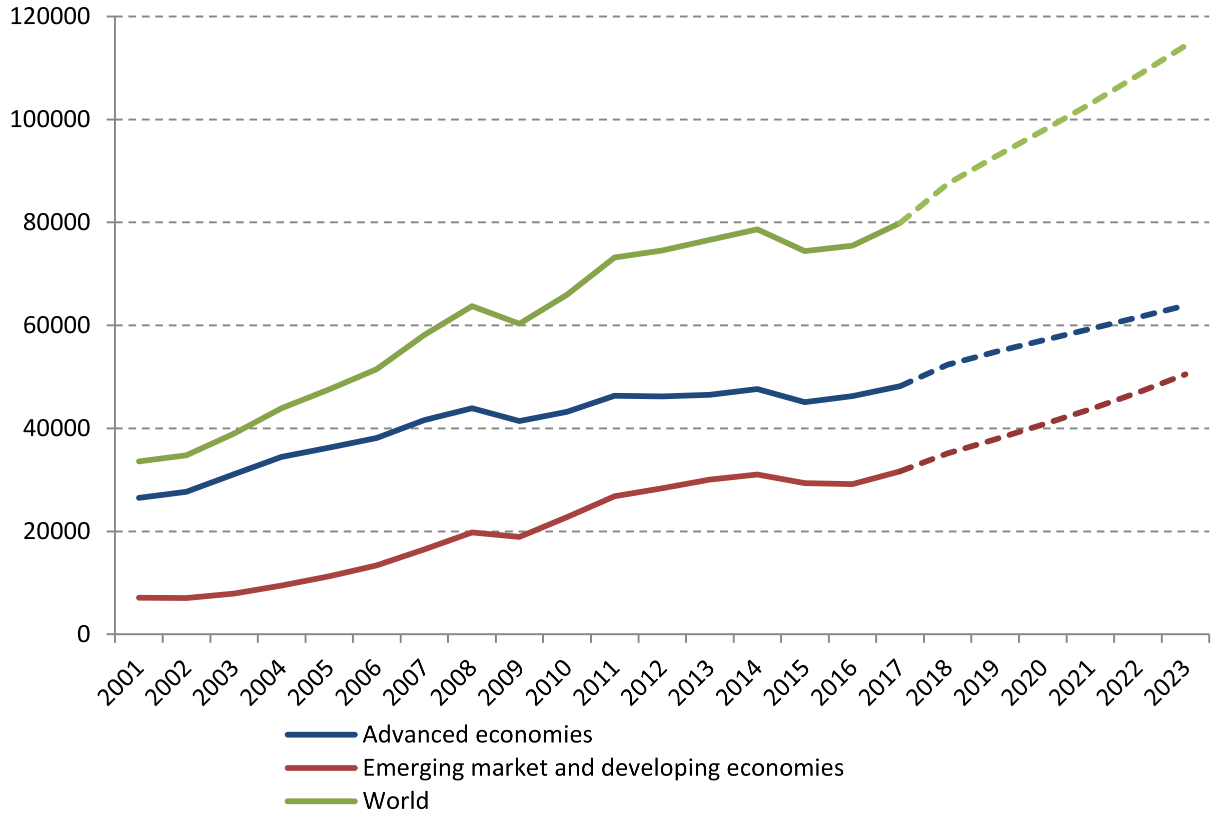
Developments in merchandise trade are the main drivers for the freight transport demand. According to forecasts (ITF, 2017a) it is suggested that the total freight transport demand will likely triple from 112 000 to 329 000 billion t-km from 2015 to 2050. The global average annual road freight transport growth rate will be 3.2% from 2015 to 2030, and 2.8% from 2015 to 2050. This growth for freight transport will primarily be driven by continued economic growth and higher international trade.

Research on the ITF report "Moving Freight with Better Trucks" was done during the economic crisis. Since then a range of economic developments have occurred that inevitably have impacted on transport in general and road freight transport in particular.

Since 2010 the world economy has been recovering from the global financial crisis, with the strongest growth in the developing market economies, as shown in

Figure 1. According to forecasts(IMF, 2018) this trend is likely to continue in the next years, see dotted lines.

Figure 1. World GDP

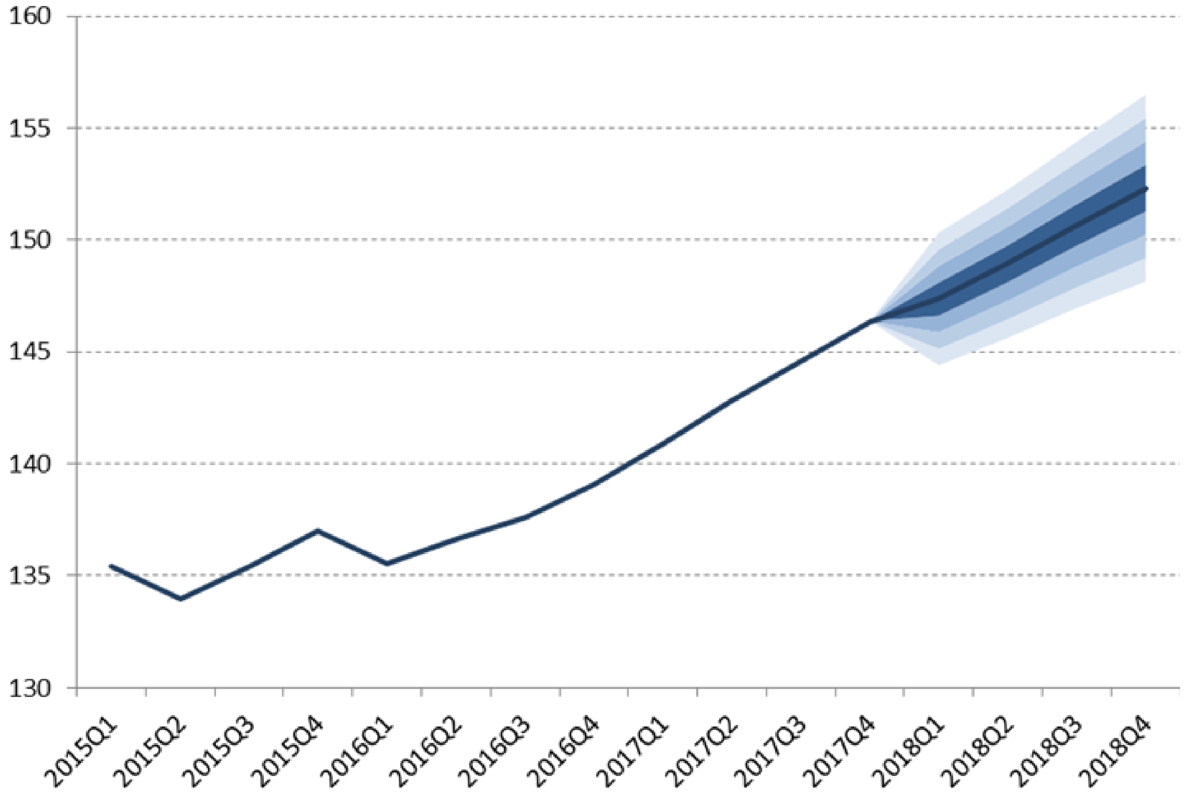


Note: USD trillion

Source: IMF (2018)

In the early 1990s trade grew twice as fast as world GDP. Further developments in the decade included integration of the former Soviet Union countries into the global economy, founding of the World Trade Organisation (WTO), and the technological change that allowed easier management of dispersed supply chains. As a result, in the 2000s the world experienced a strong trade growth up until the recent crisis of 2008, the trade volumes increased substantially. Following the 2008 crisis, trade has recovered and in recent years is showing strong signs of growth from 2018 onwards, as shown in forecasts of (WTO, 2018a) and the expectation is that the current trend is likely to soften but continue in the future (WTO, 2018b).

Figure 2. Volume of world merchandise trade and forecasts



Note: 2015Q1-2018Q4, seasonally adjusted volume index, 2005=100

Source: WTO (2018a)

The projections of economic and related traffic growth highlight the need to reassess the capacity utilisation of existing transport infrastructure and its ability to accommodate future demand. The fastest growth and strongest infrastructural pressures are likely to be experienced in Africa and Asia (ITF, 2017), but other parts of the world will also be affected.

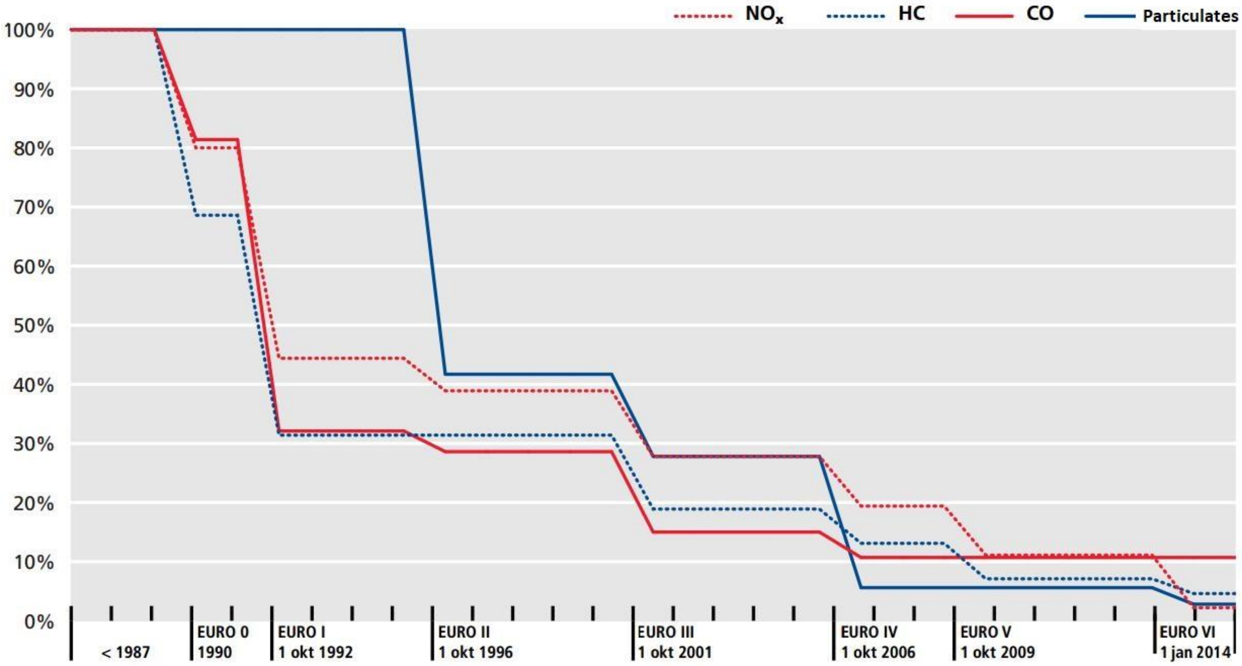
The utilisation of infrastructural capacity can be improved in various ways such as shifting freight between modes or rescheduling deliveries to off-peak periods. The level of utilisation can also be raised by increasing of the efficiency of road freight operation itself, through the use of higher capacity vehicles. This needs to be done in way that takes full account of environmental and safety impacts.

Environmental impacts of transport

Air pollution and global warming have become political priorities in recent years. At the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties held in Paris, December 2015 (COP21), nations publically communicated their climate commitments. ITF research shows that to attain the two-degree-scenario of the Paris agreement, additional commitments to cut transport-related CO_2 emissions will be required, (Windisch, 2018).

Local emissions, like NO_X, PM, HC and CO, particularly from diesel vehicles, have an impact on the air quality locally, especially in the cities. The poor air quality is to blame for various health problems that include cardiovascular and respiratory diseases such as irregular heartbeat, heart attacks, asthma, bronchitis, emphysema, and cancer. The emissions of vehicles remain high on the political agenda despite the improvements that the introduction of higher emission, noise and safety standards for new vehicles have brought, Figure 3.

Figure 3. Euro-standards on emissions reduction of lorries compared to EURO 0 (1990-2014)

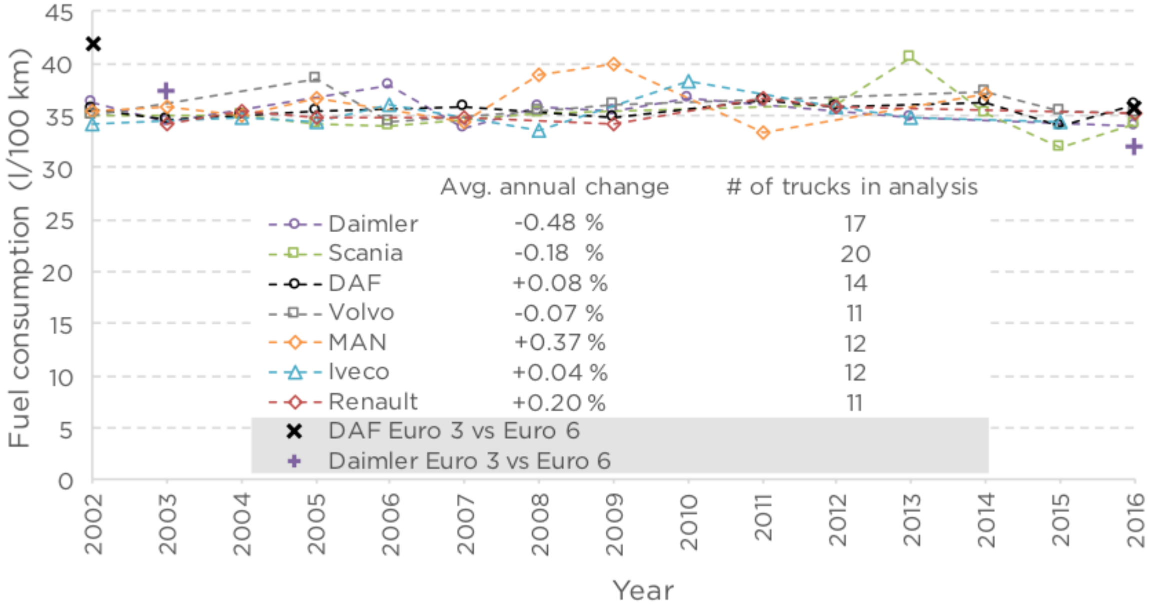


Source: TLN (2015, p.139)

Further technological progress in reducing harmful local emissions from road freight vehicles will be difficult and in the foreseeable future progress towards a EURO VII emission class is likely to be limited although emerging technologies that could contribute to lower emissions in real-world driving conditions, for example through new ammonia storage and delivery systems (Faurecia, 2018).

Data shows that the real-world fuel consumption by heavy-duty vehicles, which directly translates to CO_2 emissions, has remained unchanged in the last years, see Figure 4. But according to the International Council on Clean Transportation (ICCT) study there is potential for tractor-trailers to achieve 19 l/100km in the 2020–2030 time frame (ICCT, 2015).

Figure 4. Fuel consumption of heavy-duty vehicles with engine power of 300-400 kW



Source: ICCT (2017) based on Lastauto Omnibus

In the future emerging technologies that use alternative fuel sources, e.g. electrical power supply from highway catenary systems could help tackle both the local pollution levels and greenhouse gas emissions. In the short-term, more efficient use of long combination vehicles could have positive impacts in specific situations, as in the United States and Canada where vehicles granted unrestricted access have radically different environmental performance characteristics, Figure 5.

Figure 5. Canadian B-train and United States Tractor semitrailer

Source: Woodrooffe (2017)

Table 1. North America fuel and CO_2 emission comparison

Country and Vehicle	Fuel per cargo unit (liter/t-km)	CO_2 per cargo unit (g CO_2/t-km)	Fuel and CO_2 advantage
Canada, B-train	0.037	98.79	68%
The United States Tractor semi	0.063	165.9	-

Source: Woodrooffe (2017)

Adoption of High Capacity Vehicles

Attitudes towards the adoption of HCVs have not been progressing in a favourable way. In many places, like the United States, an evidence-based approach to policy making is currently eclipsed by emotional arguments voiced against increasing the weight and dimensions of road freight vehicles.

On the other hand, more stringent regulatory approaches have helped to enable the introduction of HCVs in some countries. To allow these vehicles on the road, regulators may choose to limit the road network that they can use, specific requirements may be imposed on hauliers, vehicle performance characteristics may be subject to additional requirements, driver qualifications and actions can be prescribed, and vehicles only allowed to operate under specific conditions. In many places the application of these more stringent rules has ensured that the HCVs can be used safely in a manner that secures wide public and political acceptance. This is exemplified in Australia, Canada, The Netherlands, Finland, Sweden, Germany, the United States, Mexico, Argentina, New Zealand and South Africa (Moore, Regehr and Rempel, 2014).

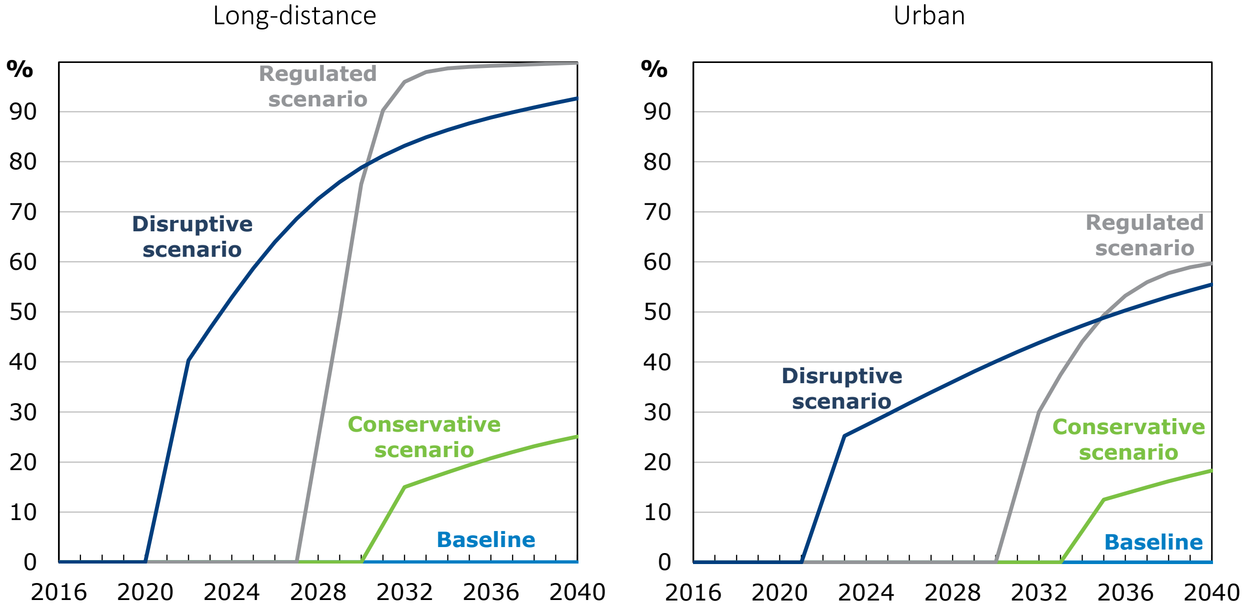
A non-exhaustive review of typical HCV combinations that are in use in different countries is available in Annex 1 of this report. It presents a selection of some commonly used HCV combinations. The aim is not to show the largest of the vehicles, but those that are commonly used. The HCVs shown are typically operated based on permits, meaning that the vehicles are adapted to the infrastructure characteristics and particular business needs.

Implications of truck platooning and automation

The development of new vehicle control systems in the road freight sector may affect the future development of HCT. Vehicle automation is now a clear trend, with governments, original equipment manufacturers (OEMs), and the IT sector competing worldwide for leadership in this space. A large variety of implementation scenarios in different sectors and environments are being developed. Due to the clear business case and relatively controlled environment, automation of road freight vehicles on motorways has generated much interest. These concepts range from twinning to platooning and ultimately full automation. Traditional vehicle manufacturers as well as new players are developing truck automation technologies, which can be applied to new vehicles or retro-fitted to existing fleets.

Figure 6 shows the four scenarios developed for study on “Managing the Transition to Driverless Road Freight Transport” (ITF, 2017b). They are not probabilistic forecasts for the future of driverless trucks, but instead indicate possible pathways. Scenarios are distinguished by the degree to which existing and future road freight transport would be undertaken using driverless trucks. The Baseline scenario was for zero adoption of driverless trucks on public roads in the next 20 years. The Conservative scenario assumed that driverless technology is slowly introduced from 2030 onwards, initially in a few long-distance markets, and (from 2033) a few cities in Europe and the United States. The Regulated scenario assumed that driverless technology is allowed on all long-distance routes from 2028 and in cities from 2030. In long-distance freight the technology is ubiquitous within three to five years, whereas in cities the take-up is less strong. The Disruptive scenario assumes that driverless technology is rolled out on only half long-distance routes from 2021 (and progressively expanded) and similarly in cities from 2022.

Figure 6. Scenarios for roll-out and adoption of driverless trucks on long-distance routes and in urban areas



Source: ITF (2017b)

As stated in (Voege, 2019) the so called "Truck Platooning Challenge" organised in Europe as part of The Netherlands' European Union Presidency in 2016 provided a proof-of-concept of how a relatively low-tech short-distance (also often referred to as a "virtual tow-bar") following of a number of trucks behind a fully manually operated lead vehicle with a specific focus on the cross-border aspect. This culminated in the development of some guiding principles in this space, i.e. (Declaration of Amsterdam, 2016).

The International Road Transport Union (IRU) Report "Commercial Vehicle of the Future" published shortly after this in early 2017, identified automation and platooning – amongst other Information Technology Solutions (ITS) trends - as areas of development to have a strong impact on how road freight transport and logistics operations will be organised in the future and could also contribute to a reduction in the sector's environmental footprint. The report also states that the implementation of largescale truck platooning across the European Union is a good example of political and legislative facilitation of new, compatible, EU-wide solutions, as well as interoperability between existing systems (Transport and Mobility Leuven and IRU, 2017).

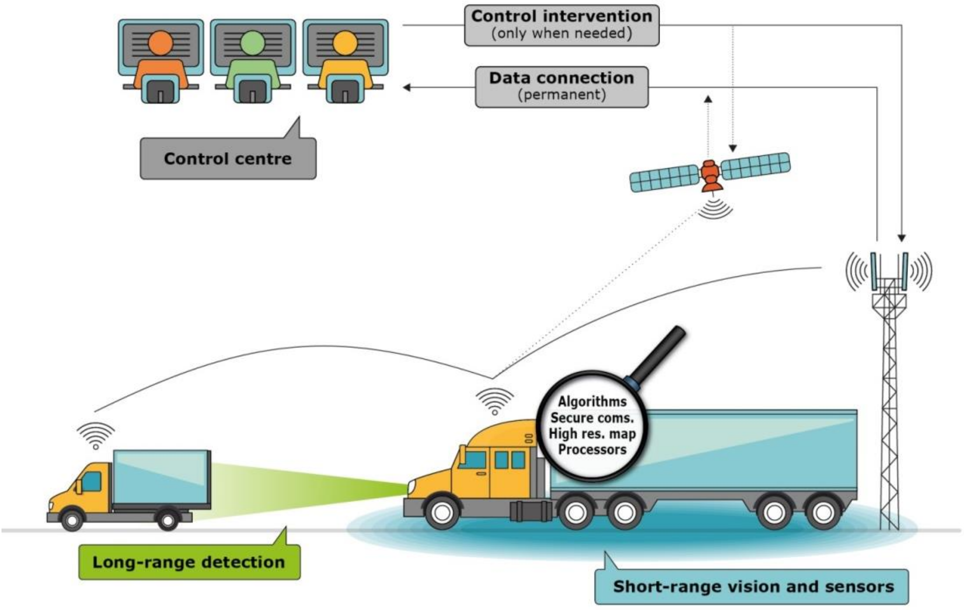
It goes on to say that truck platooning will lead the way towards increased vehicle automation and then to the use of fully autonomous road freight vehicles. This will require a fundamentally different approach to the traditional rules on the use of the road, especially regarding the role of the professional driver. Fully autonomous commercial vehicles will undoubtedly provide new opportunities for vehicle and loading-unit design and substantially overhaul the way freight is moved by road and multimodal transport. Further deployment of ITS will also speed up the digitalisation of road freight transport and logistics processes and the entire multimodal transport chain. The political and legislative groundwork that will allow further EU-wide progress needs to be carried out in advance. Wide-scale use of ITS and digitalisation will also create new opportunities for road freight transport and logistics operators to collaborate. The collaborative economy is introducing new ways of sharing resources and cooperating which could contribute to more efficient load factors. These developments, which may come about in the short- to medium-term future, will have a direct effect on HCT in terms of their operation, management and governance.

There will be a large element of interaction between manually-operated vehicles and automated vehicles. This interaction will occur with fleets and across the mix of vehicles on the road network, at least during a transitional period. Given both the specific implementation environment of vehicle automation for road freight, i.e. the whole motorway network, or specific high demand corridors, and the technical requirements for such operations, a data-rich space with high data connectivity is likely to emerge.

Looking at the driver or operator roles, for both multi-vehicle platooning and full automation, we are likely to see solutions, where a driver will always, or on parts of the trip, be inside the cab and will be able to immediately take control of the vehicle in a pre-defined time span. Based on a hand-over protocol, they will gradually be able to regain control of the vehicle either in case of system malfunction, or when entering parts of the network not equipped for full automation (e.g. part of the overall motorway network not equipped, or, leaving the motorway and going into more complex urban areas where full automation would be more difficult). In this case driver workload would be drastically reduced, allowing more flexible systems regarding working hours; this is also likely to be the main business case for logistics operators to invest in these new and likely more costly vehicles (Voege, 2019).

In the case of automation in conjunction with a control centre, regulations for working environment and working hours for these operators might have to be formulated. Furthermore, rules might have to be put in place to allow safe operation and interaction of manually operated and automated vehicles in mixed environments. In the long-term scenario of full autonomy of vehicles without any drivers or operators inside the vehicle or in a control centre, the category of driver-based rules would not apply anymore, but this then requires a precise definition of roles and responsibilities of logistics companies, OEMs, and infrastructure owners and managers, in order to have a clear understanding of liability in case of incidents.

Figure 7. Stylised driverless truck operating environment with optional control centre



Source: ITF (2017b)

It is important to appropriately respond to the economic and environmental pressures that road transport is experiencing, especially because action on these issues is in line with transport policies for most countries. Although the emerging technologies for road transport like electrification and power supply from the infrastructure are coming closer to practical implementation, they only address a part of the problem and implementation will take time. In this context relaxing the size and/or weight restrictions for road freight vehicles is a relatively quick (i.e. recent experience in Europe suggests 5-10 years of trials before full implementation) and low-cost solution, which has been validated in numerous places around the world.

HCVs bring two streams of benefit. For road hauliers and shippers of the goods there are economic benefits from the consolidation of loads. There are also the societal benefits of safer road transport operations with lower crash rates due to fewer, safer trucks on the roads for the same transport volume, and the environmental benefits from lower greenhouse gas emissions and pollution per t-km of freight movement. Lessons can be learned from those countries where HCT has been successfully implemented, often with the support of ITS.

Impacts of High Capacity Vehicles

Qualitative information on the impacts of High Capacity Vehicles (HCVs) around the world is becoming available. This sheds light on the potential market for HCV use, and its impact in existing transport service markets, including modal shift, transport infrastructure and safety.

Existing policies and programmes for High Capacity Vehicles

Several countries have set up research programmes, made investigations, set up committees to prepare policies and regulations – all in order to support introduction and implementation of High Capacity Transport (HCT).

Here an overview is presented of what has been done and is going on in some countries. Australia and Sweden could be seen as forerunners. These two countries have also established a close collaboration since 2011 with pilots and policy development.

Closely linked to this is the development of Performance Based Standards (PBS). Australia, Canada, New Zealand and South Africa have all been pioneers in this field — but with slightly different approaches.

Considerable variations between traditions, geography, road network standards and population densities in the counties of the European Union create a unique situation that must be considered when developing policies. When Finland and Sweden became members of the European Union in 1995 they got an exemption to allow 25.25m-long vehicles with a total weight of 60 t. In all other European Union countries corresponding figures are 18.75m and 40 t based on the European Union Directive 96/53/EC and a standard called the European Modular System (EMS). Trials of HCT are permitted within this regulatory framework.

Country profiles: High Capacity Vehicle policies and programmes

Australia

Australia is well recognised for their long and heavy trucks – road trains – both in and outside the global transport sector. What is not so well known is that this huge country – in fact a continent –has been for a long period at the forefront when looking at the necessary legislation, regulatory and technical frameworks for HCV adoption.

In Australia it was recognised in the early 2000s that:

- Innovative vehicle technology will be needed to absorb growing demand for road space, given tightening road infrastructure constraints (and budgets to improve road infrastructure).
- Innovative vehicle design, underpinned by PBS will enable larger and heavier vehicles to be allowed on specific parts of the road network, which are deemed suitable for the use of these vehicles.
- Customary methods of managing route and mass compliance are not capable of dealing with the safety and infrastructure management risks associated with innovative vehicles, which are

permitted to operate only on specific parts of the road network. Intelligent access methods are needed.

The IAP was approved in 2005 under Model IAP Legislation by the Australian Transport Council. One year later Transport Certification Australia (TCA) was launched as a nationally-owned company to implement and administrate IAP as the first application under the National Telematics Framework. This process lead to the introduction of PBS within the Intelligent Access Program (IAP) and later the Heavy Vehicle National Law (2014).

IAP application uses GPS and other technologies to track participating vehicles and ensure they adhere to their operation conditions, such as route, speed and temporal compliance. More recently axle group mass compliance has also been introduced. The IAP application has been designed and used to provide the highest order of assurance, namely certificate-based court evidence for compliance. Additionally, other applications to the IAP have been introduced and approved at ministerial level that deal with lower levels of assurance and task specific needs. These include IAP Lite and Road Information Monitoring (RIM). This proof of compliance may allow usage of heavier, longer and more productive vehicles onto suitable parts of the road network.

Through the IAP application, two broad dimensions can be addressed. Firstly, improved compliance to the conditions specific to the region that in some cases would not otherwise be permissible and, secondly, given the improved integrity and accuracy the ability with confidence to absorb the conservative designs that has been built into some of Australia’s infrastructure networks.

In 2014 the Heavy Vehicle National Law was introduced. The aim was to overcome the cross-border inconsistences that had become a burden on the industry when heavy vehicles were independently regulated by the six states and two territories in Australia. A review of the law began five years later.

Sweden

Historically, Sweden has allowed long and heavy vehicles on its roads. The transition from 24m to 25.25 m and 60 t trucks in 1998 was to take advantage of the new EU approach to road transport that was included in Directive 96/53/EC. This new approach was developed when Sweden and Finland joined the EU in 1995. For environmental and competitive reasons, it was unacceptable for both Sweden and Finland to apply the EU rules on weights and dimensions, as both countries had allowed vehicles longer and heavier than the EU-stipulated 18.75m/40-44t trucks on their roads for a long time prior to this. In order to find a solution that would enable foreign transporters to compete on equal terms within Sweden and Finland, or in any other EU member state that allowed longer and heavier vehicles, a compromise was reached through the creation of the European Modular System (EMS) which enables foreign transporters to increase their vehicles’ length and weight on the condition that the existing standardised EU modules were used.

In 2007 a pilot started after initiative from the forestry industry with a new vehicle combination 32 m and 90 t allowing “one pile more” for timber transport.

In 2010 the Swedish Transport Administration initiated a discussion within a group of stakeholders to form a more comprehensive approach to a lot of ideas and proposals coming up about both longer and heavier vehicles. During spring and summer in 2011 the first draft of a High Capacity Transport R&I program was presented. The term High Capacity Transport (HCT) instead of High Capacity Vehicles (HCV) indicated the ambition to launch a concept with a broad perspective including the entire transport system.

In 2011 a group of policymakers made a study tour to Australia which forged an ongoing close collaboration with TCA.

Between 2012 and 2013 a lot of activities took place:

- The new Swedish institute for research and innovation on transport efficiency, Closer, was set up. HCT was chosen as one of the focus areas from the beginning.
- The creation of the R&I program for HCT; forming a steering committee coordinated by Closer that covers implementation in 11 areas.
- The 12th International Symposium on Heavy Vehicle Transport Technology (HVTT12) took place in Stockholm; Letter of Intent between Swedish Transport Administration and TCA.
- A roadmap on HCT to 2030 was published (Kyster-Hansen and Sjögren, 2013).

In parallel a new intense discussion started on “follow Finland” since the neighbour country in 2013 decided to increase the total weight to 76 t after dialogue with EU. The Swedish forestry industry recognised a potential increase of competition with Finland. After three years of new investigations of the road network and bridges the Swedish government and parliament finally decided to open a new designated network called BK 74, which means that vehicles up to 74 t and 25.25 m are allowed. The new – from beginning – small network is in operation from 1 July 2018. In parallel, a system for monitoring the vehicles “IAP light” – like the Australian IAP Lite but adjusted to fit the regulations and context in EU and Sweden - is under development and being tested. The challenge is the regulatory side, not the technical.

During 2018 the roadmap on HCT to 2030 has been updated (Asp, Åkesson and Wandel, 2019). The result is a higher ambition for both objectives and measures. Concerning CO_2 e.g. the new goal is to make a reduction at system level of 15% only by a massive implementation of HCT-vehicles (max. 34.5 m and 74 t). By 2030, HCT vehicles should account for 80% of all t-kms transported on the roads in Sweden requiring that almost all prime movers, trailers, links and dollies are approved to be part of a 34.5 m 74 t road train.

Finland

Finland with a lot of practical and legal similarities to Sweden, e.g. a big forestry industry, EU accession in 1995, has closely followed the debate and development in Sweden. Based on Swedish examples, their own research and small pilots they have decided to extend the total weight from 60 t to 76 t without special restrictions. This new regulation was approved by the European Union and was set in operation from autumn 2013. Since then the Finnish transport agencies have continued with new trials on both longer and heavier vehicles. Based on the results from these trials it was decided in spring 2018 to go for a new legislation allowing longer vehicles up to 34.5 m. This new legislation has been approved by the European Union and has been in force since January 2019. Trials with heavier vehicles up to 88 t will continue.

The People’s Republic of China

China has turned into the world’s largest manufacturing and global trading economy and it has also become the country with the largest road freight volume.

In 1989 a national mass and dimensions standard called the GB1589-1989 was released based on European legislation including basic definitions. But at that time China still lacked the physical infrastructure and manufacturing capacity of heavy-duty trucks that matches its advanced transport demands today.

China set up programs to build its own heavy-duty trucks industry and ambitious plans for the road transport network after it was admitted into the WTO in the early 2000s. For various reasons the GB1589-1989 was never enforced and in the first years of the 2000s an overloading of trucks became more the norm than the exception.

At the beginning of the 2010s there was a growing insight that China´s growth model needed great overhaul and a move towards a more sustainable development model. A new revision of the GB1589 was inspired by the European Union Directive 96/53/EC and the European Modular System (EMS). It resulted in the Chinese Modular System (CMS).

From July 1, 2018, the transport system is moving toward legal compliance. Different vehicle combinations based on CMS are now under test by the Ministry of Transport (MOT). By a step-wise approach the first issue is to obtain control over the most extreme and destructive axle overloading. In the next revision of the standard it can be expected that a wider regulation of axle weights will be introduced coupled with an extensive classification of China´s road network axle weight capacity, including the use of GPS based geofencing.

The Netherlands

HCT has been progressively introduced in the Netherlands since 2001. Between 2008 and 2011 a research and pilot project was carried out to test 25.25 m and 60 t within a limited network of the public roads. The results were good and from 2013 these longer and heavier vehicles are permitted on part of the public road network, subject to special permits.

Denmark

A long-term pilot program with field tests of 25.25m and 60t has been underway in Denmark since 2008. Until now no decision has been taken to go from this pilot program to permanently changed regulations.

Germany

In Germany, the Bundesanstalt für Strassenwesen (BASt) carried out an extensive study which concluded that EUR 8 billion would be needed to reinforce the existing bridge stock (incl. a large proportion from former East Germany) over a ten-year period, and that HCVs could not be adapted within urban or suburban areas. An HCV field trial was conducted between 2012 and 2016. Based on the results of both the study and trial, 13 among 16 federal states authorised use of 25.25 m vehicles limited to 40 t (44 t for combined transport) from January 2017 in order to protect bridges on a restricted road network. In December 2017, two more federal states followed suit; leaving only the city-state of Berlin outside the system.

Table 2. Overview of existing regulations 2013-2018

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

The economic impacts of High Capacity Vehicles

The distinguishing characteristic of HCVs from a business perspective is that they are able to transport a larger weight and volume of cargo in one trip than a normal vehicle. The challenge for hauliers is to optimise the use of loading capacity in transport operations so that the largest amount of cargo can be transported.

The loading capacity of the vehicle will be limited either by the weight or volume of the consignment depending on the cargo type. For example, in transport of steel the volume of the freight vehicle will not be fully utilised, because the weight and axle load limitation will be reached. Similarly, the transport of plastic foam products will be limited by the cubic capacity of the trailer, but not the maximum allowed weight or the axle loads. This shows the importance of product densities to the loading freight vehicles by weight and density. Average densities of some commodities are listed in Table 3.

Table 3. The density of common commodities
(kg/dm³ = t/m³)

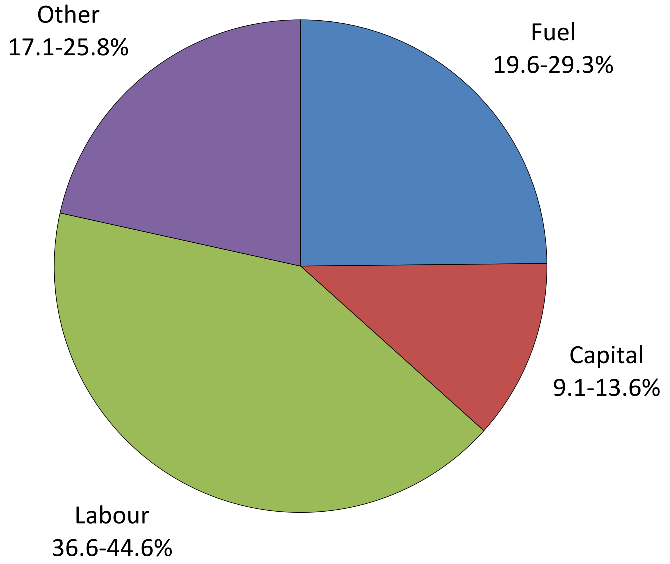
Commodity	Density (t/m^3)
Water, Milk, Beer, etc.	1
Fuel, Oil, Ethanol, etc.	0.6 – 0.8
Earth	1.3 – 2.0
Concrete	2.2
Bricks	1.9
Alloy	2.7
Steel	7.9
Wood (dry)	0.5 – 0.9
Rubber	1.2
Beer boxes with 20 empty bottles (0.3m x 0.3m x 0.4m) weigh 10 kg	0.3
Beer boxes with 20 filled bottles (same size, but 20 kg)	0.6
Refrigerators (white goods)	0.13
Nine passenger cars, 1.5 t each, on a 100m³ transporter	0.135
Single dispatched items (parcels)	0.15
Plastic foam	0.04

Source: ITF (2011)

The increase of weight limits for HCVs will mostly have an impact on the movement of high density commodities. Similarly, the increase in the maximum allowed dimensions of the vehicle will mostly impact the cargo types that are of low density and hence volumetrically limited.

With increased vehicle size and/or weight the main benefits for the haulier include: more efficient use of the vehicle (with lower amortisation per unit of cargo), reduction of fuel consumption per unit of transported cargo (Woodrooffe, 2017), reduction in labour costs per unit of cargo. The labour, capital and fuel costs are the three major cost components of road hauliers, see Figure 8. Great energy efficiency also translates into lower pollution and greenhouse gas emissions.

Figure 8. Road haulier cost structure in European countries



Note: min-max range in %

Data source: (Panteia, 2018) for Austria, Belgium, Denmark, France, Germany, Great Britain, Italy, The Netherlands, Norway, Spain and Sweden.

Real-world evidence suggest that the modal shift impacts of HCT from increased efficiency may have been overestimated in previous research based on simulation modelling (de Jong, 2017). Modal shift is only one of several possible reactions to a reduction in road haulage costs. Other possible reactions of the shippers include changes in depot relocation, changing shipment size, load consolidation, altering the supplier and customer base, relocating production operations. In an example from Sweden it has been shown that increases in road t-km are mainly driven by other factors than increases in road freight efficiency accruing from the use of HCVs (Vierth, 2017).

An attractive situation for use of HCVs could be in cases where large volumes of either volume- or weight-limited cargo need to be transported on specific routes (e.g. between two warehouses, or a mining site and metallurgical plant) within a limited road network, and where the existing infrastructure requires no or minimal investment to accommodate these vehicles on the roads, and also where alternative transport modes may be either unavailable or uncompetitive for the specific cargo type.

An application example of HCVs under the Intelligent Access Program (IAP), the national programme developed in Australia, is shown in Box 1. In the case of BevChain Logistics the weight-limited cargo using specially designed quad axle combination was allowed on a limited route for transport of beverages.

Box 1. BevChain Logistics

BevChain Logistics specialises in the transport and warehousing of beer from the Castlemaine Brewery at Milton in Brisbane to its warehouse in Hendra (another suburb in the North East of Brisbane).

The Intelligent Access Program (IAP) is a national program developed by Australian road agencies. It uses GPS technology to track participating heavy vehicles and ensure they stay on permitted routes. This proof of compliance may allow usage of heavier, longer and generally more productive vehicles onto suitable parts of the road network.

Under the framework of IAP, the company is running specially designed quad-axle semitrailer combinations across an 11 km stretch of local road. Since operating under the IAP, Bevchain has had an overall increase of 14.6% tonnage gain per load. This equates to an additional four pallets per trip.

Source: Transport Certification Australia (2010)

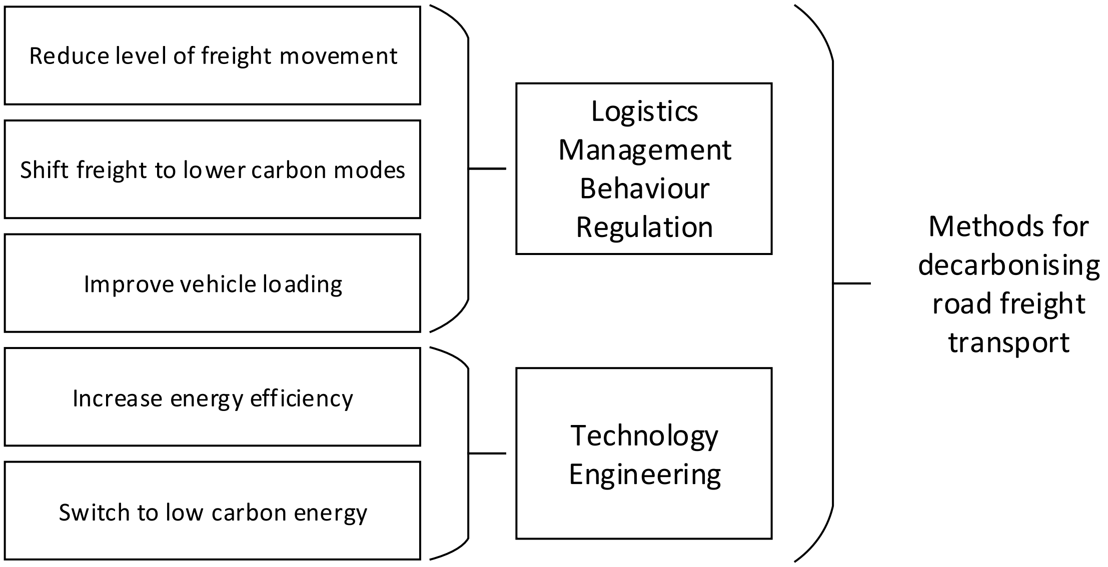
Other potential applications for HCVs are where the cargo is volumetrically limited, like in the transport of low-density cargo. Sometimes the use of HCVs is justified in sectors where transport costs are high which inhibits competitiveness, growth and employment. This was the case in far North Western Australia, where the use of HCT supported the exploitation of local iron ore reserves. (Koniditsiotis, 2018). In particular, PBS based Super Quad vehicles operate at 60 m long and at 200 t. They are also monitored under the IAP application for compliance with route, maximum speed of 90 km/h and headway compliance.

Decarbonisation of road freight transport

Decarbonisation of road freight transport is high on the political agenda to meet the decarbonisation goals that governments committed to by signing the Paris agreement. At the current rate of CO_2 emission of 41 Gt/year, the carbon budget for keeping the increase in average global temperature below 1.5^0C will be reached in only 18 years, (Figueres et al., 2017). This means that annual emissions need to peak as soon as possible to keep the subsequent decline in emissions at realistic rates in economic, social and political terms.

Two sets of approaches to decarbonising road freight transport can be distinguished. The first comprises engineering or technological solutions involving improvements in energy efficiency and a switch to low- or zero-carbon energy sources. The second set of approaches includes logistics, managerial, behavioural and regulatory solutions. Those can reduce the level of freight movement, shift freight to lower carbon modes, and improve road freight vehicle efficiency by raising load factors. For a comprehensive review of methods for decarbonising transport and logistics please refer to (McKinnon, 2018b).

Figure 9. Methods of Decarbonising Freight Transport



Source: Based on McKinnon (2018a)

The use of HCVs can be part of two of the above freight transport decarbonising methods. It can improve vehicle loading, and it can increase the energy efficiency per unit of transported cargo. Based on (ITF, 2011) carbon reduction of HCVs against baseline vehicle ranges from 10% to 20%, depending on the vehicle configuration and operation pattern. A similar result is shown by (Wandel, 2018) for Sweden with a bigger range of up to 35% for some specific vehicles and operational patterns.

Improved vehicle loading can be achieved in several ways including increased logistical collaboration between shippers, the use of online load matching platforms, the consolidation of urban deliveries and the relaxation of just-in-time delivery schedules so that shipments could be done in more optimal loads. Relaxing of weight and dimension restrictions on road freight vehicles to allow the use of HCVs can also help to raise levels of vehicle utilisation.

CargoStream, which is a neutral Pan-European platform for collaborative transport, uses data analytics to improve vehicle loading, (Verelst, 2018). It creates opportunities for different shippers to collaborate in order to improve vehicle loading by creating opportunities for combined shipments on similar routes. The combining of cargo of different densities offers a means of improving load factors in terms of both weight and cubic capacity.

A range of energy efficiency technologies can be applied to heavy-duty vehicles, (Rodríguez, 2018). Some relate to the engine such as combustion optimisation, advanced turbocharging, EGR reduction/advanced SCR, friction reduction, on demand/improved pumps, turbo compound and waste heat recovery. Others improve the aerodynamic profiling of vehicles through the use of roof spoilers, cabin side turning vanes, side skirts, active grille shutter, underbody devices, rear view cameras, tractor side panels and wheel covers. Rolling resistance can be reduced by improvements to tyres and their condition. Lightweighting can further reduce emissions, (Windisch et al., 2017), together with improvement of efficiency of auxiliaries and use of specific driver assistance systems and hybridisation in specific patterns of operation.

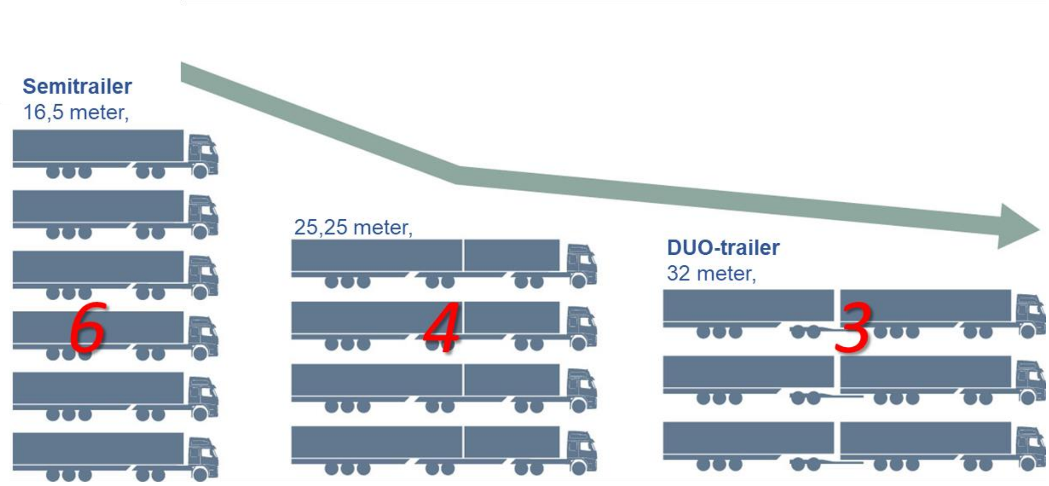
Eco-driving minimises fuel consumption and CO_2 emissions. On-board equipment can help to monitor and improve driver performance in eco-driving. Although fuel savings are substantial, many small operators lack the time and resources to run eco-driving courses for their drivers.

The use of HCVs can also contribute to increasing the efficiency of freight transport operations as several case studies have shown. The long combination vehicle (LCV) program in Alberta, Canada estimates that productivity increases allowed 32% reduction of fuel consumption with 29% reduction in costs to the shipper in comparison with United States 80 000 lb (36 360 kg) five-axle eight tractor semitrailer, (Woodrooffe, 2016a). This analysis does not take into account the operational patterns of the vehicles.

Studies from the United Kingdom have shown mixed results. A study of technology readiness levels (TRL) (Knight et al., 2008) estimated that introducing 60 t heavy goods vehicles in the UK would carry a substantial risk of increased CO_2 emissions and other environmental drawbacks due to a potential modal shift from rail to road, affecting in particular the deep sea container market. The study estimated that this risk would be substantially reduced if maximum mass were limited to 50 t. The UK Longer Semi-Trailer Trial (Risksol Consulting, 2017) showed results with average fuel savings of approximately 7%, with range from -2% to 13% depending on the operational pattern of the vehicles. The decreased efficiency was observed for operators with complex operational patterns and those that did not appear to be making use of the additional length of their cargo space very often.

In the Swedish DUO_2 project, which ran tests of “DUO-trailers”, which involved tractors with double trailers (32 m long), demonstrated the substantial fuel and CO_2 savings that can be achieved with lower number of vehicles on the road, see Figure 10.

Figure 10. Savings in CO_2 emissions, road space and accidents from high capacity freight vehicles



Payload/veh.:	100 m^3	150 m^3	200 m^3
CO_2/m^3 km :	**100%**	**85%**	**73%**
Road use all veh.:	**499 m (100%)**	**368 m (74%)**	**296 m (60%)**
Accidents(Nr veh.):	**100% (6)**	**67% (4)**	**50% (3)**

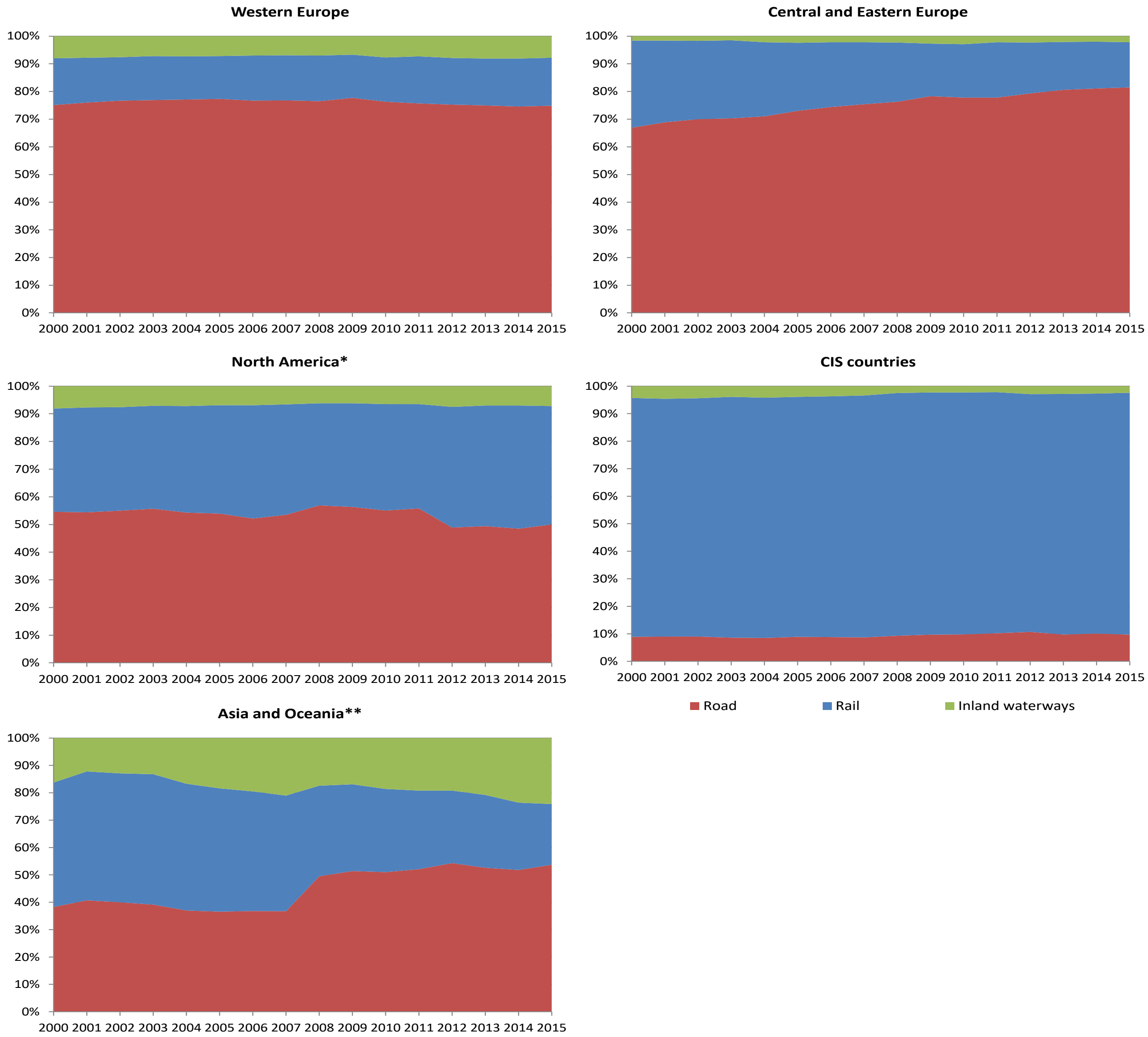
Source: DUO2 project (2018)

Experience gained through the implementation of a voluntary self-regulation accreditation scheme in South Africa, the Road Transport Management System (RTMS) (Standards South Africa, 2014), has demonstrated that significant potential exists to improve the energy efficiency of heavy vehicle road freight transport simply by implementing sound fleet management principles. These include eliminating excessive speeding, driver training in order to minimise harsh acceleration and braking, adequate servicing and maintenance of trucks and trailers and adequate tyre management (in approximate order of priority). There are a number of heavy vehicle fleets in South Africa that have reduced their average fuel consumption over a period of five to ten years by between 10% and 25% through the implementation of the RTMS management systems standard (Nordengen and Naidoo, 2014, 2017).

Modal shift

Transport policies on national and supranational levels have promoted mode shift away from road, usually to rail or inland waterways, for decades to alleviate the pressure of freight traffic flows on road infrastructure. In the European Union, for example, the most recent modal shift goals can be found in 2011 European Union White Paper on Transport, which aims at shifting 30% of road flows above 300 km to rail and inland waterways by 2030 and 50% by 2050. On the other hand, transport statistics in Figure 11 show that in the European Union the mode shift policies have not been effective, with mode shift impacts being much lower than the research results suggest, for a review of price elasticities see (Significance and CE Delft, 2010).

Figure 11. Modal split of inland freight transport modes in different regions
(% of t-km)



Notes: * Break in the series of the United States data from 2012 due to a change in the Freight Analysis Framework tool used to integrate data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation.

** Break in series of the People’s Republic of China data from 2008 due to a new statistical standard used to calculate road transport distances.

The following countries are included in the regions: Western Europe: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, The United Kingdom; Central and Eastern Europe: Albania, Bulgaria, Croatia, Czech Republic, Estonia, North Macedonia, Hungary, Latvia, Lithuania, Montenegro, Poland, Romania, Serbia, Slovak Republic, Slovenia, Turkey; CIS countries: Armenia, Azerbaijan, Georgia, Moldova Russia, Ukraine; Asia and Oceania: Australia, China, India, Japan, Korea, New Zealand; North/Central America: Canada, Mexico, The United States.

Data source: member countries of the ITF

Elsewhere in the world the share of road transport has also been growing steadily with some exceptions, e.g. in the US, where the volumes of road freight have reduced slightly. The share of rail stays relatively high in CIS countries, where primary products demand cheap transportation over long distances, which gives rail a comparative advantage.

Although the total freight transport costs are important in mode choice decision making, factors other than price, including time sensitivity of the goods, reliability and flexibility are important. It is also important to note that much of the freight market is captive to particular transport modes and not subject to competition between road, rail and water-borne modes. Therefore additional mode shifts will be difficult to achieve, unless more aggressive and/or costly policies are employed.

Within the context of this framework, a workshop was conducted in December 2016 at the University of Cambridge focusing on modal shift related to High Capacity Vehicles (see summary in Annex 2). The objective of the workshop was to examine ways of reconciling the apparent conflict between efficiency improvements in road transport from higher capacity vehicles and the shift of freight to other modes that have much lower carbon intensity.

Research efforts in Sweden, Germany and the UK have tried to quantify the actual and potential diversion of freight from rail/intermodal services to longer and heavier vehicles. These studies provided the following findings.

- Getting more freight onto rail or waterborne services is not an end in itself, rather it is a means of making freight transport more environmentally sustainable.
- Much of the freight market is non-contestable. A relatively small percent of the market is subject to road-rail competition.
- Ex-post studies of actual practice show lower levels of modal shift from rail than desk-based simulation studies.
- Desk-based studies have traditionally lacked reliable cross-elasticity values.
- Cross-elasticity values used in these studies have varied widely.
- There has been ‘reckless extrapolation’ of modal cross-elasticity values between countries, corridors and sectors.
- Cost is only one of many factors affecting modal competitiveness.

The European Commission’s Joint Research Centre (JRC) undertook a sensitivity analysis of modal shift using Monte Carlo simulation. The inputs to the impact model were systematically varied within carefully specified ranges. The salient outcomes of this study were the following (JRC, 2009):

- Overall, average impacts were a reduction in rail transport between 1.2% and 1.8%.
- Elasticities differed strongly per distance category, with low sensitivity at relatively short distances (<800 km).
- The minimal net welfare gain from the simulations was positive.

Freight modal shift from road to rail has long been a part of the EU’s transport policy. In the case of HCVs the general expectation was that these would lead to a shift away from rail transport and to a limited degree additional demand induced by the lower cost of road freight (rebound effect), which expresses itself mostly from smaller trucks to larger trucks. Although there was no consensus about the expected impacts, a comprehensive simulation study indicated that these effects would be limited, (JRC, 2009).

In separate studies the (Swedish Transport Administration, 2014) and (Lund University, 2016) studied the impacts of permitting HCVs at 74 t and 25 m in length. Transport costs per t-km are assumed to differ by 14%-24% between standard vehicles and HCVs in the studies. All studies conclude that heavier/longer HCV are beneficial for society. Reduced transport costs are the most important benefit, fewer than 10% of the benefits relate to reduced greenhouse gases and pollution.

Elasticities for the years 1991, 1995, 2000 and 2010 were calculated using a forecast based on an auto-regressive model and the Swedish Transport Council's forecast for 2000. Short-term elasticities have not the expected signs due to economic recession in Sweden in the beginning of the 1990s. In 2000, the calculated total demand elasticities for road were relatively high (-1.04 to -1.47). The increase in road t-km is mainly driven by other factors than shift from rail as cross-price elasticities are relatively low. These matters have been recently described by (Vierth, Lindgren and Lindgren, 2017) and (Vierth, Lindgren and Lindgren, 2018).

In the UK, there is minimal use of inland waterways therefore the main focus of modal split research is road-rail. The UK privatised its rail network in the mid-1990s and since then rail has increased its share of the combined road and rail freight market from 8.3% (1994) to 13.9% (2014) (measured in t-km). Internal competition in the rail freight market has also intensified as new companies have entered the market.

Considering freight moved by rail and articulated trucks with gross weights over 33 t and haul lengths of over 300km, rail's share is 42%. Over the period 1994 to 2014, the maximum weight of trucks has increased from 38 t to 44 t, there has been substantial growth of the double-deck trailer fleet and the government has instigated a trial of longer semi-trailers (1 and 2 m longer than the standard 13.6m trailer). Both of these changes favour higher value lower density freight.

The UK freight market has also been changing with the share of primary commodity movements declining and shares of retail and imported goods growing. Rail freight's commodity mix has changed accordingly: Coal's share of rail freight t-km halved from 26% to 13% between 1998/9-9 and 2015/16. Over the same period the share of non-bulk intermodal movements rose from 20% to 36%. Efficiency improvement is not confined to trucking. Competitiveness of rail is also strongly influenced by factors other than cost, including service quality, supply chain structure, customer awareness of rail potential, policy/political issues etc.

The Netherlands has a dense network of waterways; inland waterways have a substantial share in the modal split. In 2015 this was 42% on Dutch territory measured in t-km. The modal shift in the Netherlands is as follows for the period 2005-2014: road -3.3%, rail -0.2% and inland waterways +3.5% based on t-km within Dutch territory. In this period all modes showed a growth in transport performance with inland waterways experiencing the largest growth.

High capacity road freight vehicles have evolved in The Netherlands since 2001. These vehicles had a capacity of 60 t compared with regular vehicles having a capacity of 50 t. The number of HCVs operating in The Netherlands has increased substantially from only a few in 2001 to about 1400 in 2016. Between 2008 and 2011 a research project on HCVs was carried out. Based on a sample of 51 terminals operators, seven shipping companies and about 30 container road freight operators the project concluded that 100% of the freight transported by HCVs was taken over from regular trucks, and not from rail and inland waterways.

Finally, most modal split studies focus on independent freight modes and do not consider multimodal scenarios where trucks and railways cooperate. For example, scenarios where trucks deliver goods, usually bulk products, to terminals for transport by rail. Agricultural products often travel by truck from farm coop centres to centralised terminals for rail transport. Using HCVs for the truck section of the transportation chain can benefit both rail and truck modes by improving efficiency and reducing cost. Sustainable freight systems depend on multimodal use which will grow where opportunities exist. It is not an unreasonable expectation that HCVs could bring a net benefit to the railway industry particularly in multimodal transport.

In summary, 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.

The impacts of High Capacity Vehicles on road infrastructure

Primary road infrastructure elements include pavements and bridges. Pavement strength and durability are affected by many factors, which vary along any given section of road. Climate conditions (temperature, water, snow, ice) and ground motion are amongst these factors. Bridges are also exposed to a range of conditions that affect their response to traffic loads, such as wind (for long span bridges), earthquakes, climate conditions, and material ageing (resulting in shrinkage, chemical reactions, corrosion, etc.).

Infrastructure is designed to serve for longer periods than vehicles. Typically, a pavement surface is renovated every ten-fifteen years, the pavement structure lasts for 25 years and bridges are designed to last for 50 to 100 years, but some of them operate for much longer. Therefore, HCVs should be adapted to the stock of existing infrastructures, some of them having lower capacity than originally designed because of ageing. In some cases, reinforcement should be considered.

Bridges

Bridges are well-defined discrete structures, composed of materials with known properties, designed by bridge codes, including bridge loading rules, e.g. in the EU (EN1991-2, 1991). At the same time, each bridge is an original structure with its specific design and history, and even if bridges may be classified by general type, the variation of the stock remains high. Each bridge has a maximum weight bearing capacity, not always corresponding to the initial design. Moreover, bridges are rather complex structures, made of many elements (foundations, piers, beams, deck, cables, etc.) which interact. Redundancy (of hyper-static structures) may increase the reliability of the whole structure while the failure of some details may induce a series of other failures and at the limit, result in a bridge collapse. This means that there are multiple processes that can cause damage, including excessive heavy vehicle loads. Most countries maintain sophisticated bridge inventories and conduct regular bridge inspections to monitor bridge condition.

To simplify, the effect of a heavy vehicle on a bridge, mainly inducing a mid-span bending moment, increases with the gross vehicle weight (and axle or series of axles loads), and decreases with the wheelbase (spacing between the first and last axle). The ratio, gross vehicle weight divided by vehicle length, also called EUDL (Equivalent Uniformly Distributed Load) generally governs the effect of a single vehicle on a span. More axles reduce the local effects (stresses). For long span bridges (above 80 to 100 m), series of heavy vehicles at short distance (such as in congested traffic) govern the maximum stresses. For a single vehicle on a span, a dynamic safety factor applies, amplifying the stresses. Dynamic safety factors increase with velocity and gross vehicle weight, increase with pavement roughness, and are in the range of 1.2 to 1.5 for fully loaded vehicles. Finally, steel bridges are sensitive to fatigue, i.e. a cumulative effect of all stress cycles (or vehicle crossings). The individual damage is roughly proportional to the power 3 to 5 of the stress amplitude, and proportional to the number of cycles.

Based on these considerations, the following guidelines and principles should apply when considering HCVs on bridges:

- While increasing the gross vehicle weight, the total length should at least increase proportionally. Longer but not heavier vehicles are less damaging on bridges (which explain the policy in Germany, allowing 25.25 m vehicles but only with 40t or 44 t).
- The axle weight should not be increased, and it is better if it is reduced and more evenly spread on all axles.
- A bridge formula is highly recommended for a first order assessment of the acceptability of HCVs. This does not preclude a more accurate method of assessment, above all for fatigue (see the last bullet point below).
- Short span bridges with span length below 30 m are not affected by longer and heavier vehicles if the EUDL remains constant. Very long span bridges (above 200 m) are not too sensitive to HCVs because they are designed to carry a series of stopped vehicles at close spacing, at least on the slow lane. Medium and large span bridges (60 m to 100 m or 150 m) may be affected most by HCVs if heavier than standard vehicles. To mitigate the HCVs effects, the EUDL and axle loads should at least remain below those of standard vehicles, and the maximum stresses should be assessed case by case and compared to the design loads and the bearing capacity of the bridge, especially for ageing structures.
- Medium and long span steel and composite bridges are susceptible to fatigue. They should be assessed to ensure that that the maximum allowable stresses are not exceeded by HCVs. The reduction in pavement wear associated with HCVs does not apply to medium and long span steel and composite bridges.
- During HCV trials and even in full operation, the most sensitive bridges should be either periodically inspected, or instrumented and continuously monitored. The strains and stresses should be precisely correlated to the vehicle loads crossing the bridge.

The Intelligent Access Programme (IAP) implemented in Australia, or Smart Infrastructure Access Programme (SIAP) as proposed in the FALCON (“Freight and Logistics in a Multimodal Context”) project for the EU, contribute to the above recommendations. Such programmes can also take into account additional influence factors, such as the temperature gradient which may affect concrete bridges, the transverse distribution of loads (presence of multiple heavy vehicles), or other concomitant factors (e.g. wind).

Pavements

Pavements are designed today to account for several damaging processes, including fatigue, rutting and polishing, for design traffic loads defined in terms of volume and weight. Unlike bridges, pavements have a design life of approximately 20 years. It should be noted that no European pavement codes exist, however PIARC lists well-known national codes.

In the commonly accepted American Association of State Highway and Transportation Officials (AASHTOO) design rules (dating from the 1960s), only axle loads are taken into account, and not axle spacing. Tyre imprint and pressure also influence pavement wear. The scattering of wheel paths within lanes, reduces rutting wear. Heavy vehicles may be classified by aggressiveness according to a combination of their characteristics in relation to these factors (CEDR project FALCON, 2018a).

HCVs without heavier axle loads, or even with lighter axles, do not induce more fatigue damage in pavement structures than standard vehicles. Even if road wear is based on freight mass or volume, the pavement fatigue is reduced. However, some studies suggest that a series of close axles may be more aggressive than with longer spacing. Therefore, for each HCV configuration, and depending on the pavement structure (flexible, semi-rigid or rigid), pavement impact should be assessed in comparison to a standard vehicle.

For rutting wear, even if an HCV has more wheels than a standard vehicle, the global effect should not be significant because each vehicle takes its own path. The effect may be a bit higher for platoons, where the lateral positions of the successive vehicles may be aligned.

For polishing wear, the lateral forces induced under multiple axles are the most severe ones. The wear depends on the HCVs length and articulation and the geometry of the road.

Tunnels

The geometry of the road within most tunnels is designed to be the same as any other road, which means that the lane width, radiuses of curvature, longitudinal slopes, grades, etc. are in accordance with road design guidelines. However, some ancient tunnels have either narrow lanes or sharp curves, and are not suitable for HCVs. Emergency parking slots may not be adaptable to HCVs. There is a potential for increased calorific volume attributed to HCVs, depending on the type of cargo (CEDR project FALCON, 2018b). To cope with that, suitable traffic management procedures should be considered, such as limitation of the number of trucks/HCVs within the tunnel or increased minimal distance for HCVs.

Other infrastructure elements

Many infrastructure elements are designed according to traffic, and therefore changing the type of traffic will alter their efficiency or their lifetime. We consider only two examples here, namely the expansion joints and the safety barriers.

Expansion joints

When designing a bridge, expansion joints are chosen according to expected traffic, namely the number and the weight of heavy vehicles. However, expansion joints are mainly sensitive to axle loads, and not to gross vehicle mass or length. Therefore, they are not affected by HCVs unless axle loads increase.

Safety barriers

Current safety barriers are designed to restrain heavy vehicles at a speed of 60 km/h and an angle of incidence of 40°. They are not able to restrain all standard types of heavy traffic. If an HCV crosses a safety barrier, the consequences are potentially more severe than with a workhorse truck. However, the risk of crossing a safety barrier does not increase proportionally to the gross vehicle mass (in the same way as kinetic energy) because in case of a shock, HCVs with double articulation, part of the energy will be dissipated in the vehicle folding. The height of the centre of mass of the load is an important factor to be considered for all heavy vehicles. There are no rules governing the vertical centre of mass position with respect to improving crash barrier effectiveness. Nevertheless, the cost-benefit of upgrading the barriers should be evaluated.

Other issues to be considered

Variety of regulations in Europe and worldwide

There exist a variety of regulations and solutions across Europe and worldwide dealing with the interaction between vehicle and road infrastructure:

- Vehicles: Directive 2015/719 amending Directive 96/53/EC currently regulates the weight and dimensions of heavy vehicles within Europe. Nevertheless, each country may allow different (higher) loads or dimensions.
- Road (physical) infrastructure: Design and maintenance of road infrastructure is also country-specific. It is not surprising considering that maintenance is dependent on the national financial situation in the country. But it should also be noted that there are huge differences in road infrastructure design (CEDR project FALCON, 2018c).
- Digital infrastructure: Every country takes individual responsibility for the design its digital infrastructure.

Issue of the last mile

The last mile, or at least the last part of the freight journey, might be undertaken on local roads with load road owners. There might exist different road conditions, to be considered when creating the route and dealing with logistics.

This existence of locally different road conditions and road access conditions may lead to locally specific traffic management and logistic issues. Logistics hubs or platforms may be needed or regulatory discussions with the road infrastructure owner/manager.

Safety performance of High Capacity Vehicles

Road safety is an important issue with governments around the world setting ambitious goals to reduce fatality and injury rates. This decade was officially proclaimed by the United Nations General Assembly as the “Decade of Action for Road Safety 2011–2020”. Substantial socio-economic losses can be avoided by increasing the safety level of vehicles and infrastructure. It is claimed that investment in road safety improvements of USD 1 gives a return of between USD 1.48 and USD 1.8 (SWOV Institute for Road Safety Research, 2011; FIA Foundation, 2016).

Increasing trade, in line with economic growth and trade forecasts, will bring more vehicles onto the road raising the level of road freight activity. For road freight operations the accident frequency is directly proportional to the distances the vehicle travel. Therefore by improving the efficiency of these vehicles the number of vehicle-km travelled per tonne of cargo transported reduces. This measure also has a positive impact for the companies using these more efficient vehicles, because a smaller number of trips are required to transport the same amount of cargo. And from the government side, depending on the specific implementation case, this could require relatively small or no new investment.

HCVs are usually regulated as a separate vehicle class that conforms to special safety requirements, being certified within a PBS system and managed by policy designed to minimise crash risk. Under this kind of system, HCVs have significantly reduced crash risk meaning that the probability of being involved in a crash is substantially lower than other vehicle classes. HCVs also reduce the amount of truck trips required for a given freight task which effectively lowers vehicle exposure further reducing the probability of a crash.

Accident statistics of HCVs are relatively scarce due to the small number of HCVs on the roads and their limited areas of operation. Also, the limited road network for HCVs leads to a methodological problem: the movement patterns of HCVs in the reported accident data do not match the operational patterns of conventional road freight vehicles. Nevertheless, there are two Canadian studies that have compared the safety record of HCVs and conventional freight vehicles on the same road sections. However it is useful to review the data for different countries, because it shows the safety impacts of these vehicles in particular national settings.

Sweden

The permitted maximum length of vehicle combinations in Sweden is 25.25 m which is significantly longer to most other countries of the European Union, where the upper limit is 18.75 m. A safety study on transport in Sweden (Bálint et al., 2014) focused on determining whether longer truck combinations (18.76 – 25.25m) have a higher associated accident rate per vehicle-km travelled in the ten year period of 2003-2012. The study found that combinations exceeding the European Union length limit of 18.75m were involved in less fatal or severe crashes per billion VKT than regular European Union combination freight vehicles.

Table 4. Accident rates of different truck combinations in Sweden 2003-2012

	Short <12m	Medium 12m-18.75m	Long 18.76m-25.25m
Fatal or severe accidents	1 466	390	509
Vehicle Kilometres travelled per billion VKT	10.72	7.01	11.69
Accident rate per 100 million VKT	13.7	5.6	4.4

Source: Bálint et al. (2014)

Australia

Accident rates for HCVs in Australia are considerably lower than for those of conventional trucks. The comparatively good results should be considered in the context of the road infrastructure that these vehicles use and the enforcement conditions under which they operate. HCVs usually travel on much safer roads with lower traffic volumes often away from densely populated areas. Many also belong to the Australian Intelligent Access Program (IAP), which ensures significant levels of route, weight and speed compliance (Koniditsiotis, 2018).

Table 5. Major and serious accident rates for High Performance Vehicles vs conventional vehicles in Australia

Vehicle Type		Total accidents	Total serious and major
Conventional	Articulated (69%)	72	29
	Rigid (31%)	102	26
High performance vehicles (PBS)	Articulated (69%)	18	7
	Rigid (31%)	53	6

Notes: per 100 million kilometres

Source: Austroads (2014)

A recent paper by Hassall (2018), examines the safety performance of HCVs in Australia controlled by its Performance Based Standards (PBS) system. This policy mechanism was developed in Australia in 1997 which led to a number of initial configurations being modelled against this new set of 'performance engineering standards' in 1999 (NRTC, 1999a, 1999b). In 2013 the operational rollout of the PBS scheme was transferred to the new National Heavy Vehicle regulator (www.nhvr.gov.au). Since that time nearly 7 000 vehicles have been certified for operations, reflecting a growth rate of nearly 43% per annum since that date. However, some older vehicles, that were operating before the formal PBS scheme was adopted in 2006, are still operating under State permit systems. These 'permit' vehicles, of which there are just over 600, comprise nearly 10% of the current Australia PBS truck population. Many of these vehicles are BB-Triples, and A-Doubles, which are operating in rural and regional areas. Anywhere in Australia outside of Melbourne, Sydney, Brisbane, Wollongong, Newcastle and the Gold Coast is considered to be "rural and regional Australia", according to the Australian Department of Immigration and Border Protection.

Table 6. Growth in the use of Australian Performance Based Standards vehicles

Year	Performance Based Standards Population
2018 (March)	6 935
2017	5 803
2016	4 624
2013	1 169

Note: Growth per annum 42.7%

Source: Hassall (2018)

(Hassall, 2018) combined crash data, operational and truck movement data to estimate the crash rates for PBS vehicles. The comparative results of PBS and non-PBS vehicles were examined across the period 2009 – 2016, when Australian PBS vehicles travelled over 1.1 billion km. The analysis found that overall the PBS fleet's safety performance was 56% better when compared to the conventional heavy truck population.

This analysis suggests that adopting PBS policy for any segment of the truck fleet will likely result in significant safety improvements. The use of Trailer Steering Technology alters vehicle performance allowing longer vehicles to behave like shorter conventional vehicles. Performance based regulation ensures that a given vehicle is fit for purpose and provides a mechanism to permit innovation within the trucking industry.

Canada

In Canada long combination vehicles operate under a special permit system. In the provinces of Manitoba, Saskatchewan, and Alberta long combination vehicles consist of a tractor and two or three semitrailers or trailers exceeding the basic length limitation of 25 m specified by provincial truck size regulatory schemes. The three types of vehicles are Rocky Mountain doubles, Turnpike doubles and triple trailer combinations.

Overall these three HCV types had the best safety record of all vehicles during the period between 1999 - 2005 in the province of Alberta.

Table 7. Collision rate by vehicle type on the long combination vehicle network in Alberta 1999-2005

Vehicle type	Number of collisions	Distance travelled 100 million km	Collision rate (per 100 million vehicle km)
Passenger vehicle	46 375	558.7	83
Straight truck and bobtail	3 670	29.82	123
Tractor semitrailer	2 369	56.5	42
Legal-length tractor double trailer	955	21.59	44
Rocky Mountain double	36	1.12	32
Turnpike double	21	1.31	16
Triple trailer	8	0.13	62
Total	49 738	669.17	74

Note: The total number of collisions is not the sum of all collisions because there are cases where two different vehicle types are involved in the same collision. If one were to take the sum of the individual vehicle types, there would be double-counting.

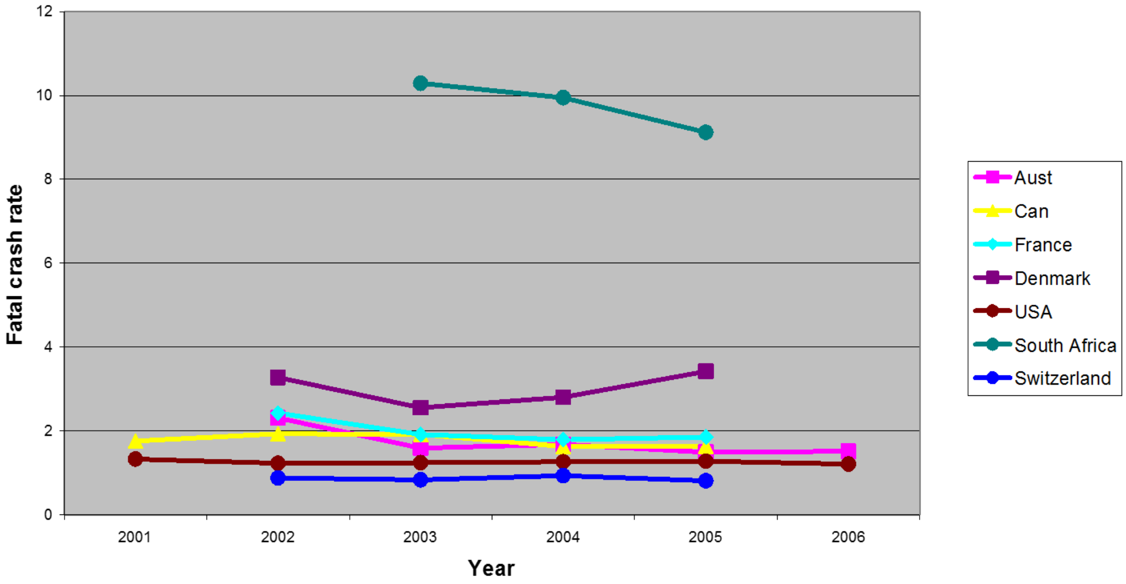
Source: (Montufar and Associates, 2007)

South Africa

In South Africa the Smart Truck or Performance-Based Standards Pilot project was introduced in 2007 as a subset of the Road Transport Management System (RTMS), to increase heavy vehicle safety and road transportation efficiency. The project has shown a reduction in the crash rate of 35.4% vs the RTMS-certified baseline fleet (Steenkamp et al., 2017).

In many developing countries (such as South Africa), truck crash rates are considerably higher than those in developed countries. For example, during the period of 2003 to 2005, truck fatal crash rates in South Africa were approximately 10 per 100 million km compared with corresponding rates of between 0.8 and 2.3 in countries such as Australia, Canada, France, Switzerland and the United Kingdom as shown in Figure 12. High truck crash rates and breakdowns result in deaths and injuries, but also frequent lane closures, which can cause high levels of emissions due to the consequent increased congestion, especially on highly trafficked routes. These crashes and breakdowns can almost always be traced to a combination of speeding, lack of driver training, and inadequate servicing and maintenance. The implementation of the RTMS by various fleet operators in South Africa has resulted in significant reductions in crash rates and breakdowns of the accredited fleets. An example for the case of Dawn Logistics is provided in Table 8, in which significant reductions in fines, crashes, driver errors and breakdowns over a five-year period are clear.

Figure 12. Fatal truck crash rates
(per 100 million vehicle-kilometres travelled)



Source: ITF (2011, p174)

Table 8. Heavy vehicle operational statistics for Dawn Logistics 2013 to 2017

Year	Fines	Crashes	Driver Error	Breakdowns
2013	218	37	19	57
2014	232	26	11	46
2015	56	17	5	33
2016	48	26	4	20
2017	46	20	5	22

Source: Nordengen and Naidoo (2014, 2017)

The Netherlands

During the four-year trials with HCVs in The Netherlands 54 accidents were reported. An analysis of these accidents found no relationship between specific characteristics of HCVs and the causes of the examined accidents (Rijkswaterstaat, 2011).

Germany

In the five-year trial of HCVs in Germany there were 13 accidents involving HCVs reported with just one personal injury. The analysis of these accidents, similarly to that in the Dutch study, found that HCVs had no adverse impact on road safety, though the database was small (Irzik, 2017).

Denmark

During the two-year evaluation period of HCVs in Denmark between 2009/10 only four accidents involving HCVs were registered across the 37 million vehicle-km driven. This results in significantly lower accident frequency for European Modular System HCVs than for the truck population as a whole. If HCVs had the same accident rate as ordinary trucks, 16 accidents would have taken place. It must be noted, however, that the road network that the EMS vehicles are allowed to operate on more restricted, and so it is not possible to make an exact comparison of HCVs' safety record and that of conventional vehicles (The Danish Road Directorate, 2011).

As shown above, the reported accident rates in all countries are lower for HCVs than conventional vehicles, but the improved safety performance is not necessarily due to the characteristics of the vehicles alone. There are several other factors that relate to system management and the on-board technology that are contributing to this:

On-board technology. The certified HCVs are often equipped with additional safety systems, which conventional vehicles do not have. These technological improvements lead to lower accident counts and lower severity of the accidents. Additional enforcement and monitoring equipment is sometimes required to be installed on HCVs. This leads to these vehicles having higher compliance rates within existing regulations thus ensuring safer everyday operation.

Skilled drivers. In practice HCVs tend to be more expensive than regular vehicles and the companies that use them tend to assign their best drivers, those with best performance, to those vehicles. In some cases the drivers of HCVs are required to follow additional training to obtain qualification to drive them.

Limited areas of operation. In most cases the road networks that HCVs are allowed to be used on are limited to specific geographical areas or specific limited routes. Therefore HCVs run on more restricted networks of higher capacity roads which are typically safer per vehicle-km travelled for all categories of traffic. If HCVs are limited to "safer" roads outside rural areas with less traffic, fewer possibilities of interactions with other road users are possible. It means that the statistics that were cited above are not always comparable with those of conventional trucks.

Regulatory framework and enforcement. Amongst factors contributing to the increased safety of HCVs are the developed regulatory framework and stricter enforcement, for which ITS technology has been successful in some of the reviewed examples.

Regulations and enabling technologies for High Capacity Vehicles

Lessons for developing suitable regulatory approaches can be learned from the various implementations of High Capacity Vehicles around the world. These include information on legislative frameworks developed for HCVs, and often involve the use of intelligent transport systems (ITS) for enforcement, and are available for the assessment of costs and benefits.

Access, monitoring, compliance and enforcement

When introducing High Capacity Transport (HCT) as an efficient and sustainable solution for transporting freight it is crucial to selectively match vehicle access to infrastructure, monitor their weights and routes as well as compliance with regulations. When opening a designated network for HCVs crucial questions are: how to prevent the adverse impacts of HCVs if they disobey the rules by taking shortcuts outside the dedicated network or are overloaded; how to monitor the routes, mass and configuration of the vehicles in the road train; how to support drivers and enforcement agencies to achieve a high-level of compliance; and how to combine infrastructure and vehicle-based monitoring. Developing the relevant legal frameworks is also imperative.

In a paper presented at the 13th International Symposium on Heavy Vehicle Transportation Technology (HVTT13) “Compliance Mechanisms for HPV´s” authors gave an overview on which types of mechanisms are used in different countries to promote compliance to existing regulations, (Moore, Regehr and Rempel, 2014).

Compliance mechanisms encompass the various approaches for achieving regulatory compliance. Like the regulations themselves, compliance mechanisms have evolved over time. Traditionally, most countries have employed on-road enforcements methods, though technologies are playing an increasingly prominent role in delivering enforcement programmes. More recently, alternative approaches to achieving compliance, such as accreditation programmes, have been implemented and directed towards certain vehicles in the fleet.

One of the most interesting is the satellite-based route compliance that exists since a couple of years in Australia, the Intelligent Access Program (IAP). In Sweden a similar approach and system is under investigation and development.

Data-driven approaches for High Capacity Transport enforcement

Various applications of new technologies can contribute to a more efficient and flexible regulatory framework for road-based freight transport. These technologies include various in-vehicle systems (e.g. on-board diagnostic modules, vehicle condition monitors, in-cabin sensors, vehicle navigation and tracking, advanced driver assistance systems) and road-side/infrastructure systems (e.g. weigh-in-motion, radio-frequency identification (RFID)/ Bluetooth transponder/receivers, automatic license plate readers, cloud-based computing platforms, variable/dynamic message signs). These and other technologies produce data that opens new possibilities for lighter but more comprehensive and widespread enforcement actions. This previously unavailable data also may make real-time enforcement a possibility and lead to an overhaul of regulatory regimes towards more data-driven approaches.

The combination of conventional and novel data sources, the innovative use of data sets and data sources beyond its originally intended purpose, advanced (both real-time and historical) data analytics, and new business models enable new tailored services to enter the road-freight and logistics market. In addition, recent developments, including vastly improved digital connectivity and ubiquitous use of mobile devices with mobile internet access, have helped speed up these processes. A shift to data-driven policy and regulation, enabled by these developments, holds the promise of offering policy makers and regulators a superior tool for detecting non-compliance to rules and ensuring that transport services contribute to fulfilling pre-defined policy objectives.

Other related technologies and systems, which are relevant in this context include road user charging schemes, infrastructure monitoring and maintenance, and vehicle automation/platooning. Distance-based road user charging systems for freight vehicles are in use in a growing number of countries in Europe; these systems already allow the tracking of vehicles, giving valuable insights for regulators. Infrastructure monitoring for road maintenance already collects a wealth of data; integration with systems for regulation of vehicles could therefore lead to better outcomes. Approaches such as the Intelligent Access Programme (IAP) using performance-based standards (PBS) can help improve compliance by ensuring that these vehicles are restricted to suitable parts of the network.

In addition, truck automation and its application in platooning are potentially transformative developments, which are currently high on the political agenda in many countries. Live tests have already taken place in Nevada and Texas and many expect to see platooning available commercially (at least in the United States to begin with) in the near future. April 2016 saw several operators including Volvo, MAN Truck and Bus, and Daimler participate in the European Truck Platooning Challenge, driving across national borders within Europe (ETPC, 2016). Vastly reduced driver workload or even replacing the driver by an operator in a remote control centre could also have large improvements for e.g. road safety.

Much of the underlying information required for regulating the various aspects of road-based freight transport relates to the geo-location of vehicles over time, e.g. knowing movements of vehicles, hours of operation and position/paths taken within the network. Different techniques have traditionally been used to gain the necessary insights to see at least parts of the overall picture, thus supplying sufficient information for regulators to monitor adherence to regulations put in place.

A more straightforward approach, seeing the whole picture through one stand-alone system and disposing of the individual fragmented systems currently used, would be tracking all freight vehicles in the network, ideally in connection with a driver ID. Recent progress in mapping, sensor, and IT technology has enabled these approaches. An example for the implementation of this is the Australian Intelligent Access Programme (IAP), which has been put in place to ensure acceptable use of larger and heavier vehicles by tracking these vehicles and managing access to the network.

But to enable cross-border operation of such a system streamlining of national regulatory approaches as well as technology interoperability (including communications) would have to be ensured. In the context of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication the underlying communication channels and technologies to be deployed need to be carefully considered. Traditionally this data exchange in the automotive sector, e.g. for many road tolling systems, relies on dedicated short-range communications (DSRC) using one-way or two-way short-range to medium-range wireless communication channels specifically designed and a corresponding set of protocols and standards.

Globally these solutions lack appropriate harmonisation as significant variations occur relating to things like frequency, baud rates and protocols. Due to lack of available frequencies opening up a specific frequency dedicated to road freight operation could be beneficial, but this would then need to be available across borders. In the context of vehicle automation, there is increasing consensus that 5G mobile communication is required in view of the increase in volume of data exchange necessary; this could then also be used in the context of road freight governance once it becomes available.

Building on the point above about rolling out a system similar to IAP to cover all freight vehicles, additional elements could be added to such an approach. One example could be to apply the approach of slot management, as used in the aviation sector, to road freight. This together with dynamic geo-fencing of certain vulnerable parts of the network at certain times could lead to a geo-timing approach. This would then widen the approach to a vastly improved logistics operation with routing/tracking vehicles through appropriate parts of the overall network at appropriate times and with pre-booked access to parking areas, loading/unloading areas in logistics centres, and border crossings.

Solutions from different countries and ongoing projects

Intelligent Access Program and High Capacity Transport telematics solutions in Australia

The Australian transport network is facing problems including a growing population and transport needs. There are constrained road budgets, infrastructure issues (in particular effects of road transport on vulnerable bridges) and increasing freight tasks; only 9% of the current and projected road freight task faces competitive pressure from other modes. There is also pressure from the road transport industry to permit operation of larger and heavier vehicles to meet freight task demand, and community expectations about the safety of the road network and in particular trucks. Policy options are either “do nothing”, “invest heavily in road infrastructure” (competition for public funds), or “get smart”; the do nothing scenario would add an additional 50 000 trucks onto the roads (one in four vehicles in urban areas are trucks in 15 years). As part of the Australian National Telematics Framework, High Capacity Transport (HCT) uses applications which provide the strongest assurances that the right truck is on the right road (IAP), at the right time, within the permitted speed (Intelligent Speed Compliance), and with the right mass (On-Board Mass Monitoring).

HCT along with ITS have been used in Australia to re-engineer the road network. This is not about physical engineering that is building new bridges or strengthening the same. Rather, the way we engineer the most effective use of infrastructure. With the accuracy and integrity that ITS brings, significant productivity gains without major investments in new infrastructure have been made in Australia.

Heavy vehicle access is based upon a number of assumptions made by infrastructure managers. Decisions about access often come down to a conservative set of assumptions, especially when it comes to axle mass loadings. It must not be forgotten, that many of the design mechanisms and associated formula as accurate as they maybe have relied on available axle group loadings and underlining assumptions. By this very nature, conservative estimates have been known to be built into traffic loading distributions. This is also not unexpected and results in the use of safety factors which simply deal with the lack of real data available. This is not a criticism, as the ability to monitor an individual vehicle during its journey is a relatively new capability, however, the ability of ITS with improved accuracy and integrity to now deliver axle group mass loadings has provided the opportunity to re-engineer the use of bridge stock and infrastructure as a whole.

The Australian Standard for bridge assessment (AS 5100.7:2017) was updated in 2017 to specifically recognise and acknowledge that High Capacity Vehicles with ITS (and the gained integrity and accuracy this brings) can accommodate reduced traffic load factors. In particular, the updated Standard incorporates reduced traffic load factors for vehicles monitored through the IAP and On-Board Mass (OBM) Systems with bridge load factors reduced from 2.0 to 1.8 for monitored vehicles. This has successfully been used in Queensland and New South Wales for a number of suitable bridges. Effectively this means increased payload for monitored vehicle over the same bridge.

Proposed telematics-based access and weight control system in Sweden

The objectives of the telematics-based systems in Sweden are to prevent premature break down of the infrastructure by minimising driving outside the BK 74 network, over 5% overloads bridge Weigh in motion (WIM), illegal combination of vehicle modules, and other rule regulations. The already installed fleet management systems should be used. This is a first step towards a National Telematics Framework for public and private applications. Other benefits with ITK include improved traffic safety, less cheating and thereby supports fair transport initiatives, better work environment with less stress (prevent shippers to press drivers to break the law), better statistics for more precise planning of maintenance and upgrading of the infrastructure, more efficient and more risk based monitoring of traffic law compliance and enforcement, more bridges can be open for 74 t before being strengthened if the safety factor is reduced due to the much fewer overloads, and easier to get public acceptance of HCT routes through local communities and on private routes.

Recommendations include: use of on-board Units (OBUs)/hardware which can perform multiple applications and services for both regulatory and private sectors; avoidance of proprietary-based systems; a multi-provider model for both hardware and services to promote innovation, competition and consumer choice; performance and outcome based specifications to promote innovation; supported by an independent certifier and auditor (like TCA in Australia) to ensure technology and services works and continues to work as intended; underpinned by a strong, deliberate separation between technology provision and policy use, defined roles and responsibilities between users, regulators and technology providers; supports Co-operative ITS (C-ITS) applications; operating Model (including certification, audit and enforcement); communications platform (Introduction to Communications Access for Land Mobiles or commonly called CALM); system security to minimise the risk for tampering, spoofing and jamming; and system integrity to safeguard against being used for other purposes than intended.

South Africa and solutions based on the country’s special conditions

Road freight challenges in South Africa relate mainly to the culture of non-compliance, with overloading, poor vehicle fitness (servicing and maintenance), poor driver fitness (fatigue, health, training), reckless driver behaviour, border post delays, bribery and corruption (impact on compliant and noncompliant operators), and inadequate periodic maintenance (roads). Effects of this behaviour include poor road safety, high cost of road transport/ logistics, deterioration of infrastructure, and high level of emissions. In the developed world, compliance is achieved through effective law enforcement combined with self-regulation. Key elements in road freight transport include road infrastructure (roads, bridges, roadside furniture, signs, road markings, eToll gantries), vehicles (design, maintenance, and operation), and drivers (skill, health, fatigue).

Three approaches to heavy vehicle monitoring are being used to combat the challenges faced by South Africa. These are accreditation schemes (ISO39001, RTMS, NHVAS), law enforcement monitoring (speed cameras, WIM systems, static weighbridges), and real-time on-road monitoring (speed, route and mass compliance). Many positive results were achieved, relating to driver behaviour, driver awareness and safety, driver wellness, and fuel consumption. Driver speeding is monitored on a daily basis through the tracking system and all events are addressed with drivers daily on debriefing. Driver awareness and safety has increased due to training, educating, posters, and truck information manuals. Driver motivation has increased due to Driver of the month and driver of the year awards, elected by tracking system which monitors driver behaviour and gives the drivers a monthly score. Driver wellness is improved as fatigue and chronic conditions are managed. Fuel consumption consistently improved, with fuel being monitored on a daily basis. This is influenced by good maintenance processes and improved driver behaviour (speeding, defensive driving, harsh braking, driving economically), which RTMS promotes in their accreditation.

High Capacity Transport development in Finland

Finland has carried out many trials with HCT technology in order to inform their transport policy making. Here experiments and trials are a part of Finnish transport policy, experiments are encouraged, performed by private sector, and experiments rather than desktop exercises serve as a basis for decision making. But of course for experiments that have an impact on road safety, the safety of the experiments must be ensured before actual tests on roads. HCT trials aim to develop ways to make road freight transport more efficient and safe. There are several points of view in this context, relating to the various stakeholders, including hauliers, industry, road safety, environmental protection, vehicle manufacturers, etc. Trials on roads need permits from Trafi, requirements here are an analysis on the safety of the vehicle combination, use of pre-defined routes and a clear plan on research and on development. Results are to be made public and available to interested parties, and of limited duration. The end result is to contribute supporting information for policymakers, recommendations for possible new combinations, and guidance on which aspects are relevant for safety and environment.

Performance Based Standards

Performance based standards (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. Pass fail criteria have been developed for the metrics allowing vehicle designers and regulators to ensure that the vehicles behave in predictable ways and that they can successfully manoeuvre in constrained space. PBS has proven useful for optimising and evaluating HCVs as a means for transport carbon reduction. This is done by increasing the cargo capacity of vehicles while ensuring that the added vehicle weight does not adversely affect pavement and bridge life.

PBS were first introduced in the mid-1980s during a successful effort to harmonise heavy vehicle weight and dimension regulations in Canada. This was accomplished through a scientifically structured size and weight research program which included full-scale testing of vehicles and pavements and computer simulation analysis of vehicle dynamic performance. Through this process it was recognised that vehicle configuration type, axle layout, and the characteristics of the load profoundly influence vehicle stability and control characteristics as well as the compatibility of the vehicle with highway geometry. To objectively assess various truck size and weight policy options, a set of “Performance Based Standards” was created. Using the PBS and the results of a sensitivity analysis, Canada developed truck size and weight policy consisting of several "vehicle envelopes" that provide flexibility in design for various vehicle classes while ensuring that the vehicles would have desirable performance attributes. The envelope concept reduced the burden of compliance evaluation when small variations in vehicle design were required.

In the late 1990s, Australia embarked on a nationwide size and weight reform where PBS would replace most of the prescriptive regulations pertaining to heavy vehicles including network access of road freight vehicles. As with Canada, PBS was developed in response to what were broadly agreed as inflexible prescriptive heavy vehicle regulations thereby providing objective and transparent national standards for vehicle compliance. The process of developing and implementing PBS in Australia occurred over a period of some 12 years and consisted of six consecutive phases (Woodrooffe, 2012).

Performance Based Standards and the FALCON Project

The European transport sector contributes approximately 20% of current carbon emissions, and of this trucks and buses account for around a quarter (European Commission, 2014). Improving the efficiency of road freight transport is pivotal in recent carbon reduction efforts. The use of HCVs is proven to be a highly effective means of reducing the carbon emissions of road freight transport, which has been demonstrated in numerous countries including Australia (Cook, 2008) and South Africa (Nordengen, de Saxe and Kienhöfer, 2014).

The use of PBS provides an objective means of assessing vehicle safety performance and mitigating the impact on vehicle infrastructure. The assessment is most often done at the vehicle design stage using computer simulation methods, allowing vehicles to be optimised with well-defined desirable characteristics incorporated as part of the design process.

The recently completed European project FALCON ("Freight and Logistics in a Multimodal Context") examined the use of performance-based standards (PBS) as a mechanism for creating freight vehicles with a lower carbon footprint, better safety performance and compatibility with the infrastructure. The FALCON project is a collaborative effort funded by the Conference of European Directors of Roads (CEDR) and has set out to address ambitious carbon emission reduction targets set by the European Commission. A primary goal of the project was to define a potential Performance-Based Standards (PBS) framework for cross-border road freight transport in Europe. Such a framework would accommodate HCVs, which have been shown to have a large beneficial impact on road freight transport efficiency and emissions. Details of the PBS portion of the FALCON project are well described by a paper (de Saxe et al., 2018).

Road access classification for Performance Based Standards vehicles

HCVs are longer than typical freight vehicles and they are suitable for certain classes of road. Table 9 provides an example that outlines the existing Australian road access classification system. It ranges from Level 1 vehicles which are permitted access to the entire Australian road network and for which the required performance criteria are set accordingly strictly. Levels 2–4 accommodate longer vehicle combinations that are restricted to increasingly smaller subsets of the road network, with accordingly less strict criteria on some standards. At the extreme end is Level 4, which caters for the longest vehicles operating in remote regions of the country. This is the category into which new Australian "road train"-type combinations are categorised.

Table 9. Australian road access level classification

Road access level	Permitted vehicle length	Permitted routes	Performance criteria
Level 1	≤ 20 m	Unrestricted road access	Most stringent
Level 2	≤ 30 m	Significant freight routes	
Level 3	≤ 42 m	Major freight routes	
Level 4	≤ 60 m	Remote areas	Least stringent

Source: De Saxe et al. (2018)

Using the Australian framework as a baseline, the proposed road access classification system for Europe is shown in Table 10. Consideration was given to the existing road network characteristics, existing regulations, and geography. The concept of "unrestricted road access" was deemed inappropriate for equivalent Level 1 European vehicles, and was replaced with "existing truck routes" to avoid the possibility of long articulated heavy vehicles travelling through medieval European city centres for example. The UK/EU roundabout test would be enforced for this level. A new "Level 0" was added, to account for city-level freight activities such as garbage collection and home grocery delivery. Here, it is envisaged that additional stricter manoeuvrability tests (yet undefined) representative of small city intersections be imposed. This also allows for the possibility of higher capacity vehicles serving these industries in the future, provided that they can be shown to meet the strict manoeuvrability criteria (using advanced steering control systems for example) as well as other city-level requirements for noise and air pollution (by using electric drive for example). Levels 2 and 3 were deemed approximately equivalent to the Australian system, with the observation that Level 1 would typically serve EMS-type vehicle combinations, and Level 2 would serve "EMS 2"-type combinations. Level 4 was deemed non-applicable to European conditions.

Table 10. Proposed European road access level classification

Road access level	Permitted routes	Notes
Level 0	Unrestricted road access	Stricter manoeuvrability criteria for city access for garbage trucks, home delivery etc.
Level 1	Existing truck routes	Includes EU/UK roundabout manoeuvre
Level 2	Significant freight routes	Approximately equivalent to EMS vehicles
Level 3	Major freight routes	Approximately equivalent to EMS 2 vehicles

Source: De Saxe et al. (2018)

Performance Based Standards supporting framework

It is proposed that a European PBS framework should adopt a supporting framework such as those that have been put in place in Australia and South Africa. These include systems that ensure adequate driver training, speed monitoring, vehicle maintenance, loading control, and vehicle tracking (to ensure compliance with approved routes). These structures are crucial for the long-term success of a PBS framework. A summary of the main elements for a PBS framework are listed in Table 11.

Table 11. Final recommendations for a proposed Performance Based Standards framework for Europe in the FALCON project

Performance Standard	Include?	Recommendations
Driveability		
Startability	Y	Consider reducing L1 to 12%. Allow jurisdictions to review criteria based on local road grades.
Gradeability A (Maintain motion)	Y	Consider reducing criteria in accordance with adjustments on startability. Allow jurisdictions to define limits on local conditions.
Gradeability B (Maintain speed)	Y	Appropriate as is (aligned to speed limits).
Acceleration Capability	Y	Review criteria. Allow jurisdictions to review the criteria based on local intersection and crossing geometries.
Manoeuvrability		
Low-Speed Swept Path	Y	Criteria too lenient – review against existing European road geometries and roundabout standards.
Frontal Swing	Y	Criterion can possibly be reduced to 0.5 m for all levels, based on the fleet assessed. However there is no documented need to reduce the limit below the current 0.7 m.
Difference of Maxima	(review)	Potentially too complicated, and not aligned with direct safety risk. Could be removed or replaced with a single standard. Requires further investigation.
Maximum of Difference	(review)	
Tail Swing	Y	Criteria can possibly be reduced to 0.3 m for all levels (subject to further investigation). Car-carriers should be included in further investigations.
Steer-Tyre Friction Demand	Y	The ≤ 80% requirement is possibly too high and should be reviewed.
EU turning circle	Y (L1)	Applicable as an additional test for Level 1-type vehicles.
Netherlands turning circle	N	Found to offer no additional information vs. LSSP, while requiring multiple different manoeuvres to assess longer vehicle combinations.
High-speed stability		
Static Rollover Threshold	Y	Applicable as is.
Rearward Amplification (last trailer)	Y	Criterion of 2 requires further review, as appropriate to the rear trailer method, and once the vehicle designs have been optimised further.
Rearward Amplification (RRCU)	N	Last trailer method preferable, as the standard has been decoupled from assessing direct rollover risk.
Dynamic Load Transfer Ratio	Y	A better indication of rear trailer rollover risk in transient manoeuvres. The criterion of 0.6 may require review in parallel with RA=2.
High-Speed Transient Offtracking	Y	Vehicle and lane widths are similar to Australia and so the criteria may be transferable, but Level 1 vehicles may use minor roads of width 2.5 or 2. 75 m. This requires further investigation.
Yaw Damping Coefficient	Y	Applicable as is.
Tracking Ability on a Straight Path	N	Found to be highly correlated with HSTO, and prone to simulation error due to complexity.

High-Speed Steady-State Offtracking	N	Found to be highly correlated with vehicle length, but also influenced by vehicle mass. Can be used to inform vehicle length limits per road access level, however for very heavy vehicles (i.e. higher than the loading conditions considered in this study), the influence of mass may become a limiting factor.
Winter conditions		
Low friction braking	Y	The faultless function of ABS system is necessary for braking stability of HCVs in winter.
Steer-Tyre Friction Demand	N	Shown to be correlated with high friction performance for the fleet considered. High friction criteria could be set accordingly to ensure low friction performance.*
Drive-Tyre Friction Demand	N	Correlated with high friction performance, and found to be less meaningful than steer tyre friction demand, due to the dissimilar direction of the forces in a two-axle drive bogie.. High friction criteria could be set accordingly to ensure low friction performance.
Low friction startability	N	Temporary drive axle load proportioning should be permitted to increase drive axle loads as required for starting.
Low friction high-speed standards	N	A speed reduction to 60 km/h was found to ensure comparable performance to high friction conditions.
Infrastructure		
Bridge-loading	Y	The proposed methodology is to: (1) define suitably representative bridge structures to consider which may be region-specific, (2) assess the impact of the representative fleet on the bridges as demonstrated, and (3) fit a suitable bridge formula to the results, matching the order of the formula as required, which could be fitted according to the most aggressive effect.
Road wear impact	Y	The proposed methodology is to: (1) use combination 2.1 loaded to 40 t as the reference, (2) select representative road structures applicable to the region (~3), (3) compute the aggressiveness of 2.1 on the road structures as the maximum permitted aggressiveness, (4), assess the aggressiveness of the proposed new vehicle, which should not exceed that of 2.1. Note that aggressiveness should be scaled by payload mass or volume, depending on which is more appropriate for regional traffic.

* For the most accurate results, friction demand should be simulated in winter conditions. However, if it is practical to perform all simulations in summer conditions without the need for winter-specific models, then correlation between summer and winter performance can be investigated (as done here) for the specific fleet under concern, and used to set a safe performance level to ensure both summer and winter performance.

Source: CEDR project FALCON (unpublished)

Performance Based Standards technical structure from New Zealand

A study (de Pont, 2018) on the development of Performance Based Standards for New Zealand, provides a valuable reference for jurisdictions contemplating the implementation of PBS policy. The study was commissioned by the New Zealand Transport Agency as part of their policy development process. It considers how PBS evolved and presents current thinking on PBS technical policy structure.

The following discussion on PBS technical structure borrows heavily from this work.

Vehicle height, width and length

Vehicle height and width limits in most countries are the same for all vehicles. An exception to this is in the UK where height clearances over the trunk road network permit the operation double-deck trailers up to a height of around 5 m (in contrast to most other European Union countries in where height limits of 4 m to 4.2 m are imposed). A study by (McKinnon, 2010) analysed what the consequences would be should double deck trailers be prohibited and replaced by standard height trailers. The study found that it would increase the distance travelled by UK-registered articulated lorries by around 4.5%. Annual road haulage costs would rise by roughly GBP 305 million. Switching from double-deck to standard trailers would increase fuel consumption and CO_2 emissions by a mid-range estimate of 64%. In terms of its impact on CO_2 emissions, this would be equivalent to adding 151 000 new cars to Britain's roads.

The New Zealand study concluded that for general or widespread access PBS vehicles, the overall dimensional envelope should be prescribed. The maximum height and maximum width limits should be the same as those for standard vehicles. The overall length limit should also be prescribed in the absence of better information. These dimension limits should be based upon the perceived capacity of the existing infrastructure. Since they are not based on vehicle performance they should be prescribed rather than the subject of performance assessment. For High Capacity Vehicles used on specific routes or primary highways, length limits may be extended depending on the geometric constraints of the roadway.

Pavements

Pavement wear is generated by repeated loading applied by the axles and tyres of the vehicles passing over it. The relationship between the magnitude of the applied axle load and the amount of pavement wear that results is not linear. As well as being non-linear it also varies with pavement type and with the pavement wear mechanism being considered. The fourth power model of pavement wear is analogous to Miner's Law for metal fatigue and describes the gradual accumulation of wear over many loading cycles. Very high loads can cause damage to the pavement in a relatively small number of load applications and so maximum axle load limits are set to prevent this overloading effect. Axle load limits are usually prescriptive and depend on pavement and, bed strength, freeze thaw susceptibility and other localised characteristics. When heavier HCVs are considered, more axles are added to the vehicle ensuring that axle loads do not exceed those of standard vehicles.

Drivetrain performance

Drive train performance is related to how well the powertrain can generate vehicle propulsion. Important questions are:

- Can the engine and drivetrain generate enough power and torque to achieve satisfactory mobility performance?
- Can the drive wheels transmit this power and torque to the road to achieve required vehicle speed?

The startability requirement is the maximum grade on which the vehicle must be able to start from rest while the low speed gradeability is the maximum grade on which the vehicle can maintain forward motion. The startability requirement will always be less than the low speed gradeability requirement for two reasons. The first; for gradeability the vehicle merely must maintain speed while for startability it has to accelerate as well albeit at a minimal rate. Second; gradeability can be achieved with the engine operating at its peak torque while startability is based on the clutch engagement torque which is always less. For the most part, vehicle manufacturers can specify the correct driveline requirements to achieve satisfactory mobility for a given vehicle mass and regional terrain. Incorporating drive train performance into a PBS system is not a necessary requirement for most countries with PBS.

Braking performance

Most vehicles are fitted with an anti-lock braking system (ABS) that prevents wheel lock up during braking. In addition, foundation brake systems on vehicles are specified by the manufacturer to manage braking requirements at the maximum allowable gross vehicle weight (GVW) of the vehicle. The vehicle manufacture effectively ensures that the new vehicle is equipped with adequate braking systems. For these reasons brake performance is not addressed by most PBS systems.

Steady turn directional performance

There are two key aspects to steady speed turning performance of vehicles. At very low speeds, there is no lateral acceleration (sideways force) generated and thus the tyres are not required to generate any sideways force to counter the lateral acceleration. However, some side force is required on the steer axle tyres to overcome aligning moments that axle groups naturally impose.

Offtracking and friction demand

The performance measures associated with slow speed cornering are low-speed offtracking where the rear of the vehicle tracks inboard of the front of the vehicle; and steer axle friction demand which estimates the amount to tyre/road friction used to overcome slow-speed aligning moments. As steer axle friction demand increases, the vehicle becomes less responsive to steer inputs at slow speed. For low speed offtracking and steer axle friction demand the most widely used test manoeuvre is a 90° circular turn with a tangential approach and exit. Various approaches have been used for specifying the turn radius. Both of these metrics can be assessed using computer simulation. The speed and turn radius of the vehicle must be controlled during low speed turn test. Sensible values are a 12.5m radius 90° curb-to-curb turn at a constant speed of 5km/h.

High-speed offtracking

Centrifugal forces are generated on high speed turns, and these forces are balanced by equal and opposite forces generated by the tyres at the road interface. The tyres generate lateral forces by operating with a slip angle which causes the rear of the vehicle to offtrack outboard of the path of the zero-slip condition. On large radius turns where the vehicle speed is high, the rear of the vehicle tracks outboard of the path of front of the vehicle and the road width required is greater than the width of the vehicle. High speed turn manoeuvre radius and criteria varies among jurisdictions. A review of the literature by New Zealand prompted the recommendation to use the 319m radius turn as the high speed offtracking manoeuvre with speeds of 90 km/h and 100 km/h. The recommended pass/fail criteria are 0.46 m and 0.68 m respectively.

Tail swing

The tail swing controls the extent to which the rear body work of the vehicle can cross over a curb or a lane while the vehicle's wheels remain in the lane. Tail swing is defined as the maximum excursion of outside rear corner of the vehicle beyond the plane of the outside edge of the vehicle at the start and finish of the low speed turning manoeuvre. The typical value used by many jurisdictions is 0.3m.

Frontal swing

Frontal swing is analogous to tail swing but in relation to the front body work. The simplest component is the frontal swing of the truck or tractor. This is the extent to which the front outside corner of the vehicle travels outside the path of the outside edge of the outer front steer tyre. The maximum value occurs as the vehicle straightens out at the end of the low speed turn. Frontal swing can also apply to the front of a semi-trailer. There are wide variations among jurisdictions on how frontal swing is defined and what the permitted limits are.

Stability: Static rollover threshold

The rollover stability of a vehicle during steady state cornering is characterised by the performance measure “static rollover threshold” (SRT). In some jurisdictions, such as Australia and New Zealand there are SRT requirements for large vehicles and then a second-tier requirement for dangerous goods vehicles and even more stringent requirements for buses. Australia requires SRT of not less than 0.35g for heavy vehicles with 0.40g required for bulk dangerous goods vehicles and buses and coaches. In New Zealand most heavy vehicles requires an SRT of not less than 0.35g, dangerous goods tank vehicles are required to have a minimum SRT of 0.45g, double decker buses and coaches require SRT of 0.53g and single decker buses and coaches are required to have an SRT of 0.70g. One common simulation method is to start with a constant radius turn to establish steady state offtracking and then progress to a gradually reducing turn radius. This is done at a constant speed of 90 km/h. To avoid dynamic effects, it is important that the turn radius does not change too quickly. The typical rate of change of steer tyre angle of 0.04 degrees per second.

Dynamic performance and high-speed lane change

High speed lane change manoeuvre is the basis for three dynamic performance measures

- Rearward amplification (RA)
- Load transfer ratio (LTR)
- High speed transient offtracking (HSTO).

The path of the high-speed lane change manoeuvre is designed to produce a single sine wave lateral acceleration response at the tractor centre of gravity with an amplitude of 0.15g. ISO has created a standard lane change manoeuvre for stability testing (ISO 2000) which provides some latitude for test conditions where speed can be adjusted in accordance with changes to the path to maintain an amplitude of 0.15g. This is particularly helpful in full-scale testing where space is limited.

Rearward amplification

Rearward amplification describes how much this lateral acceleration is amplified at the rear trailer. This measure characterizes how “lively” or unstable the vehicle combination is during lane changes. The livelier the vehicle, the more prone it is to trailer rollover. The typical maximum rearward amplification value is not to exceed 2.0.

Load transfer ratio

Load transfer ratio is a measure of the ratio of the wheel loads of either side of each vehicle combination unit during the standard lane change manoeuvre. When the ratio of a given vehicle unit reaches 1, rollover occurs. A typical limit for load transfer ratio is not to exceed 0.6 but there are jurisdictions that allow higher levels.

High speed transient offtracking

High speed transient offtracking is the maximum lateral excursion of the path of the rearmost axle from the path of the steer axle. The reference value in Canada is not to exceed 0.8m while the pass/fail threshold in Australia is 0.6m for level 1 (general access roads) and 0.8m for level 2 roads.

Yaw damping ratio

The manoeuvre used for yaw damping ratio (YDR) is a pulse steer input undertaken at high-speed. The pulse manoeuvre causes lateral sway of the trailer(s) which then decays over several oscillations. Yaw damping ratio measures the rate as which this decay occurs. The test manoeuvre commonly used is that defined in the ISO standard (ISO 2000). This standard also details the method for calculation the yaw damping ratio from the amplitude of the successive peaks in either the yaw rate, articulation angle, or articulation angular velocity. The common value for minimum acceptable level of yaw damping is 0.15 or 15%.

Default settings and data requirements

Vehicle loading

Vehicles evaluated within PBS requirements are generally loaded to maximum allowable GVW limits. It is assumed that the operator will follow sound loading practices so that as far as practicable:

- the longitudinal weight distribution results in the weight being distributed between the axle groups in proportion to the axle group's load capacity.
- the lateral weight distribution is such that the centre of gravity on the load lies on the longitudinal axis of the vehicle.
- the vertical load distribution minimises the height of the centre of gravity of the load.

Tyres

Tyre characteristics vary considerably among manufacturers and according to tyre size and category. Tyre characteristics have a significant influence on vehicle dynamic performance so much so that in PBS analysis for example it is possible for the variations in cornering stiffness to significantly influence whether a vehicle passes or fails a given metric. For consistency of results and integrity of the PBS evaluation, tyre parameters used in computer simulations should be standardised. The Australian Road Transport Suppliers Association have proposed the use of generic tyre data in two categories; standard tyres and superior tyres. The PBS assessment would be undertaken using one of these two categories of tyres and the PBS approval would be based on the tyre category used.

Comparing tyre data with from the same manufacturer and the same model series is not as easy as might be expected. Tyre data typically consists of measurements at a range of slip angles with several vertical load options. However, the vertical loads used are not necessarily the same for each tyre tested and so the data is not directly comparable. This same issue also makes it difficult to compare tyre data from different manufacturers even when the tyre size is identical.

Suspensions

There are several suspension properties required by multi-body simulation software packages to model the vehicle's responses during the various PBS manoeuvres. Some of them are much more important than others in terms of their impact on the PBS measures. Generally, the suspensions have relatively little effect on the low speed performance measures but have a significant effect on the high-speed dynamic performance. The two most important mechanical properties of the suspensions in this regard are roll stiffness and roll centre height while damping has a medium effect on rearward amplification. Most PBS systems refrain from specifying generic suspensions for PBS analysis. Because suspension properties are not always known, most analysts use representative suspension characteristics available in scientific literature.

Steerable axles

Steerable axles other than the steering axle in the front of a vehicle can be actively or passively steered. Active steering based on mechanical linkages is often relatively straightforward to model. In some cases, such as logging trailers, the steering action changes the geometry of the vehicle and this may not be easy to represent accurately with some modelling systems, but workarounds are possible. There are also active steering systems which are computer-controlled and use algorithms that may or may not be disclosed. Modelling vehicles fitted with these systems is potentially very difficult and may be impossible. This leaves us with the option of physical testing but, as we have seen, some of the proposed performance measures are difficult to evaluate experimentally. The solution may be to use a hybrid approach where a computer simulation model that approximates the vehicle is built and physical testing is used to validate the reliability of the model. The model can then be used for the performance measures that are difficult to determine experimentally.

High Capacity Vehicle policy options

There are several policy options available for implementing High Capacity Vehicles based on PBS and for the creation and management of size and weight policy. Australia, Canada and New Zealand were early adopters of PBS and each took distinctly different approaches to size and weight policy implementation. The approaches taken by Australia and Canada represent good examples of polar-opposite PBS policy instruments therefore they are particularly instructive for those considering implementing PBS policy. The different approach taken by both countries underscores the degree of flexibility open to regulators regarding the creation of regulatory instruments based on or supported by PBS. In both cases, there is strong evidence that such systems have significantly improved transport efficiency, creativity and safety.

In Canada where PBS originated, they have been used as a basis for developing a flexible vehicle envelope framework and in Australia PBS has been integrated as a working component of their size and weight regulatory system (Woodrooffe, 2012).

The Canadian regulatory approach

The Canadian approach sought to achieve regulatory harmonisation of size and weight policy throughout Canada by conducting a comprehensive size and weight study based on rigorous scientific study and engineering methods to analyse pavement and vehicle performance. The research included a parametric sensitivity analysis using vehicle dynamic simulation and field testing for stability and offtracking, full-scale pavement testing for axle loads and axle spacing. It also included laboratory road/vehicle dynamic shaker testing to define dynamic load characteristics of suspensions leading to the identification of road friendly suspensions. During this research it became apparent that the provincial regulators would be in the best position to achieve harmonisation if a set of objective metrics were created to help establish technical principals upon which the regulatory framework could be based.

The extensive testing and computer simulation carried out under the Canadian size and weight research program served to evaluate and document the wide range of stability and control characteristics of vehicles found in the commercial transport fleet at the time. In reviewing the findings, it was recognised that the way the vehicle was configured, the means by which trailers were coupled, the axle layout and the manner in which the load was distributed, profoundly influence the stability and control characteristics and the compatibility of the vehicle with highway geometry. Based on these observations, a set of regulatory principles were established that directed size and weight policy development within the context of the following objectives:

1. To encourage the use of the most stable heavy vehicle configurations through the implementation of practical, enforceable weight and dimensions limits.

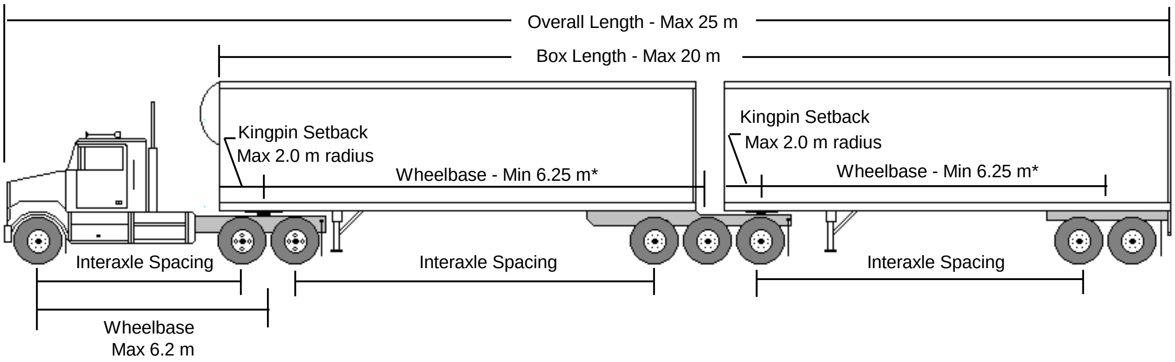
2. To balance the available capacities of the national highway transportation system by encouraging the use of the most productive vehicle configurations relative to their impact on the infrastructure.
3. To provide the motor transport industry with the ability to serve markets across Canada using safe, productive, nationally acceptable equipment.

Regulating full road system access vehicles

Canada made a distinction between common freight vehicles that travel on general truck routes and specialised very High Capacity Vehicles that are limited access vehicles that can operate only on specific routes.

For the more common full road system access vehicles, Canada used PBS and vehicle parameter sensitivity analysis to create a set of "vehicle envelopes" defining the general vehicle layout including ranges for certain component variables such as axle spacing and hitch placement. The vehicle envelope approach provides flexibility in design for various vehicle classes. The envelope concept reduces the burden of compliance evaluation by giving the vehicle designer some flexibility for vehicle optimisation within a prescriptive regulatory system. An example of the vehicle envelope is shown in Figures 13 and 14.

Figure 13. Dimensional limits and reference definitions for Canadian Vehicle Envelope System



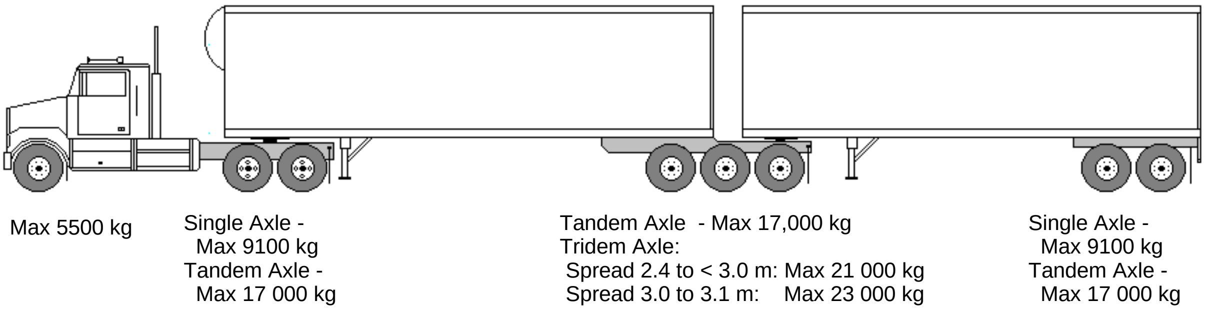
Source: Task Force on Vehicle Weights and Dimensions Policy (2014)

Table 12. Breakdown of dimensional limits for Canadian Vehicle Envelope System

Dimension	Limit
Overall Length	Maximum 25 m
Overall Width	Maximum 2.6 m
Overall Height	Maximum 4.15 m
Box Length	Maximum 20.0 m
Tractor:	
Wheelbase	Maximum 6.2 m
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Lead Semitrailer	
Wheelbase	Minimum 6.25 m
Kingpin Setback	Maximum 2.0 m radius
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Tridem Axle Spread	Minimum 2.4 m/Maximum 3.1 m
Track Width (extreme outer width)	Minimum 2.5 m/Maximum 2.6 m
Fifth Wheel Position	No more than 0.3 m behind the centre of the rearmost axle on the semitrailer
Second Semitrailer	
Wheelbase	Minimum 6.25 m
Kingpin Setback	Maximum 2.0 m radius
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Tridem Axle Spread	Minimum 2.4 m/Maximum 3.1 m
Track Width	Minimum 2.5 m/Maximum 2.6 m
*** Sum of Semitrailer Wheelbases**	**Maximum 17.0 m**
Inter-axle Spacings	
Single Axle to Single or Tandem Axle	Minimum 3.0 m
Tandem Axle to Tandem Axle	Minimum 5.0 m
Tandem Axle to Tridem Axle	Minimum 5.5 m
Tridem Axle to Tridem Axle	Minimum 6.0 m

Source: Task Force on Vehicle Weights and Dimensions Policy (2014)

Figure 14. Mass limits and reference definitions for Canadian Vehicle Envelope System



Source: Task Force on Vehicle Weights and Dimensions Policy (2014)

Table 13. Breakdown of mass limits for Canadian Vehicle Envelope System

Weight	Limit
Axle Weight Limits:	
Steering Axle	Maximum 5 500 kg
Single Axle (dual tyres)	Maximum 9 100 kg
Tandem Axle:	
Axle Spread 1.2 m - 1.85 m	Maximum 17 000 kg
Tridem Axle:	
Axle Spread 2.4 m to less than 3.0 m	Maximum 21 000 kg
Axle Spread 3.0 m to 3.1 m	Maximum 23 000 kg
Gross Vehicle Weight Limits:	
Five Axles	Maximum 40 700 kg
Six Axles	Maximum 48 600 kg
Seven Axles	Maximum 56 500 kg
Eight Axles	Maximum 62 500 kg

Source: Task Force on Vehicle Weights and Dimensions Policy (2014)

Regulating very high productivity limited access vehicles

For very high productivity vehicles that are less common, that is high productivity vehicles that are outside of the envelopes, PBS is used as a compliance tool to judge acceptability. In most provinces high productivity vehicles operate under special permit programs governed by strict operating conditions. The structure and enforcement mechanisms of the policy engender a level of safety consciousness which far exceeds that found in other vehicle classes. The principal motivating factor for heightened safety performance is related to the special safety requirements and fact that a special permit can easily be revoked for safety performance failure. The special permit system requires that operators be trained to meet and maintain the requirements outlined in the Canadian Trucking Alliance's "Longer Combination Vehicles Driver's Manual." The province of Alberta has the following requirements for LCV drivers.

Drivers must obtain an annual certificate verifying that they are in compliance with certain requirements related to the type of license, training, driving experience, physical fitness, and criminal records. Permit conditions also place controls on where these vehicles can operate including hours of operation (time of day), vehicle dimensions such as wheelbase, hitch offset and dolly drawbar length. The policy also contains operational requirements such as adverse weather restrictions, requirements that the vehicles track properly and do not sway, and requirements that vehicles do not cross opposing lanes of traffic unless absolutely necessary.

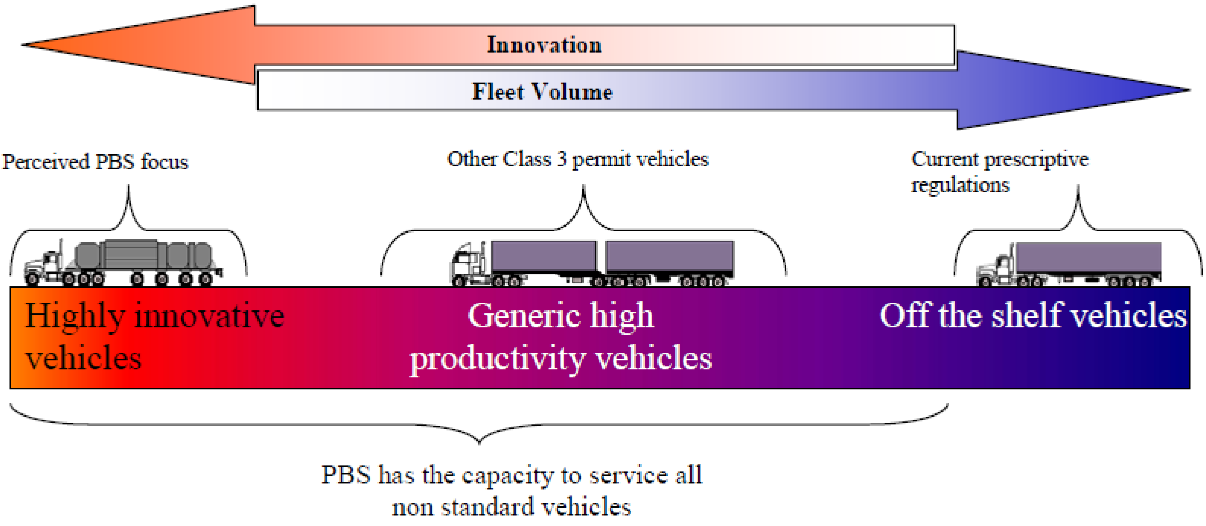
The Australian regulatory experience

Australia has implemented a nationwide PBS system for regulating weights and dimensions that is tied to a road access network based on freight vehicle class. As with Canada, the Australian PBS system was developed in response to what were broadly agreed as inflexible prescriptive heavy vehicle regulations. The reformed system provides for flexibility in vehicle design allowing creative forces to be applied to the development of specialised vehicles that improve the efficiency and safety of particular transport tasks. Australia took PBS to a higher level by largely replacing the prescriptive system with a unique PBS regulatory instrument (however the prescriptive regime operates in parallel for those who wish to continue using it). The original objectives of the Australian PBS effort can be summarised as follows:

1. Provide more sustainable transport systems through improved road vehicle regulations controlling heavy vehicle safety and infrastructure impacts.
2. Provide more flexible road transport regulations that allow increased innovation and more rapid adoption of new technologies, while providing seamless operations nationally.

Consideration was given to fleet implications as depicted in Figure 15. The focus of the PBS system was towards individual vehicle assessment spanning the space between generic high productivity vehicle such as B-doubles and highly innovative vehicles that are often required by the agriculture and mining industries.

Figure 15. Performance based assessment – fleet coverage objectives



Source: National Transport Commission (2012)

The road to implementing PBS in Australia was long and required comprehensive analysis and significant institutional change within a judicious process. The project consisted of six phases spanning some 12 years as follows (Cook, 2008; National Transport Commission, 2010):

- Phase A: Performance Measures and Standards – identifying the appropriate performance measures and standards and surveying the performance of the current heavy vehicle fleet.
- Phase B: Regulatory and Compliance Processes – establishing a regulatory system in which Performance Based Standards can operate as a seamless national alternative to existing prescriptive regulations including national compliance and enforcement arrangements.
- Phase C: Guidelines – preparing guidelines detailing the procedures and processes for the consistent application of Performance Based Standards.
- Phase D: Legislation – developing the legislative arrangements for Performance Based Standards to operate as an alternative to prescriptive regulations.
- Phase E: Case Studies – assembling work previously conducted and demonstrating the practical application of Performance Based Standards to nationally agreed priorities.
- Phase F: Implementation – putting in place the necessary legislative and administrative systems to allow Performance Based Standards to operate nationally and providing the training and information to support these changes.

The Australian heavy truck regulatory system is comprised of prescriptive regulations, a permit system and a PBS access system. The regulations are bifurcated in the following way:

- National "model" regulations developed by the National Transport Commission (NTC) in collaboration with road agencies and approved by Australian Transport Council (ATC). The ATC is a Ministerial forum for consultations and advice to governments on the coordination of national transport and road issues.
- As State or Territory regulations which may complement national model regulations, or substitute for them (where a State or Territory has not accepted the model regulations).

The national Australian PBS legislation classifies heavy vehicles based on freight task as follows.

- General access vehicles, which are those complying with the vehicle standards and mass and loading regulations (e.g. rigid trucks, semi-trailers, standard type truck trailers).
- Class 1 vehicles are engaged in "special purpose" transport operations, which include oversize and over mass, agricultural and mobile plant vehicles (e.g. low loaders, concrete mixer trucks).
- Class 2 vehicles are specific types and combinations, which are compliant with applicable model regulations. As a result of their size and/or mass they are subject to restricted access (e.g. B-doubles, road trains and long buses).
- Class 3 vehicles are non-standard heavy vehicles which do not fall within the Class 1 or 2 categories. These are typically higher productivity vehicles which operate under concessional access/permit schemes or under the PBS scheme (e.g. super B-doubles and under existing legislation, all PBS vehicles). Their access to the road network is either restricted or in accordance with the PBS access levels.

One of the objectives of the Australian PBS system was to develop a system that would match vehicles to appropriate road networks. As a result, a stratified road network classification was devised which became known as the "performance based standards road network levels". Under the prescriptive system there were four network levels that restricted heavy vehicle use in the following order:

- General access (subject to a 50 t gross mass limit)

- B-doubles
- Road train type I
- Road train type II.

Societal implications of High Capacity Vehicles

The current generation of performance-based standards focus on the essential requirements of vehicle performance and infrastructure compatibility, they do not address broader issues related to societal impact such as energy use, carbon emissions, safety impacts and transport efficiency. Policy makers are not well equipped with metrics that define the societal benefit of HCVs.

To address the shortage of objective metrics and data for assessing societal impact, the following parameters are presented for consideration.

Societal opportunity cost parameters

Many of the cost parameters listed below address the concept of sustainability which is an overarching principle that will likely guide future public policy:

- Traffic casualties
- Broader public health effects – e.g. respiratory disease
- Carbon emissions
- Truck trip reduction, the percent reduction in truck trips or required number of trucks or truck-kms (addressing exposure reduction and congestion mitigation)
- Infrastructure consumption – road and bridge consumption per tonne-kilometre of freight or per cubic metre-kilometre of freight
- Economic impact – improved productivity and greater competitiveness at national and international levels (regional, national and international).

Policy instruments need to provide ongoing accountability supported by metrics that will provide a means for measuring progress and policy effectiveness. Metrics should be robust enough to assess environmental conditions and counter anti-social policies that threaten the wellbeing of regional and global populations.

In the future the traditional approach of focusing on the road and vehicle will likely give way to a broader transportation system assessment where the task of transporting goods transcends from a single-mode focus to broader transport system optimisation. This will require a more pragmatic, thoughtful and inclusive decision-making process based on data that balances local, regional and global priorities. Some form of sustainability index applicable to all modes of transport would be helpful. With such an index in place, one possible approach to encourage low carbon transport would be to assign a minimum threshold requirement in order to qualify as “sustainable transport”. For example – door-to-door movement must achieve minimum of ‘X’ t-km of freight movement per tonne of CO_2 emitted. While this is an interesting concept it would be very difficult to apply in practice. Emissions trading/carbon pricing may prove to be a more practical approach.

Examples of sustainable parameters may include:

- Intermodal compatibility
- Electrification, hybridisation and fuel use (kg CO_2 equivalent/unit freight transported)
- System level carbon use (system boundaries to be defined)
- Load migration from smaller trucks to larger trucks
- Modal shift
- Safety and related societal impact
- Vehicle load factor (cargo mass and volume utilisation)
- Public health related to transport.

Intermodal compatibility benefits from containerised freight would not only apply to shipments in ISO standardised containers, it could also include a new generation of small containers such as cages and reusable packaging promoting innovation in handling and logistics of micro containerised freight to minimize carbon use. For example, container life cycle considerations could be included to encourage container reuse as well as back haul freight credits. Intermodal compatibility metrics could be useful in creating policy that rewards innovation in container design, handling and management.

Electrification, hybridisation and fuel use are normally assessed at the vehicle level for a given transport task i.e. how much energy is required to move a unit of freight over distance (Joules /freight-t-km). To assess and monitor carbon use in transport requires a metric that differentiates carbon from other forms of energy. Alternative propulsion options such as electrification or hydrogen fuel cells can have significant carbon content depending on how the energy used for propulsion is created. Hybridisation and electrification have the advantage of capturing kinetic energy during braking which provides significant energy recycling benefits. Alternative energy such as natural gas and biofuels are important options, but the carbon required to extract, process and transport fuels as well as leakage of gas to the atmosphere needs consideration.

System carbon use or life cycle analysis of carbon emissions reflect the "all in" carbon footprint at both the vehicle and system level. The vehicle level can include such things as tyres, and lubricants which are consumed over time and distance. It takes approximately 80 litres of oil to manufacture one new truck tyre. A six-axle tractor semitrailer on dual wheels has 22 tyres which amounts to 1 760 litres of oil invested in tyres. As the tyres wear this equivalent oil is consumed and can be accounted for. Truck tyres can be re-treaded which consumes only about 27 litres of oil per re-tread or about 66% less oil than a new replacement tyre. The carbon saving associated with re-tread tyres is compelling and while the pure economic incentives to re-tread are strong, the consideration of carbon saving is not well appreciated. While some may argue that tyres sequester carbon, the reality is that when tyres reach end of life stage many are used as fuel rather than locking the carbon in reusable products or by disposal in land fill.

Hidden carbon use at the system level is well illustrated by vehicle electrification. An electric vehicle may have zero carbon output from the tailpipe but if the electrical energy used by the vehicle was produced by burning coal then the thermal efficiency of the coal plant must be considered as well and electrical deliver losses. Coal fired power plants tend to have lower thermal efficiency than vehicle engines. Therefore, based on thermal efficiency alone, an electric vehicle powered by electricity generated from coal, can produces more greenhouse gas than the same vehicle powered by an internal combustion engine. This example illustrates the need for a well-to-wheel assessment of emissions rather than tank-to-wheel.

Load migration and modal shift can occur when High Capacity Vehicles are introduced. Whether or not this actually occurs is highly dependent on loading factors, regional transport markets and the presence of viable alternative mode options. The objective should always be to encourage use of modes and intermodal transport options that help to improve the efficiency of the overall transport system rather than improving the efficiency of one mode.

Vehicle load factor measures how well the potential transport capacity of a particular vehicle or fleet of vehicles is being utilised. Often when the mass limits of a vehicle are reached there remains some cubic capacity within the cargo area. The remaining cubic capacity represents a transport opportunity for very low-density freight. Under the right conditions, it may be possible to slightly reduce the amount of high-density freight so that low-density freight can be included to occupy the available cubic capacity while achieving maximum GVW, as described above in CargoStream example in the Decarbonisation of road freight transport section. In addition, effective use of backhaul potential has always been a priority of truck fleets but there remains significant potential for improvement.

At present these approaches present challenges for logistics operations and shippers but in the future, better cargo shipping data and freight aggregating systems and backhaul opportunity identification can be expected, improving load factor bringing significant benefits in overall transport efficiency. Having a reliable metric to measure and audit road transport load factor will be an important tool for enabling better utilisation of available road transport capacity. While such metrics exist, they are very difficult to calibrate at a macro level because governments don’t collect volumetric data on freight flows. This is particularly relevant to the HCT debate because much of the benefit comes from the extra cube but there is lack of volumetric data to quantify this.

An example of first order societal benefits attributed to efficiency improvements that HCT brings is shown in Table 14 These estimates assume a 10% reduction in truck travel in the United States through size and weight reform and the use of HCT assuming a fixed freight task. The estimates show considerable fuel and emission savings and a reduction of 330 fatalities and over 4 000 injuries per year equating to approximately USD 16 billion annually (Woodrooffe, 2016a).This type of table is very effective at showing the value of HCVs. Other elements could be added such as road and bridge life effects and larger public health benefits related to reduced pollution.

Table 14. Reduction in the number of victims, fuel use, greenhouse gas emissions and associated opportunity cost in the United States

Benefit study variable	Injury severity	Reductions assuming 10%reduction in exposure	Estimated annual benefits (USD Billion)
Estimated safety benefits attributed to a 10% reduction in truck travel distance	no apparent injury	21562	0.20
	possible injury	2,929	0.44
	evident injury	2,724	0.68
	disabling injury	1,453	0.87
	killed	330	2.54
	Total safety cost saving attributed to 10% reduction in exposure		**4.73**
Estimated fuel and emissions benefits attributed to a 10% reduction in truck travel distance	**Category**	**Quantity saved**	**Annual cost saving (USD Billion)**
	Diesel fuel reduction	10.6 billion litres	10.60
	CO_2 reduction	28.3 Million metric tonnes CO_2	0.680
Combined benefits	**Total estimated annual savings**		**16.01**

Source: Woodrooffe (2016a)

Resolving societal benefit assessment for public and political consumption

The prior detailed discussion on societal performance metrics proves how complex the evaluation of societal value can become. When considering the task of informing political and public forums, the message must be highly focused, clear and practical. This suggests that calculating societal benefit for public consumption should be strategic, having an easily understood message with content that is difficult to dispute. The top five contenders for this analysis are:

1. Safety (fatality, injury and crash reductions from reduced exposure and the implementation of advanced policy governing High Capacity Vehicles)
2. Reduced truck travel (reduced equivalent truck trips)
3. Impact on infrastructure (roads and bridges)
4. Reduced carbon consumption
5. Mechanisms to ensure that HCTs will be confined to appropriate roads and their movements tracked (IAP).

The arguments are best structured using a reference vehicle with which the HCT can be compared. The choice of reference vehicle would depend on the freight task. For example, if the candidate HCT is intended to transport a bulk commodity then the vehicle presently used for transport would be the reference vehicle. If the candidate vehicle were designed for general freight, then the reference vehicle would be the vehicle currently in use for general fright transport. In other words, the reference vehicle would be the typical one the HCT would replace. The reference vehicle comparative method can be effectively used for all five of the categories listed above.

For safety, the reduced exposure from fewer tuck trips can be applied to local crash rate statistics to produce an estimate of safety benefit. This can be expressed as a percent reduction in probability based upon estimates of expected reduced truck travel, or it can be expressed at the single vehicle level in terms of risk reduction. This assumes that the PBS truck will be no riskier than the vehicles it replaced. Experience with the introduction of PBS trucks in several countries supports this assumption. However, there is a danger that poorly crafted policy could result in higher risk vehicles which could diminish or even eliminate benefits.

Policies that control high productivity vehicles can also be a significant contributor to safety. Retrospective analysis of High Capacity Vehicle programs has shown substantial reduction in crash rate. If these data are available and applicable, then they can be added to the safety benefit pool.

Estimates of reduced truck travel from the introduction of HCVs requires estimates of the number of vehicles expected to be commissioned, the load factor at which they will operate and the degree of load migration. However, it is often difficult to project the number of HCVs that will be introduced so for public consumption it would be more direct to express the truck travel in terms of the efficiency improvement of a single High Capacity Vehicle. For example, three High Capacity Vehicles replace five standard vehicles. Always have to guard against the counter argument that this drives down freight transport costs and causes a rebound effect – generating more freight movement.

Impact of infrastructure is best done at the vehicle level in two ways. One is road and bridge consumption calculations based upon the loaded reference vehicle and the loaded High Capacity Vehicle. The other is a calculation of road or bridge usage per kg or m^3 of cargo.

Reductions in carbon emissions would be calculated at the vehicle level compared to the reference vehicle based upon carbon or energy used per kg or m^3 of cargo transported.

Finally, a key component in policy making is the ability to measure outcomes in a way that will allow for necessary adjustments to deal with change and unintended consequences such as rebound effect. It is essential therefore that data measurement and analysis be integrated into PBS policy initiatives to provide a means of reconciling and improving policy amid ever-changing conditions.

Regulatory challenges of implementing High Capacity Vehicles

For many years the focus on HCVs has been on engineering matters such as optimizing vehicle dynamic response and verifying compatibility with road geometry at slow speed. More recently, researchers have attempted to calculate the societal value of HCVs operating under advanced policy (Woodrooffe, 2016a). This approach provides an added dimension of justification allowing HCVs to be evaluated in a more balanced and objective way.

Because HCVs tend to be heavier and longer vehicles, they may be easy targets for special interest groups intent on discrediting long combination vehicles (LCVs), sometime based on unsubstantiated safety concerns. There is no doubt that collisions between light and heavy vehicles result in differential safety outcomes, for example a collision between a passenger car and a truck will favour the truck occupants as would a collision between a small car and a sport utility vehicle (SUV) favour SUV occupants. Whether or not these vehicles are loaded or empty, the relative mass and chassis height difference between these colliding vehicles will generate a similar outcome.

Intelligent Transport Systems as an enabler

Intelligent Transport Systems

An intelligent transportation system (ITS) can be defined as "the application of advanced and emerging technologies (computers, sensors, control, communications, and electronic devices) in transportation to save lives, time, money, energy and the environment" (ITS Canada, 2009). The ITS can be categorised into intelligent infrastructure and intelligent vehicles (RITA, 2009).

Information and communication technologies (ICTs) and sensor networks in particular have the potential to contribute to increased efficiency in both freight and passenger transport as well as a potential reduction of overall transportation. On the one hand, increased use of ICTs can avoid freight and passenger transport through a higher degree of virtualisation, digitisation and teleworking. Digital content is delivered electronically and virtual conferences and teleworking reduce passenger transport. On the other hand, increased use of ICTs can contribute to better management of transport routes and traffic, higher safety, time and cost savings as well as reductions of CO_2 emissions.

Telematics as a form of Intelligent Transport Systems

Telematics refers to integrated systems of information, communications and sensors to exchange data and information between vehicles and other locations, including:

- Vehicle to vehicle (V2V) applications
- Vehicle to infrastructure (V2I) applications
- Vehicle to elsewhere (V2X) applications.

The use of telematics and related intelligent technologies is increasingly being used across surface-based transport to improve the mobility of people and freight by improving safety, productivity and efficiency outcomes, including:

- Monitoring and reporting of vehicles and infrastructure
- Providing information to and from vehicles
- Connected and cooperative vehicles
- Automated and autonomous vehicles.

Intelligent Transport Systems and telematics

The opportunities made available through ITS and telematics are enabled by:

- More efficient monitoring of the use of heavy vehicles on the road network.
- Managing the interaction between vehicles, infrastructure and other road users (and associated risks).
- Changing the base-level assumptions infrastructure managers, network managers, road users and other stakeholders hold, by using data collected to create an evidence base.
- Transforming the way policy makers can deploy, monitor and manage heavy vehicle productivity reforms, by introducing new tools which can complement conventional techniques and approaches used by policy makers.

- Introducing new regulatory frameworks which leverage the use of ITS and telematics, including the ability to tailor the right truck to the right road, and/or at the right time, at the right speed, or at the right price.
- The ability to absorb the conservative designs that has been built into some of our infrastructure networks with more integrity and accuracy.

Intelligent Transport Systems as an enabler for productivity reforms

Different heavy vehicle designs have different on-road performance characteristics, which need to be assessed with reference to the infrastructure's capacity. This means that certain heavy vehicle designs are only suitable to operate on designated parts of the road network.

The management of infrastructure and risks is crucial to the management of heavy vehicles and their interaction with infrastructure. In many regions, there is a tiered approach to the management of infrastructure and safety risks:

- General access – where heavy vehicles can operate on all parts of the road network
- Restricted access – where heavy vehicles are approved to operate on specific parts of the road network
- Intelligent access – where heavy vehicles are remotely monitored to provide assurance that infrastructure capacity and safety risks are being managed.

Intelligent Access

In simple terms, the intelligent access approach ensures that 'the right vehicle is on the right road'. Intelligent access involves the use of remote monitoring of vehicles using telematics, to ensure that conditions of access are adhered to by drivers and operators, thereby ensuring that the right truck is on the right road. Policy makers may elect to use intelligent access for heavy vehicles that could pose significant risks to infrastructure and safety if not operated in accordance with the conditions of their approvals.

Intelligent access relies on the monitoring of vehicle operation through the use of telematics. It does so by making possible improved access for heavy vehicles. Intelligent access strikes a balance between industry demands and government responsibilities by creating new ways of using the road network, and new ways of doing business. The rapid advancement in information and communication technologies has made it more cost-effective to monitor and manage higher productivity access arrangements on the road network.

Intelligent access involves the structured interaction between:

- Road infrastructure managers – who grant access entitlements (or conditions) to the road network
- Transport operators – who operate vehicles in accordance with the access entitlements (or conditions) granted by road infrastructure managers
- Technology providers – who monitor the operation of vehicles against the access entitlements (or conditions) granted by road infrastructure managers.

Through these interactions, road infrastructure managers can grant access, or improved access, for transport operators on the road network, whilst governments can better manage the network itself, and better manage infrastructure assets.

Intelligent access provides new ways of enabling productivity reforms, which would not otherwise have been possible. This operating model has been internationally recognised through the International Standards Organisation (ISO) as ISO 15638 – Framework for collaborative Telematics Applications for Regulated commercial freight Vehicles (TARV).

Parallels with Performance Based Systems

There are parallels between Performance Based Standards (PBS) and intelligent access/ISO 15638/TARV, with both focussing on performance based outcomes. That is:

- PBS provides a framework to deliver innovation through performance based outcomes for vehicle design.
- Intelligent access provides a framework to deliver innovation through performance based outcomes for telematics and vehicle monitoring.

Intelligent access should not be viewed as a technology or system, but an operating framework that:

- Enables competition, choice and innovation through an open technology market, by supporting multiple technology providers.
- Provides assurance to all stakeholders that data collected is accurate, secure and can be relied upon for regulatory purposes (thereby enabling road agencies to offer improved road access arrangements).

Enabling productivity reforms through on-board mass

The performance of road freight transport is of importance, with over 75% of non-bulk domestic freight being carried on roads (BIRTE, 2014). However, governments face challenges gaining community acceptance of larger heavy vehicles and funding road infrastructure improvements.

In Australia, the absence of further heavy vehicle productivity enhancing regulatory reform, fleet-wide heavy vehicle average loads are likely to increase by less than 5% between 2010 and 2030 (which contrasts sharply with the 40% growth in average loads over the past two decades) (IA 2016). Productivity growth has been historically recognised as the primary driver of economic growth. Improvements in freight productivity and efficiency reduce the cost of moving freight, adding directly to national economic output – and economic growth.

With the forecast growth in road freight transport over the coming decades, coupled with fiscal constraints which impact on road asset maintenance and capital investment programs, alternative approaches need to be included to complement conventional options considered by policy makers and road asset managers.

In 2016 Infrastructure Australia recognised that

> *"low-cost in-vehicle transponders and satellite tracking are increasingly being used to open up parts of Australia's road network to suitably-specified trucks. Productivity improvements of up to 100 per cent are being realised, and associated reductions in fuel use are cutting emission".* (Australasian Transport News, 2016)

Infrastructure Australia also recognised that

> *"technology is now being used to remotely monitor truck mass, thereby providing assurance to road owners that overloaded vehicles are not damaging their assets. In addition, the technology allows road managers to accredit heavy vehicles to be used on roads that, previously, they would not have been able to use".* (Infrastructure Australia, 2016)

Leveraging the use of vehicle-based monitoring technologies

The collection of location, configuration and mass data from heavy vehicles through telematics and related intelligent technologies can bridge shortcomings in data collection and improve the knowledge of policy makers and asset managers about the utilisation and consumption of road assets.

The use of monitoring technologies which can calculate axle configurations and axle loads (using On-Board Mass (OBM) systems) provide policy makers with opportunities to revisit assumptions made heavy vehicle road use, particularly in relation to bridge utilisation and life-cycle optimisation.

The availability of vehicle location, configuration and mass loading data has led to bridge formulas being revisited in some region, and safety margins being reduced – which has enabled increase mass loadings for vehicles with monitoring technologies.

This represents an ability to 're-engineer' the use of road assets – and an ability to deliver significant productivity gains through heavy vehicle access policy – without defaulting to traditional engineering options/investments in road assets. Coupled with appropriate regulatory frameworks, intelligent access policies can provide the necessary levels of assurance that heavy vehicle operators/hauliers/drivers remain compliant with their conditions of access to the road network. Exception based reporting to identify non-conformances enables regulators to better target their resources to manage the risks of road asset managers.

Package for policy makers: Toolbox and performance metrics

High Capacity Transport (HCT) is not only a question of better and more productive trucks and vehicles. To obtain efficient, safe and sustainable road freight a holistic perspective on the entire transport system is necessary. This "package for policy makers" is designed to provide guidance on a smart and balanced implementation of HCT and by that High Capacity Vehicles (HCVs). ITS as an enabler and Performance Based Standards (PBS) provide a reliable means of ensuring vehicles are safe and compatible with roadways. In addition to these matters, this chapter also includes a discussion on the estimating the societal value of highly productive vehicles so that policy makers can fairly portray the merits of these vehicles to politicians and the public.

HCVs provide an opportunity to improve transport efficiency by increasing the cargo capacity of the vehicle (that is improved mass, volume or both). Research shows that by doing so, fewer truck trips are required per freight task which reduces truck travel, lowers carbon and NOx emissions, reduces fuel use, road and bridge wear and shipping costs. These benefits are critical for health, not only for society and commerce, but also the planet by advancing transport carbon reduction goals. The impacts on infrastructure should be carefully assessed, but are mostly manageable.

The evolution of freight carrying vehicles is evident and a constant throughout time. The past twenty years has seen significant progress in the efficiency, effectiveness and safety of transport networks. HCT represents the natural evolution bringing together HCV supported by PBS with ITS technology (as applicable) to progress to the next stage. To make the vehicles better, they are carefully tuned using PBS to optimise vehicle dynamic characteristics, road and bridge loading and safety performance. Since High Capacity Vehicles are normally in a class by themselves, it is possible to require additional safety technology beyond what standard vehicles are required to have. Rules governing their operation can also require higher levels of driver experience and special driver training. Many HCV programs are selective on vehicle travel by limiting them to certain roads or classes of roads and in some countries, scheduling HCV time of day operation to coincide with off-peak travel especially near urban regions.

To ensure that HCVs provide full benefit and societal value they should be configured to provide maximum benefit for the country or region where they will operate. Because of regional differences, we must expect diversity among vehicles operating in different regions. HCVs are not necessarily represented by one-size-fits-all vehicles, they are sophisticated and intelligent vehicles designed to optimize freight transport addressing regional priorities.

The following is a list of key questions that would be helpful for policy makers when evaluating HCT/HCVs.

Transport system contribution

1. What is the reason for introducing HCVs?
2. What freight segment will the HCV serve?
3. What is the likelihood that the HCV will influence freight flow from a mode other than trucks?

4. What opportunities or threats will HCVs bring to multimodal transport?
5. What is the estimated proportion of the existing fleet that will likely be replaced by HCVs?

Policy, compliance and public outreach

1. What policy instrument is most appropriate for the contemplated HCV system?
2. What role can Performance Based Standards play to ensure that safety and infrastructure compatibility can be achieved?
3. Might any special operational requirements be appropriate for HCVs?
4. Can Intelligent Transport Systems be used to ensure compliance and maximize information and data flow?
5. Is a trial or pilot program warranted?
6. What level of data collection and reporting of the HCV program can be achieved, and how can it be sustained?
7. What type of public outreach is required to objectively inform the public?

Benefits: safety, economic and emissions

1. What are the anticipated savings in heavy goods vehicle journeys?
2. What are the resulting reductions in emissions?
3. What are the estimated safety benefits in terms of reduce travel exposure?
4. What are the global, national, reginal or local benefits associated with the HCVs?
5. What is the infrastructure consumption and the associated costs/benefits associated with HCVs; will they cause more or less damage on the roads, bridges and other infrastructure?

How to implement High Capacity Vehicle programs in a smart and balanced way

The introduction of HCVs requires the support and collaboration of a myriad of stakeholders from industry, transport companies, forwarders and politicians. Having a public figure that acts as an opinion leader or influencer is beneficial. Public opinion on this issue is often emotional and the opinion leader can translate the objective benefits of HCVs into language the general population understands. This can help to counter the biased lobby efforts, which have often created false public perceptions.

Limiting the use of HCVs to specific geographical areas or specific roads can help implementation for two main reasons: the readiness of the infrastructure and lower level of opposition from competing modes. The infrastructure is not always adapted to the technical performance of heavier and longer vehicles. It is hard to transform the whole network, but specific roads may already be usable, or require minimal changes, which is easy to achieve. In specific geographical areas road transport is the only mode of transport; therefore little to no opposition to localised implementation from competing modes of transport can be expected.

The implementation of PBS in South Africa saw a win-win situation for road authorities and industry. These standards helped it to optimise infrastructure use, overcome specific compliance challenges, increase the skills of drivers and vehicle conditions, allow for a self-certification and permit system, and meant that new politicians coming in needed to be briefed again on new technologies and their implications. Australia recognised the link between transport productivity and its global competitiveness of its iron ore industry when they combined HCV with IAP to operate mine to port movement of ore in Western Australia.

Many countries have signed climate change agreements pledging to reduce carbon emissions over the coming years. Implementing HCV programs is one of many options available to policy makers for reducing transport sector carbon emissions. Of the options, it is likely the most cost-effective because it improves transport efficiency while providing significant societal benefits well beyond carbon reduction, including health and safety improvement.

Implementing HCVs as a means to support carbon reduction commitments provides an obvious and almost universal reason for implementing HCV programs. In the 1980s before climate change was apparent or observed, Canada introduced HCVs as a matter of national interest. Being an expansive country with a small population, Canada had to develop a highly efficient transport network to remain competitive and to provide an efficient supply chain for commerce and the population at large. There are also many examples of HCVs that operate within small regions. For example, transporting bulk commodities in from mine site to rail head can provide lower cost transport that can make marginal or remote operations viable and more competitive.

A clear and completing reason is required for the implementation of HCVs. Justification can be based on global, national, regional or local interests.

Trials and pilot programmes

Some countries that have introduced HCVs have done so using pilot programs or trials to provide a period of limited introduction while gathering data on performance. For example, the United Kingdom is currently conducting a trial for longer tractor semitrailers. While the increase in trailer length is modest at only 2.05 m, the length extension provides space for four more pallets of freight increasing the vehicle capacity from 26 to 30 pallets which is 15% improvement in productivity.

The trial includes an independent evaluator that collects data from carriers participating in the programme, conducts analysis of the data and issues annual publicly available documents on the performance of the vehicles operating within the trial. The trial evaluation is configured to answer the following questions.

1. What do operators use longer semi-trailers for and where?
2. What are the savings realised in heavy goods vehicle journeys?
3. What are the resulting reductions in emissions?
4. What about safety; will longer semi-trailers cause more injuries?
5. What about damage and the associated costs; will longer semi-trailers cause more damage on the roads?
6. Might any special operational requirements be appropriate for longer semi-trailers?
7. What proportion of the existing GB fleet of semi-trailers might be replaced by longer semi-trailers, were numbers not restricted?

Using reliable data to answer these seven questions provides an objective means of assessing the value to HCV policy and provides a check to determine if the policy is working and if necessary where policy modifications may be required. Since transportation is an evolving activity, data collection should continue after the trial ends to provide policy makers with objective information on the performance of HCVs. This will help alert policy makers with decision making when conditions change, or innovation reshapes the transportation landscape. An effective way to introduce HCV is through trials coupled with a well-structured independent evaluation study.

High Capacity Vehicle policy options

There are several policy options available for implementing High Capacity Vehicles through size and weight policy, memorandums of understanding or other means. Australia adopted a comprehensive PBS system which for the most part advanced prescriptive regulation. The new policy required major legislative changes at several levels. It is a practical approach for a country without international road freight borders. Canada took a less comprehensive approach and created a prescriptive vehicle envelope system for general access vehicles allowing some flexibility in various vehicle parameters based on sensitivity analysis supported by PBS. For specialised vehicles not defined by the envelope system, design and compliance can be evaluated using PBS. The Canadian Provinces signed a “memorandum of Understanding” defining the new set of vehicles and their weights and dimensions as part of the unified implementation approach. They were able to retain existing size and weight legislations which greatly simplified policy implementation and proved less disruptive. The Australian and Canadian approached to PBS policy represent opposite ends of the spectrum.

Regulatory accommodation

In order to proceed with adopting legislation that permits increase of weights and dimensions of road freight vehicles, a number of conditions need to be satisfied. In addition to support from the road transport industry itself, it is helpful if there is support from the society as a whole.

Stringent enforcement thanks to technological developments, like the use of GPS tracking systems and automated weighing and vehicle measuring technologies, can help to win public and political support. They can reliably ensure that the weight and dimension limitations are not exceeded, and that the vehicles are staying within the designated zones and routes.

Anti-HCV lobbying by competing modes of transport has unquestionably constrained the relaxation of legal limits on truck size and weight. One example of this is the “No Mega Trucks Campaign” sponsored by the rail lobby, (No Mega Trucks Campaign, 2017).

The nature of road infrastructure, in particular the geometrical and mechanical characteristics of roads and bridges, and the maximum gross weight permitted, can also be a limiting factor. Therefore often it may be wiser to limit HCT implementation to specific routes or geographical areas with niche transport markets that can benefit from efficiency increases.

Regulating high productivity limited access vehicles

For very high productivity vehicles that are less common, PBS is often used as a compliance tool to judge acceptability. In some jurisdictions high productivity vehicles operate under special permit programs governed by strict operating conditions. The structure and enforcement mechanisms of the policy engenders a level safety consciousness which far exceeds that found in other vehicle classes. The principal motivating factor for heightened safety performance is related to the special safety requirements and fact that a special permit can easily be revoked for safety performance failure. For example, the special permit system requires that operators be trained to meet and maintain the requirements outlined in the Canadian Trucking Alliance’s Longer Combination Vehicles Driver’s Manual.

Requirements for drivers

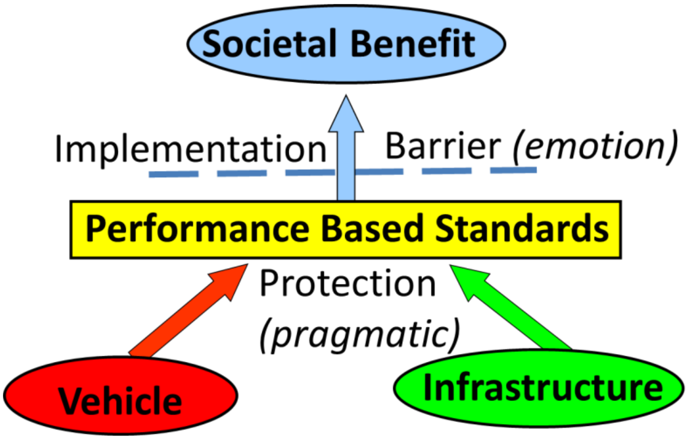
For high productivity vehicles that are less common, that is high productivity vehicles that are outside of the envelopes, PBS is used as a compliance tool to judge acceptability. In most regions high productivity vehicles operate under special driving permit programs governed by strict operating conditions. The structure and enforcement mechanisms of the policy engender a level safety consciousness, which far exceeds that found in other vehicle classes. The principal motivating factor for heightened safety performance is related to the special safety requirements and fact that a special permit can easily be revoked for safety performance failure. The special permit system requires that operators be trained to meet and maintain the requirements outlined in specific documents, such as the Canadian Trucking Alliance’s “Longer Combination Vehicles Driver’s Manual.”

Drivers must obtain an annual certificate verifying that they are in compliance with certain requirements related to the type of license, training, driving experience, physical fitness, and criminal records. Permit conditions also place controls on where these vehicles can operate including hours of operation (time of day), vehicle dimensions such as wheelbase, hitch offset and dolly drawbar length. The policy also contains operational requirements such as adverse weather restrictions, requirements that the vehicles track properly and do not sway, and requirements that vehicles do not cross opposing lanes of traffic unless absolutely necessary.

Resolving societal benefit assessment for public and political consumption

The discussion on societal performance metrics demonstrates how complex the evaluation of societal value can become. Attempts to integrate HCVs into the national fleet are often defeated through emotionally charged campaigns rather than evidence-based argument due to a lack of objective metrics and data to provide substantive support particularly with respect to societal benefit assessment as depicted in Figure 16.

Figure 16. Pictorial model showing a barrier to progressive policy



Source: Woodrooffe (2016b)

When considering the task of informing political and public forums, the message must be highly focused, clear and relatable. This suggests that calculating societal benefit for public consumption should be strategic, having an easily understood message with content that is difficult to dispute. Four main topics for this type of analysis are:

- Safety (fatality, injury and crash reductions from reduced exposure and the implementation of advanced policy governing High Capacity Vehicles).
- Reduced truck travel (reduced equivalent truck trips)
- Impact on infrastructure (roads and bridges)
- Reduced carbon consumption.

Arguments by policy makers are best structured using a reference vehicle with which the High Capacity Vehicle can be compared. The choice of reference vehicle would depend on the freight task. For example, if the candidate High Capacity Vehicle is intended to transport a bulk commodity then the vehicle presently used for transport would be the reference vehicle. If the candidate vehicle were designed for general freight, then the reference vehicle would be the vehicle currently in use for general fright transport. In other words, the reference vehicle would typically be replaced by the High Capacity Vehicle.

The reference vehicle comparative method can be effectively used for all four of the categories listed above.

For safety, the reduced exposure from fewer truck trips can be applied to local crash rate statistics to produce an estimate of safety benefit. This can be expressed as a percent reduction in probability based upon estimates of expected reduced truck travel, or it can be expressed at the single vehicle level in terms of risk reduction. This assumes that the PBS truck will be no riskier than the vehicles it replaced. Experience with the introduction of PBS trucks in several countries supports this assumption. However, there is a danger that poorly crafted policy could result in higher risk vehicles which could diminish or even eliminate benefits.

Progressive well-crafted policy instruments that control high productivity vehicles have proven to be significant contributor to safety. Retrospective analysis of High Capacity Vehicle programs has shown substantial reduction in crash rate. If these data are available and applicable, then they can be added to the safety benefit pool.

Estimates of reduced truck travel from the introduction of High Capacity Vehicles requires estimates of the number of vehicles expected to be commissioned and the load factor at which they will operate. However, it is often difficult to project the number of High Capacity Vehicles that will be introduced so for public consumption it would be more direct to express the truck travel in terms of the efficiency improvement of a single High Capacity Vehicle. For example, three HCVs replace five standard vehicles.

Impact on infrastructure is best achieved at the vehicle level in two ways. One is road and bridge consumption calculations based upon the loaded reference vehicle and the loaded High Capacity Vehicle. The other is a calculation of road and bridge consumption per kg or m^3 of cargo per kilometre. Reduced carbon use would be done at the vehicle level compared to the reference vehicle based upon carbon or energy used per kg or m^3 of cargo transported per kilometre.

A main component to policy making is the ability to measure outcomes in a way that will allow for necessary adjustments to deal with change and unintended consequence. It is essential therefore that ongoing data collection and analysis be integrated into HCV policy initiatives to provide a means of reconciling and improving policy amid ever-changing conditions.

Modal shift

Modal shift is often cited as an argument that suggests that the more productive nature of HCVs will attract freight currently transported by other modes particularly rail and inland or costal water transport. The risk of modal shift will depend on local and regional conditions. The European Commission's Joint Research Centre (JRC) undertook a theoretical sensitivity analysis using Monte Carlo simulation. The salient outcomes of this study were the following (JRC, 2009):

- Overall, average impacts of HCVs were a reduction in rail transport between 1.2% and 1.8%
- Elasticities differed strongly per distance category, with low sensitivity at relatively short distances (<800 km)
- The minimal net welfare gain from the simulations was positive.

Real-world experience appears to support the argument that HCV modal split risk is very low. The Netherlands introduced 60 t HCVs in 2001 compared with regular vehicles having a capacity of 50 t. The number of HCVs operating in the Netherlands has increased substantially from only a few in 2001 to about 1 400 in 2016. Between 2008 and 2011 a research project on HCVs was carried out. Based on a sample of 51 terminals operators, seven shipping companies and about 30 container road freight operators the project concluded that 100% of the freight transported by longer and/or heavier vehicles (LHVs) was taken over from regular trucks, and not from rail and inland waterways.

Most modal split studies focus on independent freight modes and do not consider multimodal scenarios where trucks and railways cooperate. For example, scenarios where trucks deliver goods, usually bulk products, to terminals for transport by rail. Agricultural products often travel by truck from farm coop centres to centralised terminals for rail transport. Using HCVs for the truck section of the transportation chain can benefit both rail and truck modes by improving efficiency and reducing cost. Sustainable freight systems depend on multimodal use which will grow where opportunities exist. It is not an unreasonable expectation that HCVs could bring a net benefit to the railway industry particularly in multimodal transport.

In summary, 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.

Safety

Safety is one of the most important concerns of the society despite the relevant research and experience pointing towards lower safety risks of HCVs in comparison with regular road freight vehicles. The public opinion on HCVs must therefore be taken into account by ensuring high level of regulatory compliance, the presence of safety enhancing technologies on board of vehicles and proper driver training.

HCV safety performance must be formally monitored and the collected safety-relevant data reported. This contributes to objective monitoring of the vehicle performance and development of better evidence based policies for improved HCV safety.

Because HCVs tend to be heavier and longer vehicles, they are easy targets for special interest groups intent on discrediting HCVs usually based on unsubstantiated safety concerns. There is no doubt that collisions between light and heavy vehicles result in differential safety outcomes, for example a collision between a passenger car and a truck will favour the truck occupants as would a collision between a small car and a sport utility vehicle (SUV) favour SUV occupants. Whether or not these vehicles are loaded or empty, the relative mass and chassis height difference between these colliding vehicles will generate a similar outcome.

Infrastructure impacts of High Capacity Vehicles

HCVs are different from standard vehicles in that they are longer, heavier or both. Low density freight requires more cargo space resulting in extended length vehicles. Extending vehicle length beyond designated length limits will mean that such vehicles are not suitable for urban areas because they would have difficulty negotiation intersections and tight radius roadway curves. On the other hand, longer vehicles can operate safely on roadways free from geometric constraints like limited access roads or divided highway networks. PBS analysis is very useful for determining vehicle turning characteristics and their suitability for specific road classification.

High density cargo requires a vehicle capable of increased weight capacity. This is achieved by adding axles to the vehicle ensuring that axle loads are less than those of standard vehicles. Axle weight and configuration is controlled by road authority regulation to protect roads and bridges and HCVs can be configured to comply with these regulations. In addition, PBS can be used to ensure that the heavier vehicles have acceptable vehicle dynamic qualities with good vehicle stability and control characteristics. However, some bridges may not be suitable for HCVs and may require reinforcement.

Intelligent Transport Systems as an enabler

Intelligent transport systems (ITS) are an important and new enabler for high productivity vehicles at many levels including vehicle monitoring, geofencing, compliance assurance infrastructure monitoring and a suite of commercial, contractual and regulatory applications. The following is a set of market principles related to ITS and telematics for heavy vehicles.

Own the outcomes, not the technology

Discussions about road charging reform inevitably lead to consideration of technology even when technology is not raised as a primary policy consideration. This reflects how critical technology is to the successful implementation of cost-effective policy. Technology-enabled reforms work best when the policy outcomes are clearly articulated even though they may not be fully known particularly in transition. As an example, direct road charging mechanisms have already been deployed in some countries proving the viability and success of technology. However, such cost recovery policy has significant political implications that may not be compatible with the public or the political priorities of many jurisdictions. Australia's IAP as an application of the National Telematics Framework is technology agnostic and provides an example.

Adopt a whole-of-government approach

ITS solutions such as telematics should adopt a ‘whole-of-government’ approach, ensuring harmonisation, consistency, interoperability across jurisdictions and industry sectors. Australia’s National Telematics Framework is an example of an open market digital business platform that supports many applications (Transport Certification Australia, 2018). Standalone solutions such as those for road charging developed in isolation and administered separately from other telematics applications have the potential to delay progress, create duplication of effort, stifle innovation and contribute to a fragmented approach to telematics and related intelligent technologies, ultimately increasing cost.

Promote an Open Technology Market by reducing barriers to entry

Crucial to an open technology market is the maintenance of a level playing field that ensures that all technology providers are treated equally and transparently, functional and technical requirements for regulatory telematics applications are met by all technology providers, without inhibiting the ability of providers to differentiate themselves in the market by innovating and competing on price, technology and commercial services. An Open Technology Market of approved providers offers competition and choice (and with functional, technical, operational and legal inter-operability, end-users can move between providers seamlessly). It also ensures scalability, sustainability and flexibility into the future and fosters competition, choice and innovation. The efficient operation of any well-functioning market is derived from administrative practices and business rules which provide guidance and confidence to all stakeholders.

Establish clear institutional, legislative and operational separation of roles and responsibilities

There should be clear governance arrangements assigned through institutional, legislative and operational roles and responsibilities between different parties, to articulate the function, powers, duties and obligations allocated between policy makers, administrators, technology providers, end-users and other stakeholders/entities which may be incorporated into policy deployment models.

Advice for policy makers when considering ITS and telematics for heavy vehicle reforms

The use of ITS and telematics with heavy vehicle reform has proven successful in Australia. Defining the problem and communicating the desired outcomes is seen as an important first step in garnering support. The development of innovative reforms which harness the use of technologies that respond to current and emerging public policy challenges is the primary goal. It is wise to deploy small-scale pilots with supportive stakeholders to demonstrate possibilities, and to inform policy thinking. It is also important to collaborate with stakeholders when developing new initiatives involving the use of technology.

Policy makers should avoid focusing only on technology. It is better to adopt a holistic approach to reforms that depend on technology. Quite often technologies ‘looking for a problem to solve’ usually fail to achieve success. As do ‘single-use’ or ‘stand-alone’ technologies that are not interoperable. Technologies that have proprietary lock-ins and lock-outs can inhibit operational flexibility and future policy reforms. As with all legislation, prescribing specific types of technologies should be avoided.

Policy maker toolbox

The following is a provisional list of essential tools for use by policy makers interested in introduction and implementation of HCT/HCVs, including the use of PBS.

Metrics and Definitions

- A set of standard analysis methods, metrics and criteria definitions. These definitions should be broad enough to include vehicle definitions including Performance-Based Standards (PBS), Smart Infrastructure Access Policy (SIAP) criteria, methodology, models, data and cost benefit analysis.
- Defining productivity gains as well as carbon and fuel reduction in terms of the vehicle and transport system with focus on vehicle configuration.
- The ability to evaluate innovative solutions and benchmark performance under common definition. Policy should encourage innovation – PBS helps ensure that new ideas can be evaluated outside of prescriptive regulation which often inhibits innovation.

Evaluation Methods

- A method for case evaluation is crucial to clearly evaluate and communicate benefits, risks and how to protect stakeholders from unintended consequences.
- Infrastructure analysis methods are required to determine the impact of policy options on pavements and bridges.
- Methods for evaluating the compatibility of heavy goods vehicles and the transport system at large (modal shift and modal choice) is needed. Each jurisdiction may have unique requirements.

Policy Questions

- Assessment of various policy options- regulatory instruments including special permit approach.
- Standard compliance options including ongoing data collection evaluation, policy fine tuning and evaluation of unintended consequences. Such policy lives on a continuum therefore it is important to continuously monitor how effective policy is over time and make needed adjustments.
- Regional exceptions – Nordic climate considerations, and third world realities that influence policy options. (Compiling a list of exceptions to accommodate regional and climatic difference will be an important component of the toolbox.)

Outreach

- Public education and assessment of political risk (Can this method be universal and formulaic?)
- Safety impact and societal benefits (This is a critical step needed to inform policy makers and the public. Having a blue print method would be very helpful.)
- Stakeholder champions are beneficial to ensure ownership and engagement.

- Media relations- The softer elements of how to strategically work with policy makers and politicians to ensure among other things that factual information is used in decisions. Framing of the argument and language use are critical components of the communication strategy.

One of the key principals of size and weight regulation is that a single unified policy approach domestically or internationally is in most cases not practical. Issues such as geographic terrain, local transportation priorities, population density and road quality will influence policy details. However, the definition of performance measures and the methods of calculation or measurement can have universal application. What varies from jurisdiction to jurisdiction are the pass/fail criteria and the applicability of certain metrics.

Addressing frequently asked questions about HCVs

HCVs are not always well understood by the public or politicians. The following list of questions and answers address common misperceptions of HCVs. They are intended to provide an objective view given the context of assumptions surrounding these vehicles.

What is a High Capacity Vehicle (HCV)?

A High Capacity Vehicle (HCV) is a vehicle specifically designed to carry more freight than standard vehicles. The freight can be heavier or require more cargo space or both.

Are HCVs less safe than normal trucks?

Experience has shown that HCVs have better safety performance than standard vehicles. This improvement is attributed to better vehicle dynamic characteristics, policy requiring additional safety technology, better management practices, use on the main (and safest) road network, and better driver qualification requirements.

Do HCVs cause more road and bridge damage than normal trucks?

With lower axle weights and optimised axle configuration controlled by road authority regulation, pavements are generally less stressed by HCVs than by standard vehicles. Short span bridges (below 20-30 m) are not affected because the HCV length is close to or even exceeds the span length. However, longer span length bridges may be affected by HCVs, above all if their gross weights significantly exceed the standard limits without length increase. Steel and composite bridges may be affected in terms of fatigue, thus some accurate assessments should be made.

Must High Capacity Vehicles comply with road bridge loading regulation designed to protect the infrastructure?

All vehicles including HCVs must comply with weight regulations. However, as with all vehicles, HCVs should also comply with bridge formula design standards which limit the gross weight or axle group load depending on the vehicle length, axle spacing and number, and with fatigue rules.

Will HCVs run on all roads and will they add to city congestion?

HCVs are designed to operate in specific areas. Some are only compatible with limited access and the divided highway network. Others can be used in urban areas. Regulations governing HCVs can specify time of day operation which can prevent them from operating in urban areas during rush hour thereby reducing congestion.

Do HCVs discourage freight from travelling on railways and barges?

Most studies have shown that HCVs attract little to no freight from railways and barges. This may be because the freight that HCVs typically carry is not well suited to other modes of transport. Studies confirm that HCVs attract considerable freight from smaller trucks which reduces the overall number of truck trips providing substantial societal benefit.

Are HCVs environmentally friendly vehicles?

Because HCVs are more efficient and productive vehicles, they use less fuel and produce less emissions per unit of cargo transported. This makes them more environmentally friendly than standard trucks.

Will HCVs help meet carbon reduction targets?

Policies providing for use of HCVs are one of the most practical ways to reduce carbon emissions. It has been shown that HCVs can reduce carbon emission in the range of 15% to 40% depending on the vehicle configuration. Even when diesel energy is replaced with biofuels, hydrogen or electricity, the energy savings achieved with HCVs has an impact on the indirect CO_2 emissions.

Truck size and weight policy provides significant opportunities to improve safety, and transport productivity while preserving the road and bridge infrastructure. It is one of the most effective means of reducing the carbon footprint of road freight transportation. It is recognised that such policy must be flexible given the geographic differences, regional needs and priorities of particular jurisdictions. Such policy does not suit one-size-fits-all even within countries. The elements contained in this toolbox are intended to provide insight and options for creating progressive transport policy with high societal benefit.

Conclusions

The purpose of this study was to examine the international landscape of High Capacity Transport with a focus on longer and or heavier road transport vehicles. Several countries have introduced HCV systems with policies that promote the blending of improved road freight productivity and safety together. It is no longer sufficient to focus on productivity alone. Experience has shown that with well-crafted policy instruments, HCVs can also bring significant benefits to safety and society, including reduced fuel use and carbon emissions per unit cargo transported, without any significant additional stress to infrastructure, or with a manageable and affordable reinforcement programme or limitation of routes.

The transport sector is currently facing two big challenges:

1. The ongoing growth in trade and the related increase in transport demand, especially land-based transport.
2. Climate change. Scientific literature and government reports make clear that climate change is accelerating, and that truck transport now represents the largest contributor of CO_2 emissions from freight within the transport sector.

This study has found that HCVs provide a cost effective and rapid means for reducing carbon emissions with no or limited modification to road infrastructure. Experience from countries with HCVs has been positive with minimal disruption. HCVs were initially introduced in Canada in 1986 as part of truck size and weight reform. It is a vast country with relatively low population density that requires efficient transport. Consequently, policy makers framed the HCV initiative as being in the "National Interest". More recently several countries have implemented HCV policies that are proving to be very effective at improving transport efficiency and reducing carbon emissions at a time when governments are attempting to honour international climate change agreements.

Most countries have a strategy to move freight from road to rail, but currently the railways lack the capacity to absorb significantly more freight. This study found cases where HCVs complement and extend the market for rail transport instead of competing directly with rail. With or without HCVs, road transport will continue to dominate freight transportation for the foreseeable future. To make road transport more sustainable it must be made efficient at the vehicle level.

Potential benefits and risks

Based not only on the fact that HCVs can consolidate freight from smaller less productive trucks, the study found HCVs have a strong potential in the following areas:

- Decarbonisation – the reduction of CO_2 emission per unit of freight is between 15% and 40%, depending on many factors discussed in this report.
- Cost reduction and higher productivity – HCVs make drivers and trucks more productive because two or three drivers and trucks may carry as much goods as three or five standard vehicles.

- Congestion mitigation – the reduction by one-third to two-fifths of the number of trucks required when using HCVs, assuming that 15% of standard vehicles are replaced by HCVs, means that the total truck volume could be reduced by 5-6%, reducing congestion. For example, Australia developed and implemented a number of HCV solutions that have absorbed the annual increase of transportation demand of about 5% over the past ten years.

The work documented in this report has focused primarily on three important areas; modal shift, safety and bridges, which are often seen as barriers to the implementation of HCVs. The greatest potential risk facing HCVs is careless implementation without carefully crafted policy to guide their use, specify road access conditions, and ensure that the vehicles comply with weight and dimension limits and satisfy dynamic vehicle requirements defined by Performance Based Standards (PBS). The study found that PBS are an effective means of objectively assessing vehicle design and regulatory compliance, ensuring the HCVs bring maximum societal benefit.

Modal shift

The investigation shows that in most cases there is little evidence to suggest that HCVs cause significant modal shift from rail to road. There is, however, strong evidence that HCVs replace smaller, less efficient trucks in segments of the market with intensively trafficked routes, which is one of the goals of HCV systems.

There is also evidence that HCVs can benefit railways in intermodal transport. Integration of railways and trucks is most apparent in intermodal freight which is a cooperative arrangement between modes. With trucks and railways working together intermodal freight tends to optimize transport efficiency. Some intermodal freight operations can benefit significantly from larger more efficient HCVs supplying the railways with bulk commodities and packaged freight for longer distance railway transport. Land-based transport is a multimodal system and each mode contributes to overall transport efficiency. To do this successfully, each mode must be optimised within the transport equation and cooperate in freight movement ensuring that system wide transport efficiency is realised, and that freight can be moved with minimal societal and global cost.

Safety

Safety is one of the most important public concerns regarding HCVs. The size of trucks makes them appear to present much more of a risk to road safety than revealed by crash data. These fears are easily exploited when longer and heavier vehicles are considered. All relevant data, research, trails and experience over many years and from many countries show that the safety risk of well-regulated HCVs is lower than standard trucks.

Nevertheless, public perception must be taken seriously and measures to increase safety should be taken, including a requirement for crash avoidance technology and special driver requirements, including experience and training. Such safety enhancement programmes specifically tailored to HCVs are discussed in this report. It is also important to formally monitor HCV safety performance by collecting and reporting data relevant to safety. Such data collection and reporting efforts should continue so that performance can be objectively monitored and if necessary, policies can be modified based on evidence.

Bridges and roads

Bridge and road wear vary significantly with changes to gross vehicle or axle weights. Bridges are mainly sensitive to gross vehicle mass (GVM) and axle loads of the vehicle. When implementing HCVs with higher gross weight, the wheelbase (spacing between the first and last axles) and the number of axles should increase proportionately with the gross vehicle weight. Special attention should be paid to fatigue of steel and composite bridges.

When assessing the influence of HCVs on infrastructure consumption, it is important to use a freight-t-km basis as opposed to a per vehicle basis given that infrastructure life is dependent in part on cumulative truck travel. The more efficient the transportation network becomes, the fewer truck trips are required and the less impact there is on the infrastructure.

Most countries maintain detailed bridge inventories and conduct regular bridge inspections to monitor bridge condition. One of the main considerations of truck size and weight policy is bridge strength. Axle weight and spacing and gross vehicle weight are specified and controlled to be compatible with bridge structures. Bridge strength is a fundamental underpinning of any transport system and each country will consciously choose a design strength limit that is best for its transport needs. Therefore any vehicle, including HCVs, operating on a given road network must comply with such requirements.

Where weak bridges represent bottlenecks, On-Board Mass or Weigh in motion system monitoring have proven effective in Australia and in other countries, in combination with an Intelligent Access Programme (IAP). By confirming weight compliance of all vehicles passing over a bridge it is possible to eliminate overweight vehicles and reduce risks to the infrastructure.

Infrastructure access, monitoring, compliance and enforcement

Free and unrestricted use of longer and heavier vehicles on public roads is most often not an option despite the benefits that they bring to society and the industry. The vehicles´ presence and movements must be monitored and managed in an efficient way.

Experience from Australia and other countries should be used to deploy ICT-based solutions like the Intelligent Access Program, with data collected from vehicles to monitor position, status and compliance in real time. The experience accumulated already with this system will also help develop solutions needed in the future for self-driving trucks.

Advice for implementation

An effective and proven approach to ensuring balanced policy for deployment of HCVs is through trials coupled with independent evaluation studies. The “package for policy makers” in this report outlines the policy recommended approach to implementation and to messaging on HCV programs. While there are great differences between countries and between regions within countries, many issues pertaining to road freight transportation are similar. Lessons learned from experience in the countries that have introduced HVCs can be extremely useful for other countries.

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Annex 1. Typical High Capacity Vehicle combinations

HCV combinations differ globally. The listed combinations below are not the maximum permissible combinations by law, but rather a selection of some commonly used combinations. These HCV schemes are usually not country-wide. They are typically permit-based, which means that the vehicles are adapted to the infrastructure characteristics and particular business needs. The permits are issued to individual companies for use on specific routes or zones and for vehicle combinations subject to particular weight and axle load restrictions.

Argentina

In Argentina the trials of HCVs had been delayed due to opposition by truck owner associations since 2014, when it was planned to allow b-trains of up to 75t and 30.25m in length to operate in specific corridors. In January 2018, following negotiations with the associations, a new decree authorising b-trains came into force. The first national trial with a 75t 25.5m b-train started in January 2018, Figure 17.

Figure 17. First national trial in Argentina

Note: This is a b-train, 75t 25.5m

Source: Ministerio de Transporte (2018)

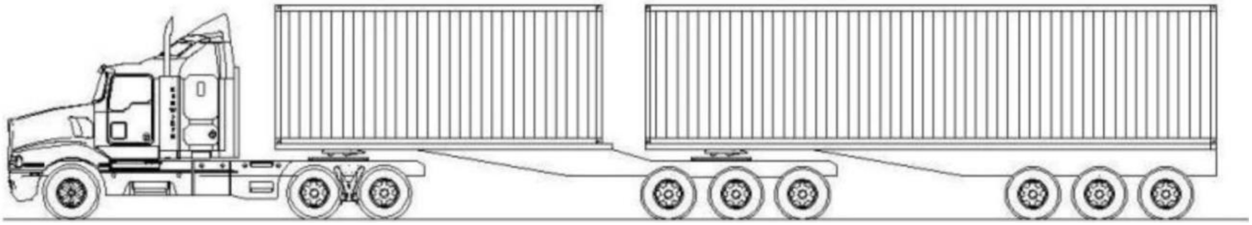
Australia

In Australia there is an important distinction between *general access road freight vehicles*, which comply with mass and dimension requirements and do not require a notice or permit to operate on the road network, and restricted access vehicles that can only be operated with a notice or permit allowing them to operate under higher mass limits on particular roads. According to the Heavy Vehicle National Law, freight carrying vehicles are included in the Class 1, 2 and 3 heavy vehicles categories. Oversize and over mass vehicles are in Class 1 and fall out of scope of this investigation.

Class 2 vehicles include such general access vehicles as B-doubles, B-triples, Road Trains, Vehicle carriers, Livestock vehicles and Performance-Based Standards vehicles. Freight carrying vehicles that are longer than 19 m are limited to specially designated road networks, but if such networks do not exist where the vehicle would be used, the operator has to apply for a permit.

An example of Class 2 combination is B-double, see Figure 18. It consists of a prime mover towing two semitrailers. It must comply with prescribed mass and dimension requirements (maximum length 26m, and maximum mass 62.5t-68t depending on accreditation).

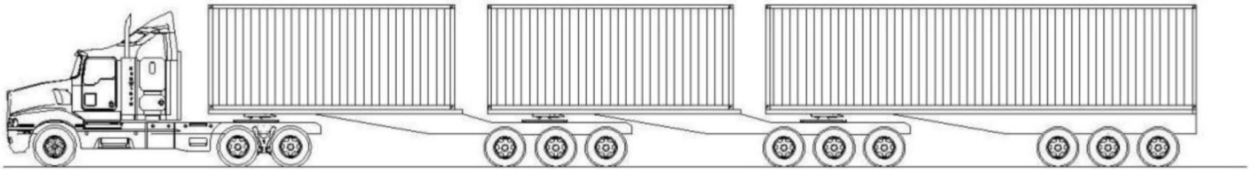
Figure 18. Typical 9-axle B-double (other axle combinations are possible)



Source: National Heavy Vehicle Regulator (2014)

Another example, B-triples, shown in Figure 19, are categorised as road trains and must also comply with prescribed mass and dimension requirements (maximum length 36.5m, and maximum mass 82.5t – 90.5t depending on accreditation).

Figure 19. 12-axle B-triple

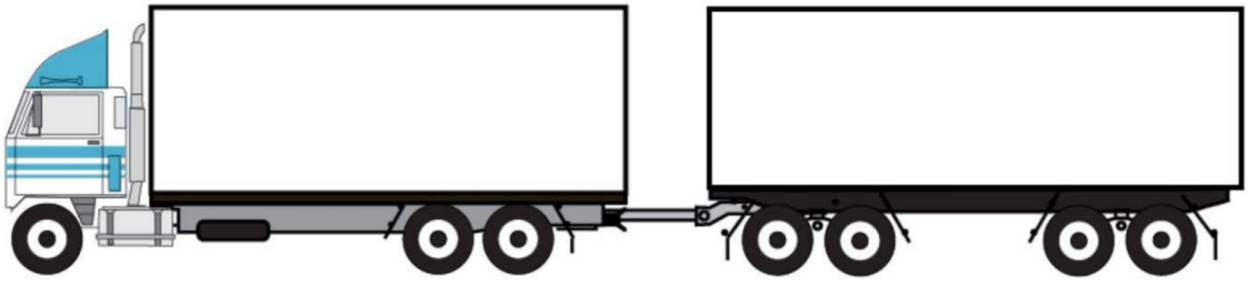


Source: National Heavy Vehicle Regulator (2014)

The largest of the Class 2 road trains can have up to four trailers, reach the length of 53m and have a mass of 130t.

Class 3 vehicles are those that when loaded exceed the prescribed mass or dimension limits and are not Class 1 vehicles. A truck and dog trailer (an Australian term for drawbar trailer) combination consisting of a rigid truck with 3 or 4 axles towing a dog trailer with 3 or 4 axles weighing more than 42.5t is an example of a class 3 heavy vehicle, see Figure 20. Other examples include a B-double or road train transporting a load wider than 2.5m.

Figure 20. Truck and dog trailer combination over 42.5 tonnes

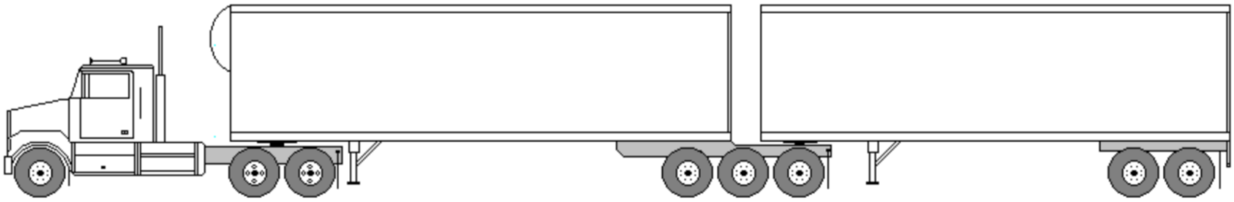


Source: National Heavy Vehicle Regulator (2017)

Canada

B Train Double is a vehicle combination, which can reach a maximum length of 27.5m and the maximum weight limit range of 40 700 kg - 62 500 kg if the vehicle has five to eight axles respectively, see Figure 21.

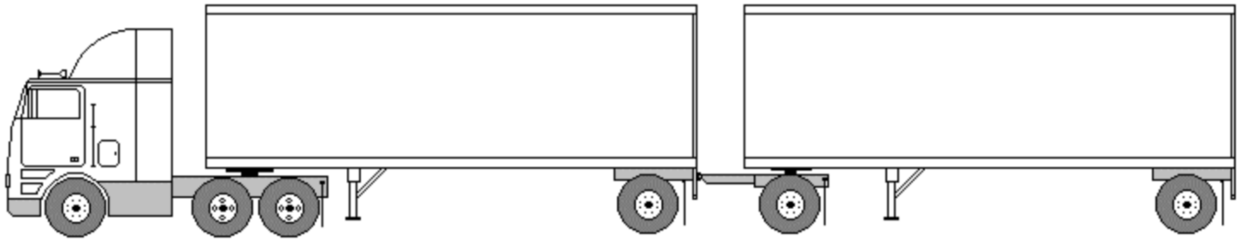
Figure 21. Canadian B Train Double, eight axles



Source: Task Force on Vehicle Weights and Dimensions Policy (2014)

A Train Double and C Train Double are vehicle combinations that can reach maximum of 25m and 53 500 kg or 58 500 kg weight respectively. These combinations are very similar. The difference between A and C combination is that instead of one pintle hook between the trailers in A combination, there are two in C combination. This removes one of the points of articulation from the unit, and makes the second trailer much more stable. However, it also makes it a lot harder to hook the dolly to the lead trailer, and the tyres on the dolly will wear much more quickly from going around corners (Jakubicek, 2014).

Figure 22. Canadian A or C Train Double

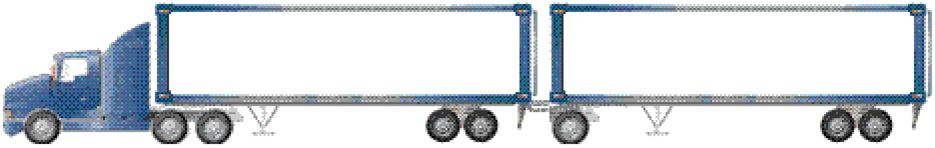


Source: (Task Force on Vehicle Weights and Dimensions Policy, 2014)

Mexico

In Mexico the truck vehicle weight and dimension regulation allows road freight vehicle combinations of up to 66.5t weight and 31m in length to be operated, depending on the type or road network that the vehicle is used on. The weight limits have been lowered in recent years. The weight and dimension limitation on lower categories of roads is lower (Secretaría de Comunicaciones y Transportes, 2014).

Figure 23. Common 8-axle full double semitrailer combination



Notes: up to 31m long, up to 63t

Source: (transporte.mx, 2015)

HCVs in Mexico operate subject to permits, which specify weights and dimensions limits, routes, driver qualifications, operating requirements (speed, lane selection, following distance), (Moore, Regehr and Rempel, 2014).

New Zealand

In May 2010 the Land Transport Rule, Vehicle Dimensions and Mass Amendment 2010 came into effect allowing the introduction of High Productivity Motor Vehicles (HPMVs), (de Pont, Hutchinson and Smith, 2018). The amendment specified no upper limit for overall length or gross combination weight for these HPMVs. It simply required that they should be able to operate safely and that the infrastructure should be able to accommodate them. In practice the upper limit for length has become 23m although a few trial vehicles are operating at up to 25m. The gross combination weight is constrained by the bridge formula with the maximum achievable level being 61 t but most vehicles being limited to 58 t or 59 t.

The most common combinations of High Productivity Motor Vehicles (HPMVs) are:

- 8-axle rigid truck and trailer (4-axle rigid truck towing 4-axle trailer)
- 9-axle rigid truck and trailer (4-axle rigid truck towing 5-axle trailer)
- 8-axle B-train (3-axle tractor towing a 3-axle and a 2-axle semi-trailer)
- 9-axle B-train (3-axle tractor towing two 3-axle semi-trailers)
- 23m truck and simple trailer (car transporter restricted weight).

Initially these vehicles could operate with general access at the standard legal maximum weight (44 t) and at higher weights on approved routes. In 2013, the 50MAX concept was introduced where the 9-axle combinations could operate on an extended set of approved routes at 50 t. The basis of the 50MAX concept is that 9-axle vehicles at 50 t will generate no more pavement wear than the standard 44 t 7-axle and 8-axle combinations. This argument was used to persuade the local road controlling authorities to allow higher weight vehicles on their roads. The 50MAX network is now virtually general access with some specific exclusions.

Currently more than half of the combination vehicle fleet operate at either 50MAX or full HPMVs. Because of the 50MAX requirements most of these vehicles are 9-axle combinations. These can reach gross weights of 50 t across nearly all of the network and up to 61 t on the HPMV network illustrated in Figure 24.

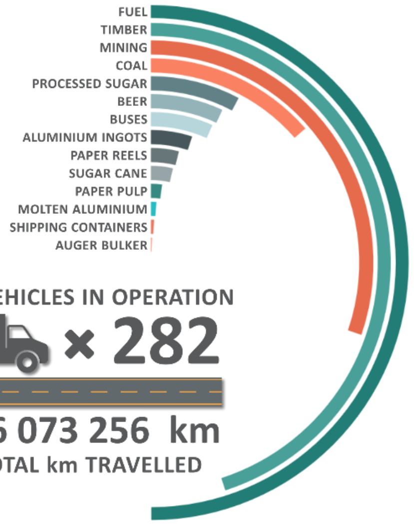
Figure 24. New Zealand High Productivity Freight Network, 5469 km, August 2017

Source: NZ Transport Agency (2017)

South Africa

South Africa's PBS pilot project was initiated in 2004 by a committee consisting of representatives from national and provincial Departments of Transport, industry, the Council of Scientific and Industrial Research (CSIR) and other stakeholders. The committee recommended that in order to ensure acceptable levels of compliance, operators participating in the pilot project should be certified through the Road Transport Management System (RTMS), a self-regulation accreditation scheme based on the national standard SANS 1395. The introduction of self-regulation was also intended to be part of a comprehensive long-term solution – a scheme whereby initiatives are implemented by industry to establish sound vehicle management practices. The rules and performance standards of the Australian PBS scheme were adopted as the benchmark upon which to build the South African PBS scheme. The resulting framework defined how vehicle designs should be assessed and the performance standards against which they should be evaluated. It also defined the classification of road networks, the formulation of a practical approval process, the definition of monitoring and control requirements, and the formulation of a legislative framework under which PBS might be formally adopted. The first two PBS vehicles were commissioned at the end of 2007 in the timber industry. As of June 2018, data for over 136 million km of PBS truck travel had been collected. Each vehicle is systematically monitored, with data being collated and studied by the CSIR and its project partners. This allows researchers to objectively evaluate the project impact and determine whether or not PBS could help solve South Africa's pressing logistical issues. Monitoring data from the demonstration vehicles have given researchers an insight into key metrics such as fuel consumed, emissions generated and kilometres travelled, but also record incidents, crashes and violations that have occurred. Monitoring data have also been collected for 'baseline' vehicles for comparison: conventional vehicles from the same fleet adhering to normal mass and dimension limits performing the same freight task. By June 2018, the number of PBS vehicles had increased to 282, transporting a variety of products as indicated in Figure 25. Monitoring results based on the first 136 million km are summarised in Figure 26, (de Saxe, Nordengen and Berman, 2018).

Figure 25. Summary of commodities transported by Performance Based Standards vehicles: South African project



Source: Nordengen et al.(2018)

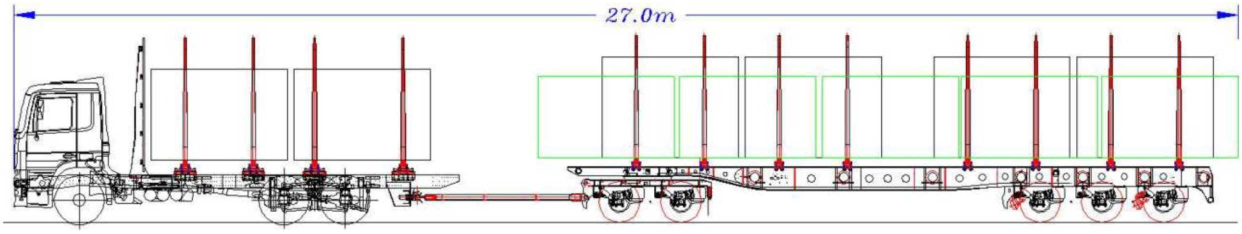
Figure 26. Summary of benefits measured in the South African Performance Based Standards pilot project after 136 million vehicle kilometres

Note: Statistics are reported as at June 2018
* Fuel at R14.19 per litre

Source: Nordengen et al. (2018)

South African Level 1 and Level 2 PBS vehicles range in length from 18.6 m to 30.0 m with combination masses ranging from 56.8 t to 82 t. There also Level 3 and Level 4 PBS vehicles operating either in remote areas or on private mines. These vehicle combinations are up to 42.8 m in length and 185 t combination mass. (Nordengen, 2016).

Figure 27. South African Performance Based Standards vehicle with 67.5 t combination mass



Source: Nordengen, Prem and Mai (2013)

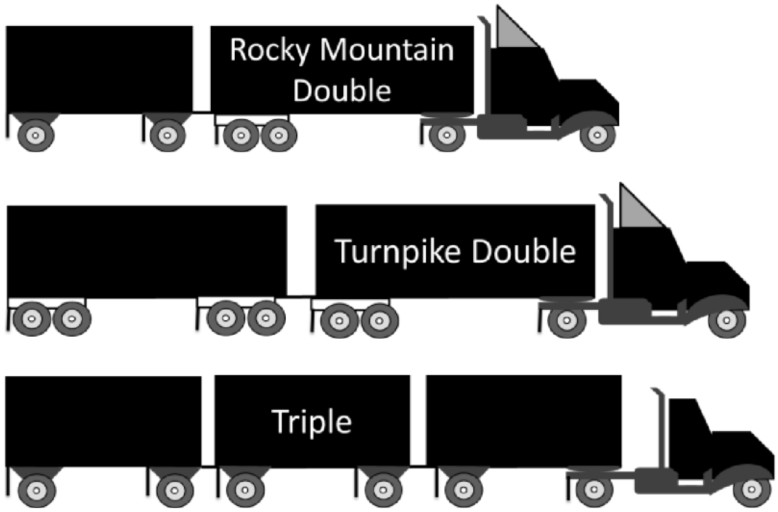
The United States

In the United States truck size and weight regulation is a blend of federal and state regulations and laws. Federal weight limit is 80 000 lbs (36 287kg) gross vehicle weight with up to 20 000 lbs on a single axle and 34 000 lbs on a tandem axle group.

Conventional Class 8 trucks are those vehicles that exceed gross vehicle weight of 33 thousand lb (14 969kg). A combination vehicle usually consists of the tractor unit with typically two or three axles and a trailer usually having tandem axles in the rear with dual wheels. The typical cargo carrying unit of a tractor-semitrailer combination can vary in length from 40 ft to 53 ft, with a few states allowing semitrailers of up to 59 ft.

Long combination vehicles (LCVs) are a subset of combination vehicles that can only operate in certain states, where they are allowed to exceed 80 000 lbs (36 287 kg). The LCVs are three- and four-unit combinations that use at least one full-length trailer in the combination (up to 48 ft) or three shorter trailers. The three common LCV types are in operation across the United States, see Figure 28.

Figure 28. Common LCVs in operation across the United States

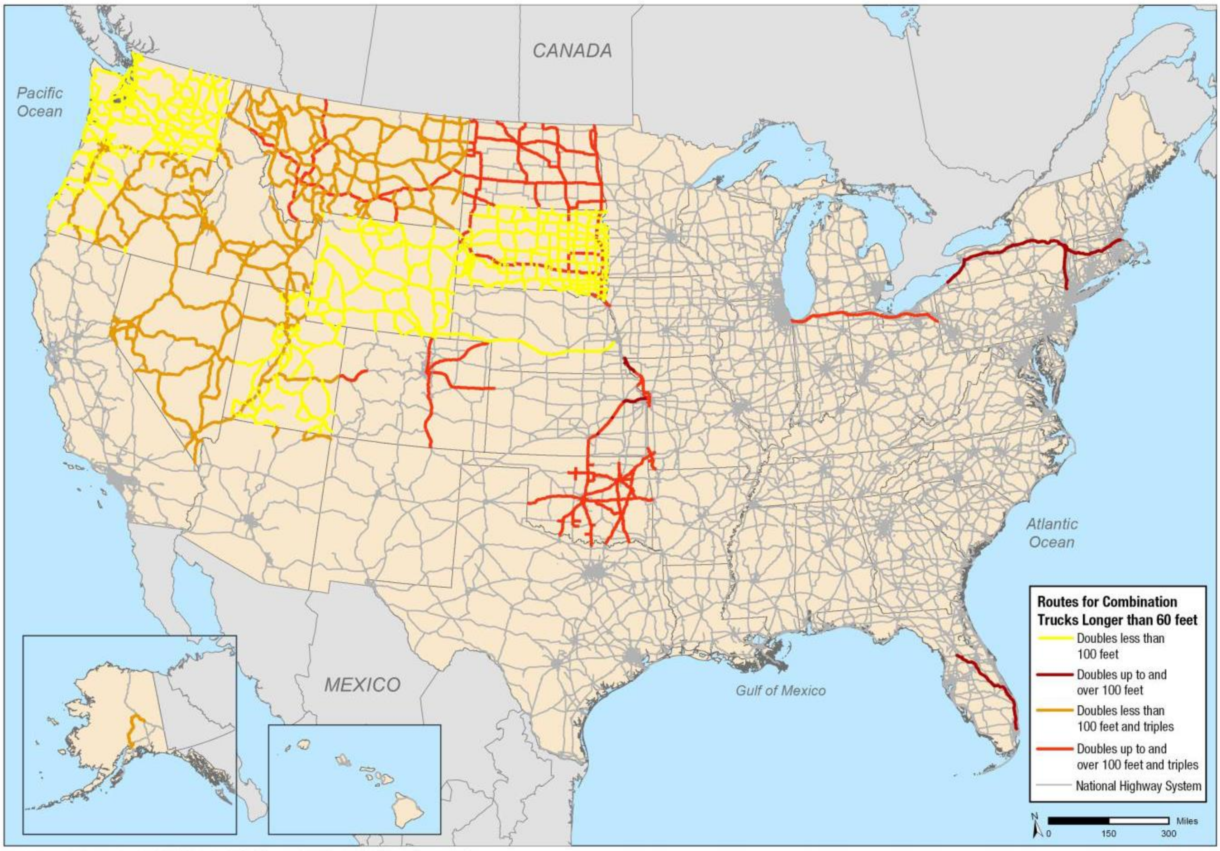


Source: Federal Highway Administration (2015)

- Rocky Mountain Doubles – a tractor with two trailers: a long front trailer (usually 48 ft.) followed by a shorter second trailer
- Turnpike Doubles – a tractor and two long (usually 48 ft. each) trailers
- Triples – a tractor and three short trailers.

LCVs are allowed in 23 states, but in six states they are allowed to operate only on turnpike facilities, which are toll roads in the U.S. The Intermodal Surface Transportation Efficiency Act, passed in 1991, prohibits all States from expanding these routes, shown in Figure 29, or removing restrictions on LCVs.

Figure 29. Permitted Longer Combination Vehicles on the United States National Highway System



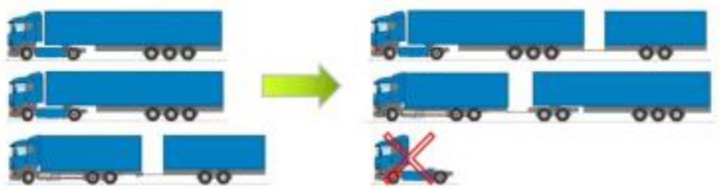
Notes: Empty triples are allowed on I-80 in Nebraska. NHS mileage as of 2011, prior to MAP-21 system expansion.

Source: Federal Highway Administration (2015)

European Modular System

The European Union Directive 96/53/EC, introduced in 1996, established the European Modular System (EMS), which attempts to standardise the dimensions and weights of trucks on a modular basis. Within EMS a maximum length of 25.25m and maximum weight of 60 t are typically used, though these limits are not specified in the Directive. The limits of EMS combinations are decided by the several member states in specific applications but could be increased if individual members states so decide (under the condition that European Loading Units are used).The advantage of EMS is that it creates flexibility in the adaptation of vehicles to different situations and permits the use of longer combinations when possible, and shorter ones when local conditions or logistical requirements dictate, see Figure 30.

Figure 30. European Modular System



Source: Serena (2016)

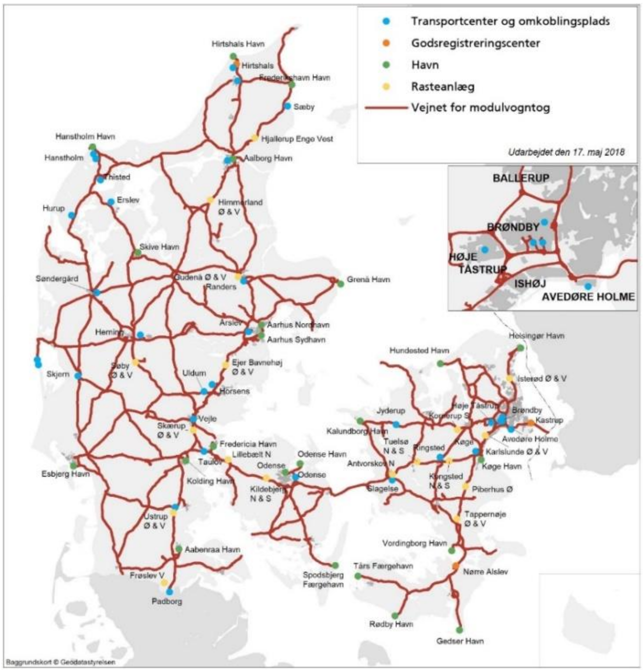
Larger vehicles have been used in Finland and Sweden even before the introduction of first length limits at the end of 1960s. It was when these countries applied for membership of the European Union in the early 1990s, that the EMS concept was developed as a compromise to allow them to keep the larger vehicles, but using the standardised European Union modules. The 1996 Directive also granted other European Union member the right to increase truck size and weight in accordance with the EMS system. Since then several other countries have trialled EMS-compliant HCVs (Netherlands, Germany, Denmark and Spain) and approved them for general use.

EMS trial in Denmark

The Danish trial for using EMS started in 2008 on a very limited road network of approximately 1 000 km state roads and 10 km local roads. It connected a total of 36 areas (private companies, harbours, logistic centres etc.). Since 2008 the trial has been extended and prolonged twice. The current trial will run until 2030, though has become nation-wide.

By 2018, almost all the state roads have been made accessible for EMS trucks. So in total, approximately 4 200 km state roads, and 585 km local roads, are connecting a total of 240 areas (private companies, harbours, logistic centres etc.), see Figure 31.

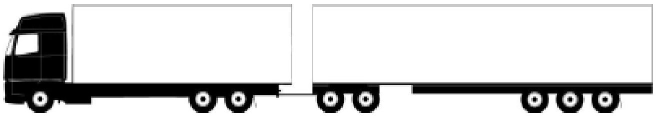
Figure 31. Danish EMS road network

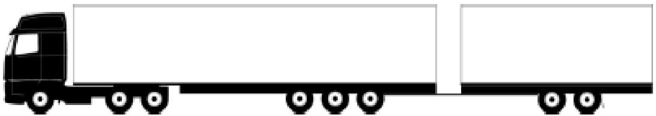


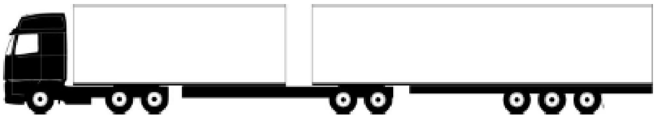
Source: The Danish Road Directorate (2018a)

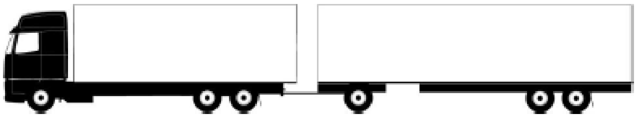
EMS vehicles in Denmark can reach 25.25 m with total mass up to 60 t – max 10 t per axle. The four truck configurations shown in Figure are allowed.

Figure 32. EMS vehicles in Denmark


Type 1: Truck and semi-trailer with dolly unit


Type 2: Tractor with ordinary semi-trailer and centre axle trailer


Type 3: Tractor with link trailer and ordinary semi-trailer


Type 4: Truck with long trailer

Type 3 has dictated the dimensions of the reconstructions carried out on the EMS road network.

Source: The Danish Road Directorate (2018b)

The implementation of the Danish EMS-trial is characterised by the fact that a large number of crossings and roundabouts have been rebuilt or adjusted to make the roads accessible for EMS trucks. Type 3 trucks have been the defining dimension.

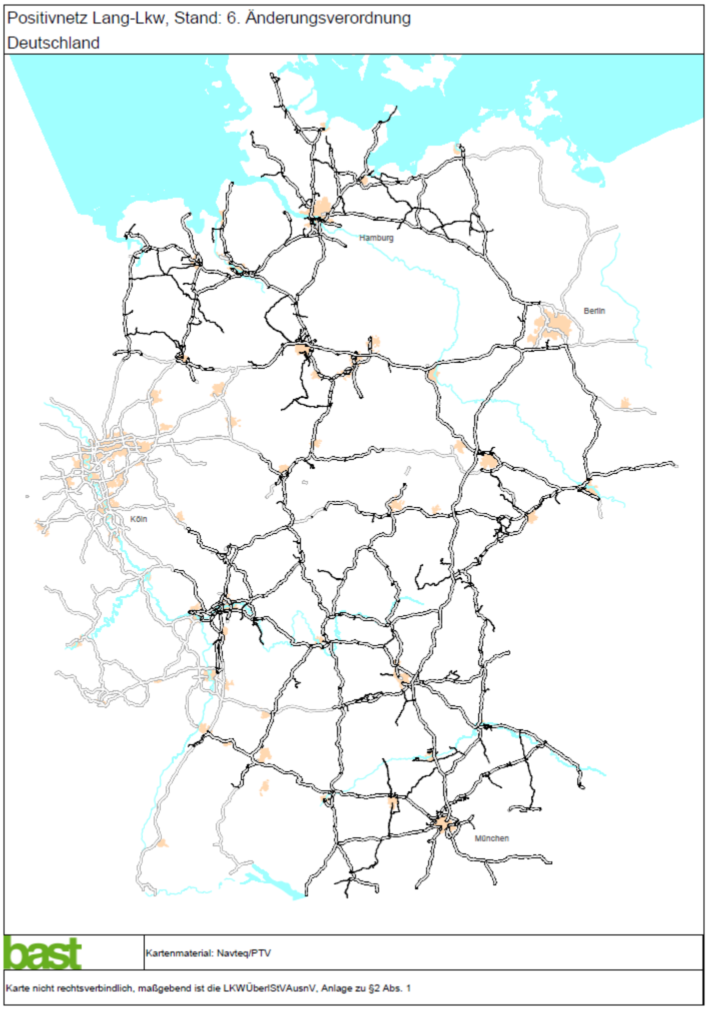
The necessary adjustments, stipulated by the Danish Road Directorate and the local police, are financed by the government on state roads, and by private companies or municipalities on the local roads.

Longer trucks trial in Germany

In Germany the Federal Government carried out a field test of longer trucks from 2012 to 2016, which was legally based on exceptions to road traffic regulations, which allowed the use of articulated trucks up to a total length of 17.80 m. The weight restrictions for these HCVs remained unchanged and they are not allowed to exceed 40 t, or 44 t in combined transport operations.

The road network for the trial was limited, because some federal states refuse the operation of longer trucks, and had a total length of almost 11 600 km, of which around 70% are federal motorways. This is equivalent to just over 60% of all federal motorways in Germany, see Figure 33.

Figure 33. Authorised network for trial



Source: Federal Highway Research Institute (BASt) (2016)

Following the trial, HCVs can continue operation on the previously used network until the end of 2023. The network is being revised in response to the route requirements of the interested companies – if the route a company wishes to use are not included in the authorised network, it is possible to request those to be included at the responsible ministries of federal states. The federal states continuously monitor these requirements and report to federal government which then updates the route network, (Federal Highway Research Institute (BASt), 2017).

Annex 2. Workshop on modal shift

Within the framework of the ITF Group on Intelligent Transport Systems for Heavy Goods Vehicles, a workshop was conducted in December 2016 at the University of Cambridge focusing on the impact of High Capacity Vehicles on freight modal split. The objective of the workshop was to examine ways of reconciling the apparent conflict between efficiency improvements in road transport from higher capacity vehicles and the shift of freight to other modes that have much lower carbon intensity. Fundamental to this reconciliation is the cross-elasticity of demand for road, rail and water-borne services. Various attempts have been made by academics and consultants to quantify this cross-modal elasticity, but their estimates vary widely and cannot be easily extrapolated between national freight markets, industrial sectors and commodity types. During the workshop the current state of knowledge on cross-modal elasticity was reviewed based on past applications of cross-modal elasticity values in freight planning. The discussion sought ways to enhance the accuracy and validity of these elasticity values and identify the opportunities for future research in this field.

Alan McKinnon of Kuehne Logistics University made reference to research in Sweden, Germany and the United Kingdom which has tried to quantify the actual and potential diversion of freight from rail/intermodal services to longer and heavier vehicles. Partly based on this research, rail interests in Europe have argued that, by lowering trucking costs, increases in vehicle carrying capacity will cause a modal shift from rail and generate additional freight movement – largely, or entirely, negating the benefits of load consolidation. The presentation put this claim into perspective by making several points:

- Getting more freight onto rail or waterborne services is not an end in itself, rather, it is a means of making freight transport as a whole more environmentally sustainable.
- Much of the freight market is non-contestable. A relatively small percent of the market is subject to road-rail competition.
- Ex-post studies of actual practice show lower levels of modal shift from rail than desk-based simulation studies predict.
- Desk-based studies have traditionally lacked reliable cross-elasticity values.
- Cross-elasticity values used in these studies have varied widely.
- There has been ‘reckless extrapolation’ of modal cross-elasticity values between countries, corridors and sectors.
- Cost is only one of many factors affecting modal competitiveness. The use of generalised cost incorporating money values for other factors such as speed and reliability would address this point though are seldom applied in HCT impact studies.

Lóri Tavasszy of Delft University of Technology cited the 2011 European Union White Paper on Transport which set the objective of having 30% of t-km moved over distances greater than 300 km carried by rail or water by 2030, rising to 50% by 2050. A noteworthy aspect of this ambition was that, given the statistical distribution of freight volumes by trip length, a relatively small proportion of the total freight tonnage would be affected by the target. Only 11% of all European Union freight tonnage is moved more than 300 km, though it does account for 56% of the t-km.

However transport policy has not been very effective at achieving modal shift. Since 2011, the European Court of Auditors has twice issued a negative verdict about European Union modal shift schemes, in 2013 and 2016. Transport statistics mostly show a change of the modal shares within Europe in the "wrong" direction. An interesting observation is that when a freight shift between modes occurs, it is often driven by external circumstances such as economic cycles. Examples of autonomous positive modal shift (i.e. not intentionally driven by public policy) include the increase of inland waterways' share of container transport in the hinterland of the port of Rotterdam between 2001 and 2012, and the move of high value goods from air to sea transport during the global financial crisis. This raises the question: what actually determines the freight modal split?

Technological innovation could be one of the external drivers of modal shift. Interestingly, however, most innovations in transport technology are mode-specific and tend not to be applied at the level of a multimodal transport system. The market for intermodal and synchromodal technologies is still a niche area, and only responsible for a small share of rail and inland waterway flows.

Modal shift may be intended to move freight from road to other modes. One should not overlook the fact that there also exists competition between the alternatives to road transport. These alternative modes will not necessarily be affected equally by changes in road transport performance. A recent study (Zhang, 2013) indicated that a price increase for road transport in the Hinterland of Rotterdam will mostly benefit waterway transport. Rail would benefit only marginally and under very high level of cost increase for road.

Competition between modes can lead to unintended modal shift. From 2009 onwards, several studies were undertaken to understand the societal impacts of LHV's. A modal shift to road from rail was one of the expected negative consequences. The approach adopted to calculate impacts relied on elasticity values. The total modal shift effect was the combined result of a change in transport demand and a change in modal split, both driven by reduced costs of road transport. The different studies varied enormously in their estimates of the expected change in rail transport volumes varied, from -1.4% to -55%. This variation was a result of differences in the many assumptions. The road haulage and truck manufacturing sectors challenged high estimates of modal shift and questioned the validity of the modelling. Their arguments focused on the notion that much of the rail market is relative 'captive' to certain types of traffic, with products of low value and/or long haul lengths, not easily penetrated by trucking companies, even using HCVs.

After a review of the main assumptions, the European Commission's Joint Research Centre (JRC) undertook a sensitivity analysis using Monte Carlo simulation. The inputs to the impact model were systematically varied within carefully specified ranges. The salient outcomes of this study were the following (JRC, 2009):

- Overall, average impacts were a reduction in rail transport between 1.2% and 1.8%.
- Cross-modal elasticities varied strongly by distance category, with low elasticity at relatively short distances (<800 km).
- The minimal net welfare gain from the simulations of HCT use was positive.

Freight modal shift from road to rail has long been a part of the EU's transport policy. In the case of HCVs the general expectation was that these would lead to a shift away from rail transport. Although there was no consensus about the expected impacts, a comprehensive simulation study indicated that these effects would be limited. The factors considered, however, were limited; for example the models did not allow for logistics reorganisation effects. One recommendation is that comprehensive empirical models be developed to assess HCV impacts which incorporate relevant logistics reorganisation effects and improved cross-modal elasticity values for all modes.

Gerard de Jong of Significance and University of Leeds conducted a literature review for Transport & Environment reported in Significance and CE Delft (2010). He found there to be a wide range of price elasticities of freight transport demand in the literature. Elasticities can differ because of differences in research methods used but also because of:

- Different stimulus variables (fuel cost, all transport cost)
- Different response variables (fuel use, t, t-km, v-km)
- Different market segments (bulk vs general cargo, short vs long-distance)
- Price increase vs decrease, magnitude of price change
- Different response mechanisms included (related to long vs short run); in case of a price increase, the possible reactions of carriers and shippers are:
- Change fuel efficiency (buy other vehicles, change style of driving)
- Change transport efficiency (depot locations, shipment size, consolidation, empty driving)
- Change mode choice (rail, inland waterways, short sea)
- Change transport demand (different suppliers or customers, nature and scale of production per location)
- Change commodity demand.

Mode choice therefore is only one of the possible reactions to a price change. Significance and CE Delft provided both an 80% range for the own-price elasticity of single mode road freight transport.

Estimated elasticities related to change in transport demand and change in commodity demand are 0.4 for a change in mode and, -0.6 for a change in transport demand and 0.0 for the following parameters:

- fuel price
- vehicle-km price
- t-km price
- modal shift.

The price increase not only leads to a modal shift away from road transport, but (in the long run) also to shifts to different suppliers and customers to reduce the transport distances. Since transport costs are only a small fraction of the price of a good, it was assumed that the commodity demand effect to be 0. An important caveat is that the -0.6 figure for a change in demand was based on limited empirical evidence. For the -0.4 there was considerably more evidence, though containing substantial variation around this value.

Inge Vierth of Swedish Road and Transport Research Institute, VTI, made the point that in Sweden, the policy goal is to ensure the economic efficiency and long-term sustainability of the transport provision for citizens and enterprises. The Swedish Transport Administration (2014) analysed the effects of allowing HCVs with maximum weights of 64 t-74 t instead of 60 t. Lund University (2016) studied the impacts of permitting HCVs of maximum 74 t and maximum 25.25 m/34 m. Transport costs per t-km are assumed to differ by 14%-24% between standard vehicles and HCVs in the studies. All studies concluded that heavier/longer HCVs are beneficial for society. Reduced vehicle-kilometres are the most important benefit.

Elasticities for the years 1991, 1995, 2000 and 2010 were calculated using a forecast based on an auto-regressive model and the Swedish Transport Council's forecast for 2000. The results for 1990s were impacted by the economic recession in Sweden in the beginning of the 1990s. In 2000, the calculated total demand elasticities for road are relatively high (-1.04 to -1.47). The increase in road t-km is mainly driven by factors other than the shift from rail as cross-modal price elasticities are relatively low. The Swedish National Road and Transport Research Institute (VTI) is continuing to work on the ex-post analysis.

Allan Woodburn and Alan McKinnon studied modal split in the United Kingdom. As there is minimal use of inland waterways in the UK, the main focus of modal split research is road-rail. The UK privatised its rail network in the mid-1990s and since then rail has increased its share of the combined road and rail freight market from 8.3% (1994) to 13.9% (2014) (measured in t-km). Internal competition in the rail freight market has also intensified as new companies have entered the market.

If one defines the U.K. road – rail freight market as comprising freight moved by rail and articulated trucks with gross weights over 33 t and haul lengths of over 300km, rail's share is 42%. Including all trucks with a gross weight of over 3.5 t in the calculation reduces this share to 12% (McKinnon, 2015). This shows how modal shares are affected by the definition of the contestable freight market in a country. Between 1998 and 2001, the maximum weight of trucks increased from 38 t to 44 t. There has been substantial growth of the double-deck trailer fleet and the government has instigated a trial of longer semi-trailers (1 and 2 m longer than the standard 13.6 m trailer).

The U.K. freight market has also been changing with the share of primary commodity movements declining and shares of retail and imported goods growing. Rail freight's commodity mix has changed accordingly: Coal's share of rail freight t-km halved from 26% to 13% between 1998/99 and 2015/16. Over the same period the share of non-bulk intermodal movements rose from 20% to 36%. Such movements are more exposed to competition from HCVs.

Efficiency improvement is not confined to trucking. The productivity of railway freight operations has also been increasing when measured against operational criteria such as average tonnage per trainload (up 83% between 2003/4 and 2014/5) and staff per million t-km (down 35% between 1998/9 and 2008/9).

Competitiveness of rail is also strongly influenced by factors other than cost, including service quality, supply chain structure, customer awareness of rail potential, policy/political issues etc. Research by the UK Office of Rail and Road found that while cost/price was the most cited barrier to using rail for domestic movements, other barriers were also frequently mentioned including lack of service flexibility/recovery strategy (54%) and access to the rail terminals (48%).

Olaf Jonkeren and Loes Aarts discussed the experience of modal split within The Netherlands. Because the Netherlands has a dense network of waterways, inland waterways have a substantial share in the modal split. In 2015 this was 42% on Dutch territory measured in t-km. Considering the period 2005-2014, the change in modal shift in the Netherlands was as follows: road -3.3%, rail -0.2% and inland waterways +3.5% based on t-km within Dutch territory. In this period all modes showed an increased level of freight movement with inland waterways experiencing the largest growth.

High capacity road freight vehicles were introduced into The Netherlands in 2001 on a trial basis. These vehicles had a capacity of 60 t compared with regular vehicles having a capacity of 50 t. The number of HCVs operating in the Netherlands has increased substantially from only a few in 2001 to about 1 400 in

2016. Between 2008 and 2011 a research project on HCVs was carried out. Based on a sample of 51 terminals operators, seven shipping companies and about 30 container road freight operators the project concluded that 100% of the freight transported by HCVs was transferred from regular trucks, and none from rail and inland waterways. There was therefore no evidence of the introduction of HCVs causing a modal shift from rail or waterways.

High Capacity Transport
Towards Efficient, Safe and Sustainable Road Freight

This report explores the impacts that the introduction of higher capacity vehicles has on road freight transport markets, modal shift, infrastructure and safety. It investigates how appropriate regulation together with ITS measures could be applied for relaxing the weight and dimension restrictions and allowing the use of these vehicles in specific geographical areas or on specific routes.

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