International Transport Forum

Moving Freight with Better Trucks

Research Report

OECD

Moving Freight with Better Trucks

Research Report

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FOREWORD

This report *Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability* is the result of a three-year co-operative effort by an international group of experts representing 15 countries as well as the European Commission, under the aegis of the Joint Transport Research Centre of the Organisation for Economic Co-operation and Development (OECD) and the International Transport Forum.

The purpose of this report is to identify potential improvements in terms of more effective safety and environmental regulation for trucks, backed by better systems of enforcement, and to identify opportunities for greater efficiency and higher productivity.

The report is based on review of literature, consultation among stakeholders, research and analysis from working group members. It also presents the results of a comprehensive benchmarking study of 39 truck configuration – from typical workhorse vehicles to very high capacity vehicles -- in operation in OECD/ITF countries; to assess their performance in terms of dynamic stability, productivity and impact on the infrastructure.

This report presents state of the art research findings, literature survey and benchmarking studies. Key messages are not designed to represent a political consensus on the issues examined and do not necessarily reflect the policy of any individual Government in the Membership of the ITF or OECD.

ABSTRACT

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The purpose of this report is to provide insights into the development of the heavy road freight transport system to facilitate development of policies to improve its productivity and its social and environmental sustainability. It presents a comprehensive review of current trucks performance.

The report first documents the recent trends in road freight transport in OECD and ITF countries and the logistics challenges in the road transport market, highlighting the need for a more efficient transport system. It reviews the regulations in place in OECD/ITF countries concerning weights and dimensions, technical standards, environmental standards, truck operations and transport operators. The report then presents the summary results of the performance benchmarking of 39 truck configurations across 10 countries, focusing on the safety and productivity impacts of changes in the configuration of heavy vehicles including weights and dimensions and articulation. It reviews the environmental challenges – in terms of local air pollutants and greenhouse gases – the safety challenges and the infrastructure challenges – for roads and bridges –of road freight transport, including technologies to mitigate their impacts. In this context, the report reviews the current use of higher capacity vehicles. The last part of the report focuses on options for an improved regulatory framework, including opportunities offered by performance based standards improved regulations, and the approached used to achieve compliance as well as the role of enforcement.

Fields: vehicle design and safety (91), traffic and transport planning (72)

Keywords: freight transport, policy, improvement, environment, sustainability, efficiency, weight, safety, pollution, design (overall design)

NOTE

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Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability

KEY MESSAGES AND CONCLUSIONS

Context

Freight transport demand has grown rapidly and will grow further as our economies recover from the current downturn. This puts pressure on the capacity of transport networks and community acceptance of the environmental and safety impacts of freight transport, especially by truck. Regulatory and pricing frameworks can be improved to deliver more optimal outcomes as the freight task grows. The purpose of this report is to identify potential improvements in terms of more effective safety and environmental regulation for trucks, backed by better systems of enforcement, and to identify opportunities for greater efficiency and higher productivity.

In particular, the report aims to inform deliberations on authorisations for more extensive use of higher capacity vehicles[1]. This is currently under consideration in many countries because of the potential of such vehicles to yield major productivity gains:

- Several northern European nations are testing European Modular Vehicles, a family of vehicles composed of combinations of standard trailers with length limits of 25.25 m and load limits of 60 tonnes.
- The State of Victoria, Australia, started testing of a family of trucks with length limits of 30 m and load limits of 77.5 tonnes in 2009.
- The Province of Ontario, Canada, issued a limited number of permits in 2009 for testing long combination vehicles capable of hauling two full size trailers up to a mass of 63.5 tonnes and to a length of 40 metres.
- There is some discussion in the United States in relation to the surface transportation authorisation bill about possibly increasing length and mass limits for trucks in interstate traffic where the current mass limit is 80 000 lbs (36.3 tonnes) and the maximum length of combination vehicles is established by Federal law and State permit programmes.

The net effects of such vehicles depend on a range of factors that vary widely between regions. The report reviews the information available on the economic, safety and environmental characteristics of heavy trucks and supplements it by modelling the performance of 39 workhorse[2] and higher capacity vehicles in use around the world.

The report offers proposals on how regulatory frameworks can be modified to promote innovation that can improve safety and environmental outcomes, protect infrastructure assets and drive efficiency. This includes the use of higher capacity vehicles in appropriate circumstances but involves better regulation for all vehicles. The report does not propose specific interventions but offers a series of options for governments to respond to the challenge of rapidly increasing demand for road freight.

Key Messages

1. **The freight transport task is growing rapidly in most regions and requires effective utilisation of all modes of transport**. Road haulage is most suited to serving much of the growing demand for transport. Other modal options provide competitive services on key freight corridors but cannot serve all of the locations required.

2. **The safety and environmental impacts of road haulage require regulatory intervention for optimal outcomes**. This includes controlling access to the road network and safety and emissions standards. Regulatory systems can be improved through more effective compliance regimes and through performance based standards that provide flexibility to enable technological innovations to deliver better levels of safety and environmental protection.

3. **Compliance can be improved greatly through legislation that assigns responsibility** for respecting the regulations to actors across the supply chain and grants powers to compliance agencies to use alternatives to roadside checks. This includes inspecting the financial and loading records of shippers, receivers and transport companies to control overloading.

4. **Compliance regimes can be enhanced by exploiting technological innovations** such as GPS tracking for route access compliance, advanced weigh-in-motion systems to monitor truck loading without the need to stop vehicles at the roadside and the use of remote checking of on-board diagnostic systems. Enforcement can be automated with vehicle recognition systems. Information technologies can be used to target high risk drivers and transport operators. Accreditation schemes can be used to stimulate the adoption of best practice safety management systems.

5. **A performance based approach to regulation offers the potential to meet community objectives for road freight transport more fully**. Such an approach — adopted in a number of countries, including Australia and Canada — defines the environmental and safety objectives to be attained whilst leaving the means for achieving them unspecified. This allows industry to innovate to increase productivity whilst meeting sustainability and safety goals. In Australia performance based standards have been used to authorise access to suitable parts of the road network for vehicles that do not conform to prescriptive limits on mass or dimensions.

6. **Many higher capacity vehicles have equivalent or even better intrinsic safety characteristics in some respects than most common workhorse trucks**. This is suggested by the literature and by computer modelling undertaken for this report of 39 heavy truck types and confirmed by a number of case studies of higher capacity vehicles on the road (*e.g.* in Canada, Sweden and Australia). Their dynamic stability tends to be superior. Their axle load distribution, on a greater number of axles, often enhances brake capacity, with shorter stopping distances[3] and reduced brake fade. For HCVs on the road today, driver selection, operational controls and higher levels of safety equipment contribute to significantly better safety records for these vehicles[4].

7. **Truck crash energies mean safety regulation must pay particular attention to managing truck speeds and driver alertness and impairment.** Safety barriers and bridge piers are vulnerable to the energy of impacts from all categories of heavy trucks and most are fitted with guard rails designed to redirect large vehicles away from critical structures. Bridge piers might need to be protected with additional barriers. Lane departure warning systems promise to reduce risks of collision for all types of trucks. Modifying regulatory frameworks to deploy such electronic safety systems and incentivise uptake ahead of prescription is a clear priority.

8. **Further research is needed into other safety aspects of trucks**, including the potential aggravation of the consequences of accidents when higher capacity vehicles are involved and possible countermeasures. Vehicle length also presents risks for overtaking and blocks visibility for other road users. The impact of vehicle length on safety and congestion are yet to be fully quantified.

9. **Higher capacity vehicles have potential to improve fuel efficiency and reduce emissions**. Basic aspects of truck design such as the length, wheelbase, width, height, axle loads, axle spacing and gross vehicle weight are limited by size and weight regulations. These factors directly influence fuel consumption. Computational analysis show that in many instances higher capacity vehicles can perform equally if not better than workhorse vehicles in terms of fuel efficiency and emissions.

10. **Higher capacity vehicles can result in fewer vehicle-kilometres travelled** for a given amount of freight transported. This is particularly true in relation to the volume of goods that can be carried per truck. Load volume rather than weight now often determines the number of trucks required. The reduction of truck numbers is contingent on avoiding a major decline in vehicle load factors[5]. Modular systems that couple standard trailers provide valuable flexibility for matching loads and for facilitating intermodal transfers. Case study results (Alberta and Saskatchewan in Canada, Sweden and Australia) suggest that the use of higher capacity vehicles has reduced the amount of truck traffic on the road, with benefits for safety and the environment, including reducing the growth of fuel consumption and CO2 emissions.

11. **The lower unit costs offered by higher productivity trucks could result in increased overall demand for road freight transport and a transfer of freight from other modes,** Even if this has not been the case to date where higher capacity trucks have been introduced, it could be the case in other regions or countries depending on the local conditions. Induced demand effects are likely to be small but the potential for modal transfer varies greatly between commodities and markets. This can introduce an inter-modal component to truck regulation. Policies to shift freight from roads to rail and inland waterways may lead some governments to prohibit higher capacity vehicles from the road network or from specific corridors, foregoing possible efficiency gains.

12. **Road pricing systems can be developed to manage use of the transport network more efficiently,** including with respect to the choice of mode for freight transport where alternative options are available. Fixed road network access charges, tolls and electronic kilometre charges can be differentiated to link them to truck road-wear, safety and environmental characteristics, truck productivity, and provide incentives for the use of low impact vehicles. Electronic kilometre charges provide incentives for improving truck load factors and can be varied to manage congestion if they are applied to passenger cars as well as heavy vehicles. Efficient pricing for the use of all transport infrastructure, including in relation to environmental and safety costs, is critical if the modes are to compete on an equal footing.

13. **The capacity of the road network is not uniform**. Optimising the use of higher productivity trucks will involve limiting their access to the network to links where their use is compatible with strength and geometry of the infrastructure. Technology is available to monitor and control access. Higher capacity vehicle access to the road network needs to be based on a balance of productivity benefits, infrastructure costs and safety and environment costs and benefits. Such investments, however, need to be considered carefully as in some cases the costs of adjusting infrastructure to accommodate HCVs could outweigh the benefits of their introduction

14. **Road infrastructure and trucks need to be developed in concert.** The benefits from the higher productivity of higher capacity vehicles sometimes justify investment in parts of the main road network to accommodate them. In these cases the productivity benefits might provide resources to finance these investments. National approaches to infrastructure funding differ. Some countries earmark revenues from road charges and fuel taxes to expenditure on roads, or in some cases other transport infrastructure, others prefer to avoid earmarking. Bridges are often the weak points, but appropriate regulation of vehicle design, targeted bridge protection or strengthening programmes and intelligent truck traffic management can provide the necessary protection for bridge assets.

15. **Further research and data is needed for solid, evidence-based decision making.** While this report is broad in scope it is not exhaustive. In order to properly evaluate the impact of road freight operations, the safety and compliance performance of the whole truck fleet should be consistently measured and monitored. The output of such monitoring would better inform the public of the performance of the trucking industry, support policing and enforcement and facilitate evidence driven policy development.

16. **Significant opportunities for improvement of the regulation of heavy trucks have been identified.** With more flexible regulation and enhanced compliance systems for safety, environmental and asset protection rules, simultaneous improvements in safety, sustainability and productivity of the general heavy vehicle fleet can be achieved. Appropriate use of higher capacity vehicles, assessed against performance standards, subject to route restrictions and enhanced road access and safety compliance regimes will lead to improved productivity and sustainability. Flanking measures are a potential means to guard against a shift from rail to road in markets where this might occur and is counter to national transport policy. Higher capacity vehicles have been operated extensively for a variety of freight tasks in some areas of the world without adverse impacts. The evidence available indicates significant safety, sustainability and productivity improvements. The experience also demonstrates that effective regulation is essential to benefiting from this potential. The benefits achievable depend on national and regional geographic infrastructure and market conditions. These have to be accounted for in assessing the merits of authorising higher capacity vehicles.

Conclusions

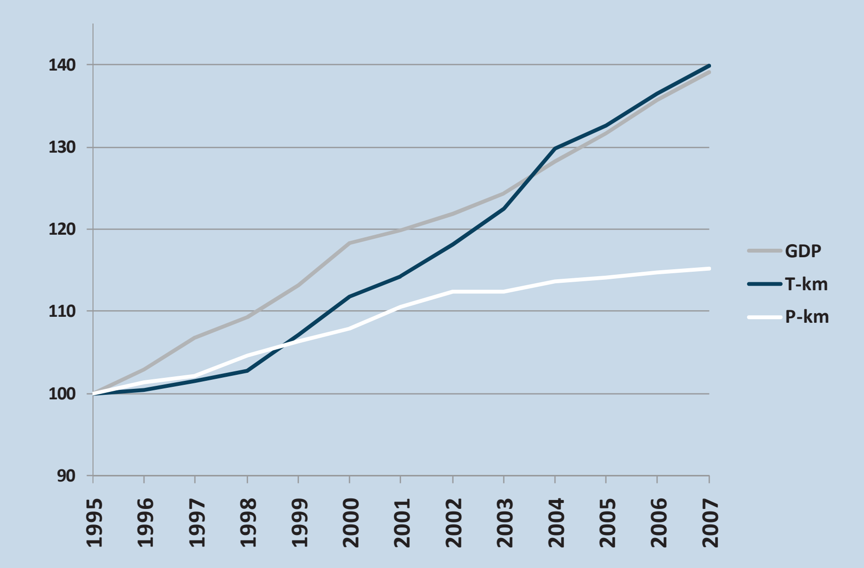
The Freight Task

1. *The amount of freight transport is increasing, with road haulage carrying the major part of the growth.*

The different transport modes develop their capacities and qualities in mutual competition and interdependency, as demonstrated by the increasing importance of intermodal terminals. Key factors in the choice of transport used by shippers are service quality requirements, the value to weight ratio and the density of the goods to be transported.

The freight transport task has grown significantly in recent decades in most countries; growing faster than passenger transport and in line with GDP for ITF countries in aggregate (see Figure 1). Trends differ from country to country and differ markedly between the three largest regions (Figure 2): in the United States the growth rate of 12% over 10 years to 2005 corresponds closely to the overall rate of economic growth in the country. Freight transport increased much more rapidly over the period in Europe (32 %) largely as a result of ongoing integration of the region’s economy. Russia also saw rapid growth, 37%, in the recovery following the collapse in trade with the fall of the Soviet Union. Japan at the other extreme saw only 2% growth, in line with its sluggish economic performance. In the UK freight transport and GDP growth has decoupled, with freight growing more slowly than GDP. For most countries, growth in road freight transport has exceeded overall growth in surface transport, with Russia and Mexico the major exceptions.

Figure 1. **GDP, Freight and Passenger Transport Growth in ITF Member Countries**
(GDP in 2005 Euros–1995=100)

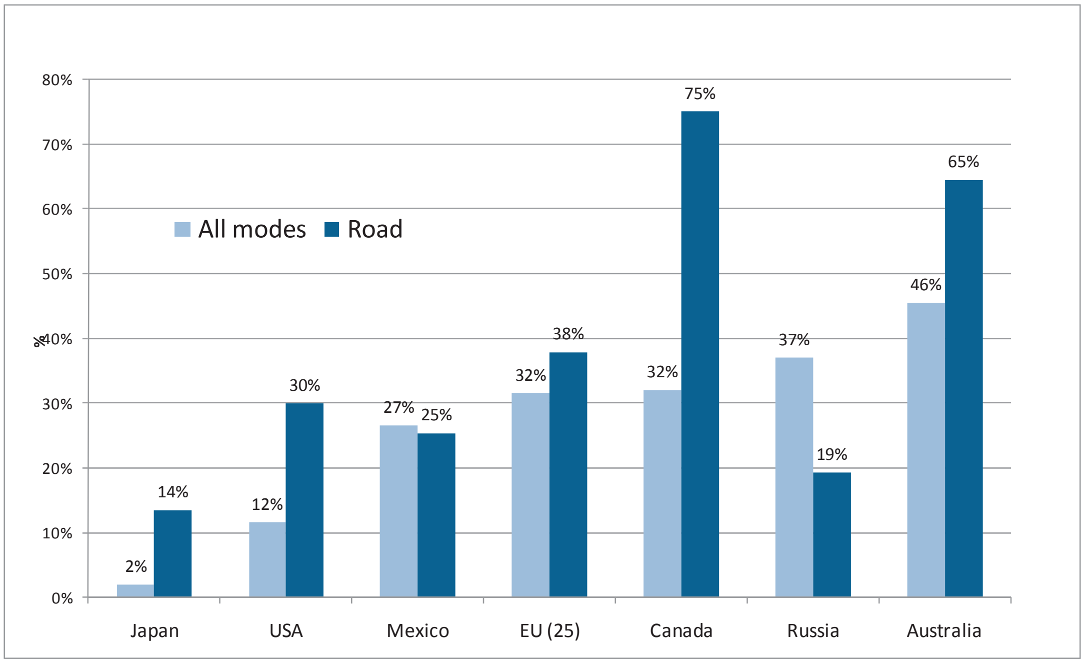


Source: ITF database.

The current recession is likely to shift these projections several years to the right. Recovery may take several years but when it comes freight will probably grow rapidly, as has been the case with previous recoveries. Long term trends may see some attenuation in the rate of trade growth as a result of a rebalancing of flows of capital and goods, but any reduction in international transport might be compensated by increased domestic transport of intermediate and finished products.

Because of its flexibility and timeliness, road transport is expected to account for much of the growth in freight transport for the foreseeable future. Projections, made before the onset of the recession in 2008, forecast very significant growth in road freight transport. The United States expected the volume (in tonnes) to double between 2000 and 2035 (FHWA, 2008). Projections reported by Bureau of Infrastructure, Transport and Regional Economics in Australia foresee an annual increase of 5%. Projections made in 2003 for freight transport growth to 2030 in the European Union are shown in Figure 3. In the USA and Russia (as well as India and China) growth is expected to be more balanced between roads and railways, with rail maintaining a dominant if eroding share of overall freight transport.

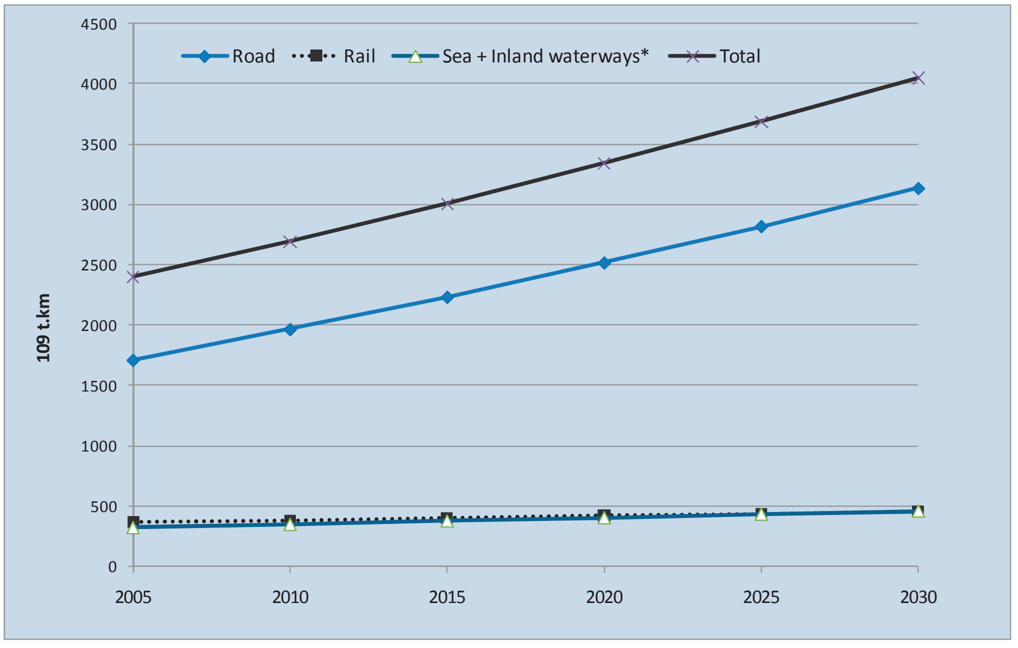
Figure 2. **Volume (ton-miles) growth in % for domestic freight transport by road and for all modes between 1995 and 2005***



Sources: European Commission, Directorate-General Energy and Transport, Japan Statistics Bureau, Transport statistics in North America, Federal State Statistics Service (Russia), ITF, Bureau of Transport and Regional Economics (Australia).

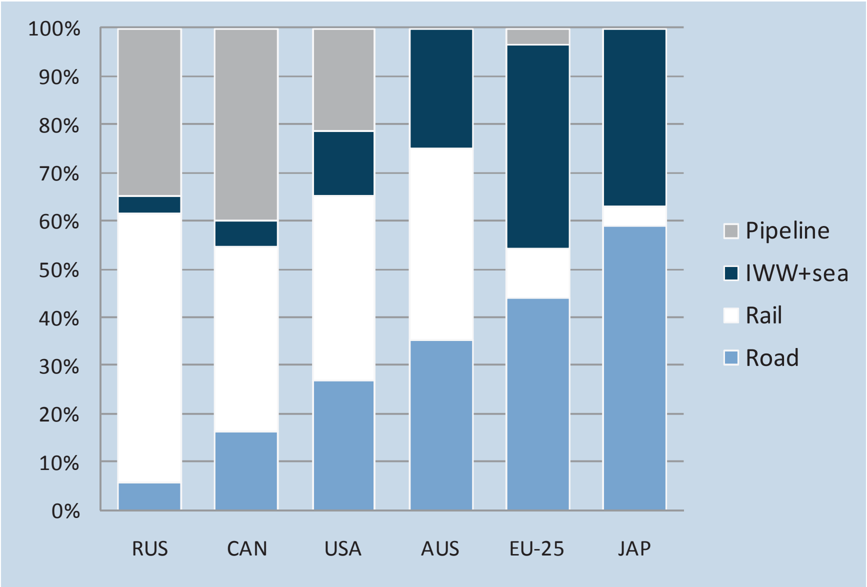
* US data (all modes) do not include container freight that is shipped inland without being opened and repackaged at the port

Figure 3. **Projections for volume of freight transport in the EU-25 by 2030 in billion t-km**



Source: European Commission, Directorate-General Energy and Transport

Figure 4. **Modal distribution of inland surface freight transport 2005 (tkm)**



Sources: European Commission; Japan Statistics Bureau; US Bureau of Transport statistics for North America; Federal State Statistics Service, Russia; ITF database.

2. *Trucks are here to stay; managing their impacts is therefore critical to sustainable transport policy.*

Although trucks have benefited in recent decades from innovations that have improved their fuel efficiency, reduced emissions and lessened infrastructure impacts and crash rates, there remains further capacity for improvement with respect to their performance on these measures. All avenues to reducing their impacts need to be explored.

The evolution of technical regulations for environmental protection and improved safety generally follows some form of "best available technology at no excessive extra cost" (BATNEEC) approach. Regulations are largely driven by developments in technology but regulations also drive innovation by setting performance standards that can sometimes be met through alternative technological development routes and competing technologies. One of the keys to developing new regulatory standards is to avoid picking winning technologies or locking technological development into specific paths that might discourage investment in developing alternative and more effective technologies in the longer term. This is difficult as regulators will naturally be inclined to assess what is currently possible using knowledge of current technologies to determine standards.

For many proposed regulatory interventions, benefits and costs are quantified in monetary terms. In other cases, assessments are based on the cost-effectiveness of meeting agreed standards for air quality for example. Greenhouse gas targets may begin to drive fuel efficiency regulations for trucks in the future and crash fatality targets are becoming increasingly central to road safety policy.

Regulatory standards are only one of the elements to managing freight transport environmental and safety outcomes. When the marginal benefits of regulations for new vehicles show declining returns it can be more effective to instead target the worst performing vehicles in the current vehicle fleet. For example, in 2002 Japan introduced retrospective NOx and PM emissions standards for old heavy duty vehicles. These require old trucks and buses to be retrofitted to meet 1997/98 emissions limits, or scrapped. Enhanced maintenance and inspection programmes can also be effective.

Contemporary road safety policy, following safe system approaches, emphasises synergies between the full range of potential interventions – regulation of driver behaviour, infrastructure design, vehicle technology, traffic management, fleet maintenance, personnel management and shipper responsibilities. Environmental performance is also conditioned by the combination of vehicle technology, vehicle configuration, traffic management, vehicle maintenance and fleet management, driver behaviour and logistics.

Achieving major improvements in performance requires improvement on all fronts. This includes: using the right vehicles for the right tasks, to optimise the number of vehicles used; charging transport services efficiently, to reflect external costs and price them efficiently in relation to other logistic costs; and improving load factors both by customising vehicles, improving the supply chain and setting transport charges to provide efficient price signals. There is scope for improving the regulatory framework in all of these areas.

Regulatory Challenges

3. *Governments have a responsibility to establish regulatory conditions that improve road transport efficiency, safety and sustainability.*

The challenge for governments is to establish the right framework conditions for minimising the external impacts of freight transport whilst allowing the trucking industry to provide efficient transport services. The overall aim of government policies towards transport is to maximise socio-economic welfare. External costs, such as congestion, air pollution, greenhouse gas emissions and safety, require regulatory or pricing intervention to reduce them to acceptable levels. These costs also need to be accounted for in planning and investment decisions.

Government intervention in trucking and associated activities is extensive. It includes regulation of vehicle weights and dimensions, technical characteristics of vehicles, vehicle access to the road network, driver licensing and behaviour and the practices of transport operators. Regulatory solutions must respond to freight needs whilst meeting community expectations for improved health, safety and quality of life. In some instances, trucking regulation is fragmented (between jurisdictions), excessively prescriptive, and slow to respond to changing technology, industry needs and community expectations. This undermines its effectiveness in meeting objectives.

A more sophisticated approach to heavy vehicle regulation could deliver better outcomes through the adoption of regulatory mechanisms that promote innovation by providing for flexibility in the way outcomes are met. Well designed regulatory intervention will achieve safety and environmental objectives in the most cost effective way, *i.e.* with the lowest impact on productivity.

A way forward for road transport regulation is to implement a package of:

- Measures to enhance compliance, exploiting the full potential for technological and regulatory innovation to improve enforcement.

- Performance based standards that allow higher productivity whilst maintaining or improving safety outcomes.

- Pricing reforms, to allocate costs between heavy vehicle types more closely according to their impact on road infrastructure, provide stronger incentives for mitigating environmental and safety costs.

These points are considered in more detail below.

Compliance

4. *Innovative approaches and new technologies are available for achieving more effective compliance with regulations.*

Improvement in regulatory compliance is a vital component of the effort to achieve a more sustainable transport system. Regulatory enforcement can benefit from the same advances in technology and management as general transport operations. Achievement of improved safety, productivity, and asset and environment protection requires a comprehensive approach to compliance. More effective enforcement alleviates problems of unfair competition from companies that break regulatory requirements. The main method of achieving compliance has been enforcement based on designated officers observing an offence. However, other tools are being developed to improve safety and compliance outcomes, such as weigh-in-motion systems.

The current trend in trucking enforcement includes:

- Electronic detection of non-compliance.
- Use of information technology to gather and apply information on patterns of behaviour, to enable the focussing of enforcement resources on high-risk drivers and operators.
- Use of accreditation and safety ratings schemes to encourage the application of safety management systems.
- Imposition of legal requirements on off-road parties with control over truck operations.

Regulatory enforcement can benefit from the same advances in technology and management as general transport operations, using vehicle positioning systems, weigh-in-motion systems, on-board monitoring systems and detection and measurement equipment at the roadside and embedded in the roadway, *e.g.* advanced weigh-in-motion systems.

Improved information technology enables more rapid and efficient processing of detected breaches and the development of operator compliance and risk profiles. That enables the targeting of high-risk operators, either through safety ratings, compliance scores or operator licensing schemes. A range of flexible interventions can be used to achieve behaviour change or the removal of recalcitrant parties from the road transport industry. Operator licensing or safety rating schemes are in place in many countries. They require operators to manage company practices in order to achieve satisfactory safety and compliance levels.

Compliance and Chain of Responsibility

5. *Compliance can be improved greatly through legislation that assigns responsibility for respecting the regulations to actors across the supply chain and grants powers to compliance agencies to use alternatives to roadside checks.*

Accreditation may be used as a complement and/or a substitute for operator licensing and will typically have external validation that agreed standards or agreed processes, rules and procedures are being adhered to. In return for demonstrating high levels of compliance through auditable systems, transport operators can be granted concessions of commercial benefit, such as increased road access, higher mass limits and reduced incidence of road-side vehicle inspections.

For many breaches of road transport law, the party directly responsible is the driver. However, in most cases, the driver is not the only party to exercise a degree of control over on-road outcomes. In a fiercely competitive industry, each party in the transport chain is subject to pressure from those exercising higher control. For example, speeding offences, overloading and hours of service may be a response to schedules for which little or no flexibility is allowed. Recognising this, Australian States and Territories are progressively implementing 'chain of responsibility' laws which extend legal liability for compliance to all parties who exercise some degree of control over on-road outcomes. This 'chain of responsibility' principle is: *all who have control, whether direct or indirect, over a transport operation bear responsibility for conduct which affects compliance and should be made accountable for failure to discharge that responsibility.* Individuals held to be at fault under these provisions are required to demonstrate that they have taken 'reasonable steps' to achieve compliance with road transport law.

Operator licensing schemes, mandatory and non-mandatory accreditation and a requirement to undertake 'reasonable steps' under chain of responsibility legislation are all means of encouraging or requiring transport operators to take a systematic approach to management systems in order to achieve high levels of safety. Route compliance, vehicle mass and other vehicle and operator characteristics can be monitored. The challenge is to develop the administrative and institutional arrangements to cost-effectively maintain compliance. Enforcement agencies can be given powers to inspect financial and commercial documentation held by shippers and their clients as a highly cost effective approach to monitoring compliance, including speed, mass, vehicle condition and hours of service. Legal regimes of shared responsibility can be effective in reducing conflicts of interest in the observation of regulatory requirements.

If the community can gain greater confidence that heavy vehicles are complying with operating conditions, it is more likely that it will tolerate flexibility in standards that have traditionally been imposed as absolutes. This has the potential to change the nature of standards from 'one size fits all' to an to a more differentiated approach based on the nature of the specific freight task and requirements that vary in time and by place, supported by systems to ensure that compliance with regulatory requirements is achieved. Rather than preventing variation, modern approaches to compliance can enable variation in standards and result in safety and productivity gains.

Regulatory Approaches

6. *Performance based standards can enable innovation in truck design to more fully respond to industrial and societal demands.*

Current regulatory frameworks can be improved by introducing performance based standards as an alternative to some prescriptive vehicle design regulations. This would enable standards to be more closely linked to the safety, operational, infrastructure and environmental performance outcomes sought and would provide the industry with more freedom to release the maximum potential for innovation in both vehicle design and use.

Heavy trucks, including higher capacity vehicles, are capable of achieving better productivity, infrastructure wear, environmental and safety outcomes that serve the objectives of the broad community but careful regulation is required to ensure that all four outcomes are improved. Regulatory requirements may be formulated in various ways:

- A prescriptive standard specifies the means by which the regulatory objective is to be achieved. Prescriptive standards applied to trucking include vehicle length, width and mass.
- A performance based standard specifies the objective to be achieved, but leaves the means to achieve it flexible.

Most requirements relating to vehicle weights and dimensions are prescriptive. They have evolved over a long period and with significant regional differences, including within federal jurisdictions. With prescriptive measures, industry has little flexibility in determining how the objectives underlying regulations are to be met and innovation in vehicle design is constrained.

Performance based regulation can be used to either replace or supplement prescriptive standards for truck weights and dimensions. This form of regulation has been adopted in other sectors, such as occupational health and safety and food standards, and is now well established as the approach preferred for effective and efficient regulation.

Canada pioneered the use of performance standards for trucks (in the 1980s) and used them to develop a set of heavy vehicles considered most appropriate for use in inter-provincial operations. The initial set of vehicles comprised four types of truck. A later amendment added three more truck types and an intercity bus. The Canadian approach has been to use performance standards as the basis for the development of prescriptive standards to describe specific vehicle types.

The Australian PBS scheme has substituted performance standards for many prescriptive regulations and this higher degree of flexibility has allowed for more innovation in vehicle design. Initial industry concerns over the expense and difficulty of the process led to a review of the system and recommendations to simplify the process. This experience should be of use for other countries seeking to make use of PBS.

In both Canada and Australia it has been demonstrated that if regulatory arrangements can offer flexibility, industry will respond by operating the most efficient vehicle combinations. In these two countries, there appears to have been widespread community acceptance of larger freight vehicles, provided that their operation is managed effectively.

Environment and Efficiency

7. Improved productivity can contribute to reducing the number of trucks on the road.

Higher capacity vehicles provide major productivity benefits to their operators. Where they have been introduced they also appear to have substituted for a larger number of conventional trucks. Evaluations of the operation of HCVs are available from Sweden, Canada and Australia. The experience in these three countries supports the proposition that considerable productivity improvements and emissions reductions can be achieved by the use of HCVs, although this result can not be simply transferred to areas with very different conditions, *e.g.* in terms of geography or infrastructure, without specific evaluation.

A study of the freight market in Sweden (Vierth *et al*., 2008) – where HCVs have been allowed for many years – considered the impact of restricting vehicle types to those universally authorised under EU directives for use in international trade. The study found that the cost per truck trip would decrease by five to twelve per cent, depending on commodity group, but the number of trucks needed for transporting the same quantity of freight would increase by 35-50 per cent. On average, 1.37 trucks of maximum EU size would be required to replace one truck of maximum Swedish size. It was estimated that the overall cost of transportation by truck would increase by 24 per cent.

In a Canadian study, Woodrooffe (2001) found that using single semitrailer configurations in Alberta in place of HCVs would lead to an 80% increase in truck movements and result in a 40% cost increase for shippers currently using HCVs. The increased use of HCVs has enabled Alberta's growing freight task to be serviced by a smaller number of heavy vehicles. From an economic efficiency and societal benefit point of view this amounts to a significant gain in transportation cost efficiency with a major reduction in fuel use and greenhouse gas emissions and a large reduction in pavement wear.

In Australia, B-doubles (vehicles comprising a tractor towing two B-coupled semi trailers – length 26 metres and gross combination mass 68.5 tonnes) were introduced in 1984, based on a Canadian design. By 2006, Australia had a total of 69 600 articulated trucks, of which 11 400 were B-doubles. Under conservative assumptions, it is estimated that if Australia had not introduced B-doubles, an additional 6 700 articulated vehicles would have been required to undertake the same road freight task. A more recent estimate places the reductions in articulated vehicles use at between 15 000 and 20 000. Use of B-doubles is estimated to have reduced the fuel consumed by the articulated vehicle fleet by 11% (Victoria Department of Transport, 2008).

8. *Improvements in road freight productivity will have an impact on road freight demand and on other modes of transport.*

Reducing the unit cost of road freight will tend to stimulate demand for road haulage. This will erode some of the reduction in truck numbers that might result from the introduction of HCVs. The impact of road freight productivity improvements on other modes of freight transport varies greatly between freight market sectors and between regions. It will depend to a large extent on the efficiency and regulatory arrangements for competing modes of transport but in some regions the adverse effect on other modes could potentially be sufficient to outweigh positive effects within the road sector.

Reducing road freight costs per unit of goods moved through the introduction of HCVs will have a number of effects on the transport market and will stimulate overall demand for road haulage. The initial effect of productivity gains will be to yield higher profits for the operators using these vehicles but in a market as competitive as road haulage the benefits will rapidly be passed on to shippers and to final consumers resulting in lower costs for transport and lower prices for the goods transported. Some of the gains may be offset by logistic changes that result in additional km travelled but save on overall logistic costs. There may be a tendency for trucks to be used less efficiently, at lower load factors, although this appears less likely than with other factors that reduce transport costs (such as falling fuel prices) because the rationale for using HCVs is to achieve higher productivity. The economic literature on the price sensitivity of road freight demand is thin and records a wide range of responses for vehicle km travelled, ranging from near zero to around 80%[6] depending on the market examined, the commodity carried the size and the source of the price change, and the methodology used (Graham and Glaister, 2004).

Increases in the productivity of road haulage will also influence overall modal split in freight transport. The impact is limited by the fact that many freight transport markets are not contestable between modes. It will be proportionately largest where rail carries only small quantities of freight in comparison with road as in these circumstances a relatively small addition to the quantity of freight carried on the roads can equate to a large part of the volume of rail traffic.

Facilitating an increase in the use of intermodal load units (containers, swap bodies etc.) will help to develop the markets for these non-road modes. Multimodal operations also benefit when truck regulations allow road freight vehicles to move more than one standard container or swap body per haul. The introduction of HCVs can therefore have positive impacts on rail markets as well as negative impacts, depending on whether road and rail are complements or substitutes.

Investment in infrastructure and improvement in the regulatory environments for rail, coastal and inland shipping are essential to their future competitiveness, and more important than changes in road haulage productivity in determining modal split. Using regulations to impose a modal split on the freight task, rather than limit external costs per unit of freight moved regardless of mode, risks using resources very inefficiently and is difficult to sustain in dynamic economies.

Some of the potential for reducing truck numbers as a result of the use of HCVs is eroded by the stimulus to demand from cutting costs. The size of the impact overall is difficult to predict. One recent study used a value for average price sensitivity on the trans-European road network to model the impact of reducing road freight costs 33% through the introduction of heavier (60 t) and longer (25.25 m) trucks (EC 2008). It found an initial reduction in the number of vehicles kilometres driven of 13% as a result of authorising these HCVs. This impact was slightly offset by induced demand and through modal shift, which together added 1% to truck vkm. Thus the net overall effect was a 12% reduction in vehicle kms driven.

A cross-European average hides substantial variation between regions. Some other studies have suggested much larger impacts on modal shift. A study in the United Kingdom by TRL (Knight *et al.,* 2008) illustrates the limitations of applying average values across diverse markets. It estimated that introducing 60 t heavy goods vehicles in Great Britain 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 tonnes.

The impact of the costs of transport on demand for freight transport services varies greatly between market segments. Variations in the cross elasticity between road and rail freight are particularly large, highly sensitive to the relative size of road and rail freight shares in the market segment of interest and poorly researched. This is reflected in the difference between the EC and TRL results as the UK rail market is not typical of Europe. Differences between European, Japanese, North American and Australian markets are pronounced and the results of these kinds of study are not easily transferable. Detailed modelling of the changes in the costs that result from using HCVs in specific markets is needed to better estimate the impact on demand and on modal shift for countries without experience of operating HCVs.

9. *Improvements to systems of road charges can contribute to the efficient development of surface freight transport.*

Road charge can be used to allocate costs between vehicle classes according to their impact on infrastructure and differentiate between vehicles according to environmental performance and relevant safety impacts. Differences in the way road and rail infrastructure use is charged can be a critical factor in intermodal competition.

An effective road pricing regime for trucks is seen by many as a key requirement in the development of efficient freight transport. The primary objective of a more refined road pricing system for trucks would be to more directly link charges for road use to road wear and to the external costs of using roads including safety and environmental impacts. Electronic truck km charges can also be used to manage congestion but are more effective when they also apply to light duty vehicles. Ensuring these variable costs are paid for pro-rata is the primary task.

Recovering the fixed costs of building capacity, for territorial development or to relieve congestion, can also be an objective for road pricing. The prices that result from this approach do not always coincide with charging to cover the variable costs of using roads. On lightly used roads, charging variable costs will result in lower prices than charging to cover fixed costs. On heavily congested routes, where expansion is not a realistic possibility, charges for managing congestion can increase prices higher than required to recover fixed construction costs. Charges for using rail infrastructure can similarly be based on covering a variety of fixed and variable cost elements. Divergence in the approaches applied to charging for roads and rail use can have major consequences for intermodal competition. Any tendency to cross-subsidise passenger rail services from freight revenues will also undermine the competitiveness of rail freight transport.

In most countries road user charges are not closely related to road use or the associated infrastructure or social costs. The main charging instruments are some form of fixed periodic charge (*e.g.* vignette or registration charge) and a fuel tax. Revenues from these charges typically accrue to general government funds, although in some countries they are paid into dedicated road or transport funds. Charging for the variable costs of road use by trucks, taking into account axle mass, road type and road condition, could enable shippers and transport operators to factor key costs into their choice of mode, route, vehicle, axle mass and vehicle configuration. Pricing reforms could be incremental, beginning with supplementary charges for HCVs to the extent that they impose additional costs, for example in relation to bridge strengthening. If road owners received such incremental infrastructure-related road revenues, they would have an incentive to respond to demands for the operation of higher capacity trucks.

Safety

10. *Many technologies are available for improving truck safety but some may need incentives for large-scale implementation.*

Safety improvements can be gained from recent advances in active safety equipment and driver support systems that alert the driver or intervene when risks are detected and not responded to promptly. Where the social benefits of these systems are greater than their private benefits to transport operators there is a case for regulatory intervention. The productivity gains available through changes in the regulation of truck weights and dimensions could provide an opportunity for accelerated introduction of some of the more expensive safety technologies.

Recent years have seen the development of systems that detect crash risks and either alert truck drivers to the need for action and/or intervene directly to avoid the crash or mitigate its consequences. Table 1 lists a selection of systems which are relatively new to the market, and thus not widely deployed, or still in the stage of final development but expected to be available within the next few years. Common to all of them is the need for concerted efforts by many actors in order to achieve successful implementation.

Table 1. **Key truck safety systems**

Imminent risk detection, alert and avoidance systems	7. Curve Speed Warning
1. Roll Stability Control	8. Intelligent Speed Adaptation
2. Lane Departure Warning	**Vehicle component condition warning system**
3. Forward Collision Warning	9. Onboard Brake Stroke Monitoring
4. Electronic Stability Control	10. Tyre Pressure Monitoring
5. Side Collision Warning	**Driver condition warning system**
Anticipating risk detection and prevention systems	11. Driver Fatigue Detection and Warning
6. Adaptive Cruise Control	12. Onboard Monitoring and Reporting Systems

Motor carriers are slow to voluntarily adopt new safety technologies unless tangible safety and economic benefits are evident. In the case of crash avoidance technologies such as ESC, small fleets and owner operators are less likely to see direct benefits because of limited travel exposure therefore acceptance of the technology among this industry sector is low. On the other hand large fleets can measure the benefits directly through reduced crash rates and are more likely to invest in the technology. Test evaluations and analyses are critical to demonstrating benefits. When the major beneficiaries of a safety feature are not the operator or occupant of the vehicle to which it is fitted there are several approaches to promoting uptake. These include provision of tax offsets or rebates, direct subsidy of purchase and fitment costs, reduced charges for vehicles with the safety feature, relaxation of an existing regulatory restriction (*e.g.* access to parts of the road network where the new technology resolves safety issues), and regulation mandating the fitment of the safety feature.

An opportunity for mandating new safety systems arises where regulations are modified to permit higher capacity trucks. In a *quid pro quo* approach the industry could be given the benefit of higher productivity whilst being required to improve safety. The costs of new safety technologies often delay their consideration for mandatory fitment and the regulatory process itself can add significant further delay. One opportunity to accelerate the process is to incentivise operators to fit the system voluntarily by making it a condition of productivity concessions, such as wider access to the road network or increased payload capacity.

11. The use of higher capacity vehicles can improve overall safety outcomes.

Analyses and practical experience with higher capacity vehicles, on the roads where they have been permitted, have concluded that their safety performance is no worse than that of traditional workhorse trucks. If higher capacity trucks substitute for a larger number of smaller vehicles their use may improve road safety overall.

In most studies of the potential impact of HCVs, it has been assumed that the crash risk of HCVs per vehicle km travelled (VKT) is the same as other heavy trucks, so that reduced aggregate VKT will lead to proportionate safety benefits. This assumption is generally supported by the findings of the computer-based analysis discussed below, although the exact effect would depend on which HCV was compared to which workhorse vehicle. On the key manoeuvrability and stability measures that most influence crash risks, higher capacity vehicles often perform better than the workhorse vehicles used to transport the majority of road freight around the world today.

Lack of detailed data makes it difficult to assess crash risk on an individual truck basis. A study by TRL in the U.K. (Knight *et al.*, 2008) assessed the various consequences of allowing different types of longer and heavier vehicles (LHVs) on the roads in Great Britain. It concluded that vehicles significantly larger than the current limits would be likely to increase safety risks per vehicle km, but decrease safety risks per unit of goods moved. Mandating new safety technologies, specific to vehicle configurations, and existing manoeuvrability standards would mitigate many of the risks, increase the reduction in casualties per unit of goods moved, and encourage wider use of new technologies in the standard goods vehicle fleet.

Studies of experiences in Canada (Barton *et al*., 2003, Woodrooffe *et al.,* 2004, Montufar *et al.,* 2007, Regehr, 2009) found that accident involvement of higher productivity vehicles per kilometre are significantly less than those of single trailer trucks in general operations. A study on the use of long combination vehicles (LCVs) in Alberta showed that for a given quantity and density of freight transported by articulated trucks, each LCV replaces one and one-half to two standard five-axle semitrailers, which, over the same period and on the same roads, had higher collision rates than LCVs. Thus, with appropriate regulatory controls, LCVs provided increased freight productivity and had significantly fewer collisions than would have occurred if standard configurations had been used to haul the freight. Driver selection, operational controls and higher levels of safety equipment may contribute to significantly better safety records for these vehicles on the road.

The various studies and experiences from recent years agree that a transfer of goods to trucks with higher cargo capacity should result in a reduction in casualties per unit of goods moved. The potential for further safety benefits depends on operational controls and the extent to which new, available, safety technology is successfully introduced with these types of trucks, *e.g.* as part of a legislation package through which they become permitted. Some of these technological safety measures can equally be applied to the current workhorse trucks, while others are inherent in the configuration of the higher capacity trucks.

Benchmarking

12. Computer simulations show major variations in truck performance, with some Higher Capacity Vehicles (HCVs) performing better than today's workhorse trucks.

A comparative analysis of the dynamic stability, geometric performance, payload efficiency and infrastructure impact of 39 workhorse and higher capacity vehicles, using computer simulation, revealed major differences between these vehicles. The study demonstrated the potential value of this tool for optimising truck design and vehicle standards. The analysis indicates that, on key performance measures, higher capacity vehicles perform often better than the workhorse vehicles used to transport the majority of road freight around the world today.

Computer simulations were undertaken to benchmark safety and productivity performance of representative trucks from participating member countries. Each vehicle was classified in one the following three general categories:

- Workhorse vehicles – the trucks most commonly used for long haul transport, with a gross combination mass (GCM) of less than 50 tonnes and a length of less than 22 metres.
- Higher capacity vehicles – with a GCM of up to 70 tonnes and a length of up to 30 metres, typically operated under restricted access conditions dependant on the road network.
- Very high capacity vehicles – with a GCM of at least 52 tonnes and a length of at least 30 metres and typically operated under permit conditions and often in rural or remote areas.

Each truck was assessed against key vehicle safety performance measures. The measures were based largely on a subset of the Australian National Transport Commission's (NTC) Performance Based Standards (PBS) scheme and are consistent with the measures used in Canada since the 1980s. The study provides an understanding of general vehicle performance in the broader international context. Table 2 shows the selection of standards used in this study to benchmark the performance of the 39 trucks.

Table 2. **Performance Standards – used in computer-based benchmarking of trucks in this study**

	Standard	Description
Vehicle stability	Static rollover threshold	Ensures that geometry and suspension provide a set level of vehicle stability
	Yaw damping coefficient	Ensures that vehicles do not suffer excessive roll oscillation after manoeuvres
Trailer dynamic performance	High-speed transient off-tracking	Ensures that trailers follow the path of the prime mover during unbraked avoidance manoeuvres
	Rearward amplification	Ensures that trailers of multi-articulated vehicles do not swing excessively after avoidance manoeuvres
	Load transfer ratio	Ensures that the vehicle does not approach wheel lift-off and possible roll-over during avoidance manoeuvres
Vehicle manoeuvrability	Low-speed swept path	Ensures that a vehicle may safely manoeuvre around corners typical of those found on its compatible network without cutting the corner

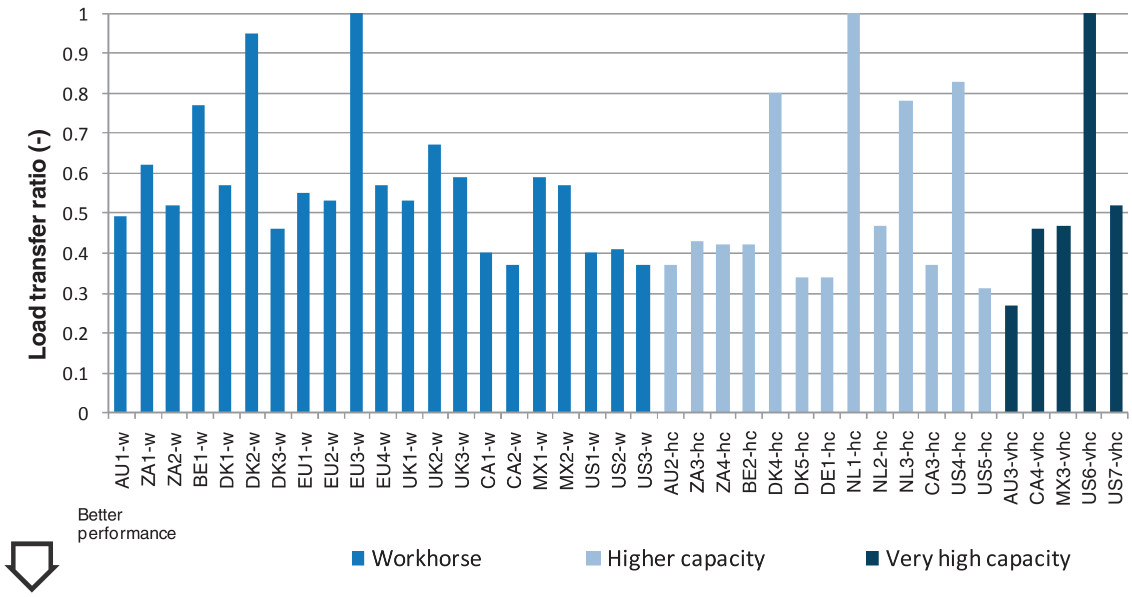
High-speed transient off-tracking, *rearward amplification* and *load transfer ratio* all relate to stability in lane change manoeuvres. The results were similar within each vehicle category and Figure 5 shows that very high capacity vehicles can offer comparable, and in some cases better, dynamic performance than some common workhorse vehicles. One truck from each category reached critical instability (wheel lift off or rollover at LTR values of 1.0) during this manoeuvre.

The *yaw damping* measure quantifies the rate at which yaw oscillations decay after a short duration steer input and pertain to heavy vehicles with one or more articulation points. The best performing vehicles are workhorse semi-trailers. Higher capacity and very high capacity vehicles perform well if the trailers are roll-coupled throughout.

Static rollover threshold is determined by increasing the lateral acceleration of the vehicle until rollover occurs. Of the vehicles examined, 64% of the work horse vehicles, 76% of the higher capacity vehicles and 100% of the very high capacity vehicles exceeded minimum requirements, indicating that, static rollover threshold tends to improve with vehicle length.

Low speed swept path is a measure of amount of road width required to negotiate a specific turn at low speed. The data clearly indicate that the workhorse vehicles have the best performance and the very high capacity vehicles have the poorest performance. In general, shorter vehicles have better low speed swept path performance.

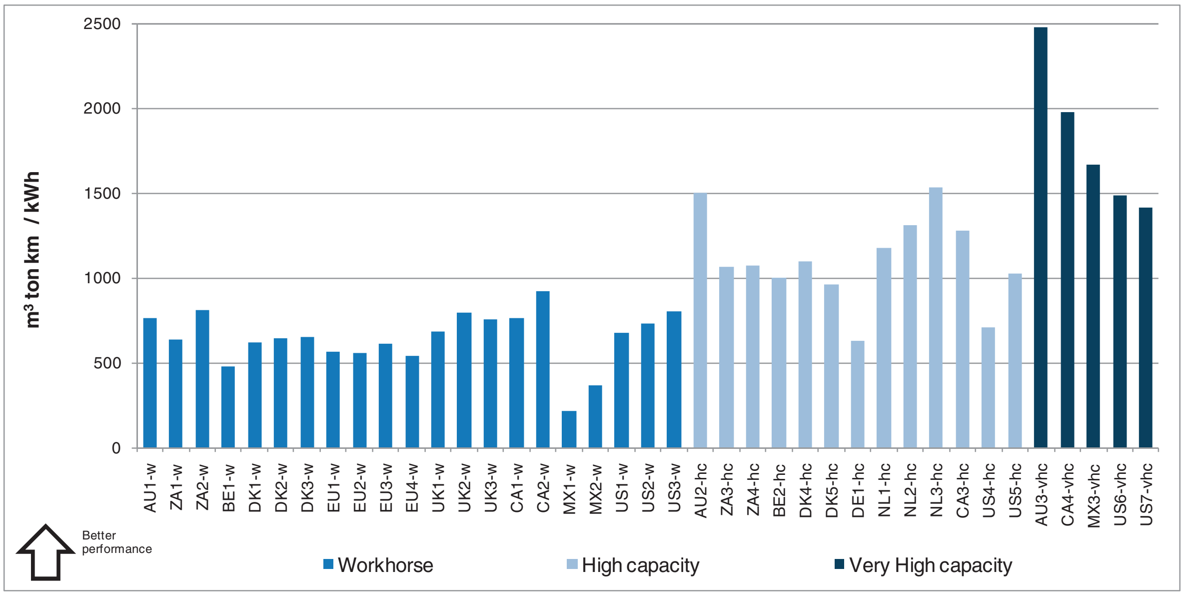
Figure 5. **Load transfer ratio**



A major part of the benchmarking investigation was directed at comparing productivity and fuel efficiency measures, which are influenced by vehicle mass, aerodynamic drag and tyre rolling resistance and therefore affected by size and weight regulation. Other important variables such as engine and driveline efficiencies also have significant influence but they are limited by technological development applying more or less equally to all vehicles and not influenced by size and weight regulation. Therefore this study focussed on the energy consumed to overcome rolling resistance and aerodynamics by the trucks at a steady state speed of 90 km/hr on level ground with no wind effects.

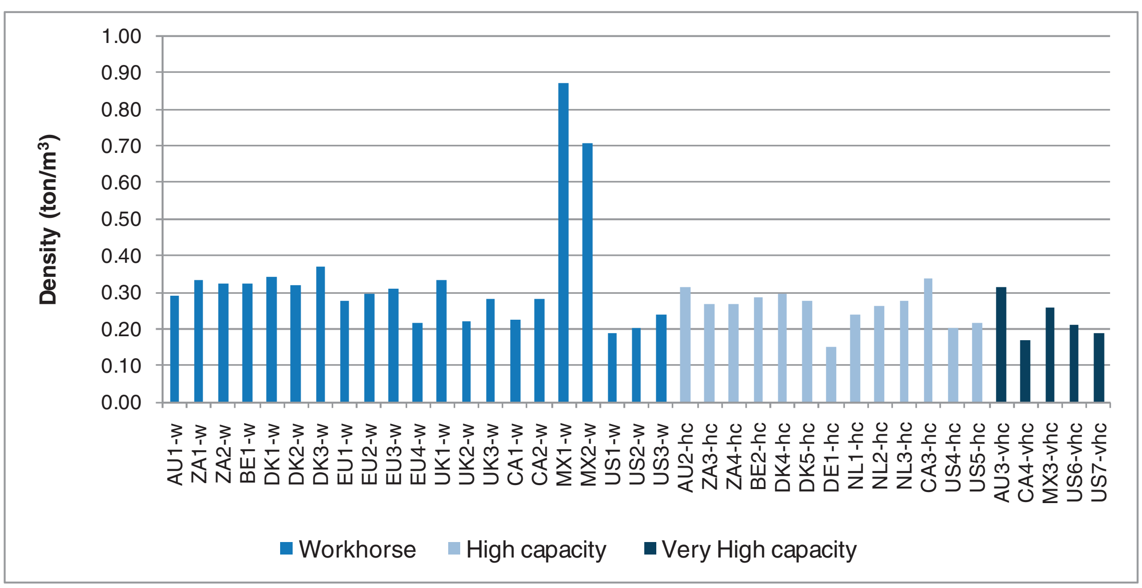
There is no simple measure with which the productivity of different vehicles across different commodities can be compared, but combining mass and volume capacity – while remaining imperfect– considerably improves the differentiation of different vehicles. The resulting cargo size (mass x volume) per unit of energy consumption values shown in Figure 6 very effectively differentiate the productivity performance of the three vehicle classes. Within each vehicle class the variations are significant and the performance measures improve with increasing vehicle capacity category. Since CO_2 emissions are directly proportional to diesel fuel use, the relative emission characteristics of the trucks will match those shown in Figure 6.

Figure 6. **Cargo size (mass x volume) per unit of energy consumption**



Optimum cargo density is defined as the density of freight that would occupy the total available cubic capacity of a truck while simultaneously reaching its cargo mass limits. The optimised vehicle densities, illustrated in Figure 7, show the specificity of the tanker vehicles (MX1 and MX2), specifically designed to carry high density liquid product and that the very high capacity vehicles are better suited to lower density freight. On balance, the workhorse vehicles appear to be better suited to carry higher density freight. This finding is of particular interest to assessment of potential shifts from rail to HCVs, given that rail is best suited to dense bulk freight while increased truck size is best suited for freight of decreasing density. That may obviously induce a higher shift from rail to road for low density freight.

Figure 7. **Optimum cargo density**



The benchmarking exercise included a comparison of the impacts of the trucks on pavements. The road wear comparison was based on the relative vehicle wear factor (VWF) for each truck which is the ratio of the VWF of the truck and that of a reference vehicle (a 40 t/16.50 m long 5-axle truck with a 2-axle tractor and a 3-axle semitrailer). The higher capacity vehicles and the very high capacity vehicles generally cause less wear and tear to the road. Most of the workhorse vehicles have quite a high wear factor. Similar comparisons were made for different pavement types, including rigid pavements, with similar results.

The benchmarking process showed that simulation based analysis of trucks can be useful for improving vehicle performance, safety and efficiency. The data obtained from the vehicle simulations and the comparison of vehicle performance against the selected measures highlighted areas for improvement as well as good practice and showed that HCVs can on a number of parameters perform better than workhorse vehicles.

Infrastructure

13. Trucks and road networks need to be developed in harmony

In the short term, truck traffic and truck configurations must be adapted to road design, geometries and above all to the strength of pavements and bridge assets. Truck combinations that are less aggressive to pavements should, as far as possible, be preferred. The infrastructure assets should, in the longer term, be developed to facilitate optimal use of road capacity by trucks. This development might be funded by financial mechanisms that recover any additional cost from the introduction of higher capacity vehicles, such as differentiated charges for road network access based on vehicle road wear characteristics.

Existing main roads were constructed according to guidelines based on weight and geometry characteristics of the vehicle fleet envisaged when the guidelines were made. Making such roads available for longer and heavier trucks requires careful evaluation and may call for infrastructure strengthening and modification of geometry. The benchmarking study undertaken for this report confirms a need to monitor the impacts of current truck traffic on road infrastructure. It also underlines the need for road owners and the trucking industry to actively engage in coordinated and optimised development of trucks and infrastructure to allow improvements in truck productivity with minimised increases in network costs.

Pavement wear varies greatly with truck configuration and pavement type. Axle numbers, axle group spacing, wheel types (dual or single) and tyre properties all contribute to this variation within groups of trucks of comparable gross mass. Gross mass is of less importance for pavements than the load distribution between axles and axle groups. Carriers should be encouraged to optimise the distribution of axle loads. The modern instrumentation of trucks, in particular on-board weighing systems allowing the driver to know the loads on each axle, is expected to permit implementation of such policies.

The challenge for the road owners is to preserve the road asset at minimum cost whilst accommodating higher capacity vehicles to the extent that maximises overall benefits. It means that the gain of productivity shall be shared between all parties, including the road owner. The experiences of Australia and Canada in this regard are instructive.

Many of Australia's safety-related performance-based standards specify four different performance levels. The purpose is to match the on-road performance of the truck to the risk environment that it will be operating in whilst making optimal use of available capacity in the network. Guidelines assist road owners in classifying routes into one of the four levels: Level 1 - General Access; Level 2 - B-double routes; Level 3 - Double Road Train routes; Level 4 - Triple Road Train routes. With vehicles assessed as meeting one of the four performance levels, access may be granted to the corresponding network level. A similar system has been adopted in the Netherlands.

In 1994, the province of Saskatchewan in Canada implemented a policy of partnerships with private companies to reduce truck transportation costs and ensure a "safe, reliable, efficient, environmentally sound highway system", financed by a combination of public and private sector funds. New truck configurations that will reduce trucking costs by optimising the vehicle with the highway system as well as cargo handling facilities are evaluated on the basis of safety, road and bridge impacts, and haul savings. The cost savings generated for trucking companies by these partnerships provide new revenue for making improvements to the specific highways used by their vehicles.

Investment to adapt infrastructure is a component of many changes in vehicle mass limit regulations. For example, the Swedish parliament adopted a 10-year programme in 1987 to modify national regulations for conformity with EU law, authorising higher axle loads on all arterial roads throughout the country and also on some county roads. At the same time it increased the maximum permitted gross load to 60 tonnes. Associated infrastructure investment costs amounted to a total of SEK 13 billion (EUR 1.5 billion), primarily for bridges, which was recovered from the transport companies by general truck taxation.

Such investments, however, need to be considered carefully, as in some cases the costs of adjusting infrastructure to accommodate higher capacity vehicles could outweigh the benefits of their introduction.

14. Optimised truck configurations are required to minimise damage to bridges.

To protect bridges, if truck mass is increased truck length and the number of axles should at least be increased accordingly. One factor determining the vehicle mass limit should be the assessment of bridge capacity using evaluation tools such as a bridge formula. For trucks that exceed bridge-dependent gross mass limits, and for medium and long span bridges, the increased risk of bridge damage can be limited by managing traffic on the bridge. Signposting and automatic weighing stations can be used to ensure that minimum distances between heavy trucks crossing bridges, thus avoiding overloading the structure.

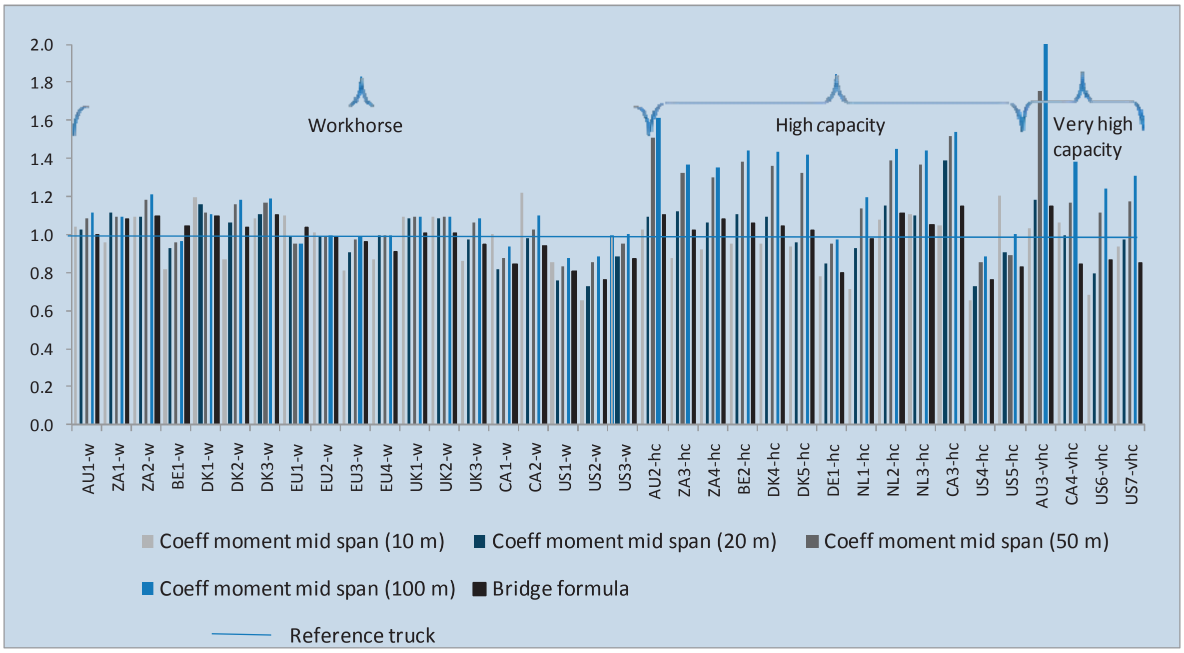
Bridges are routinely designed for loads considerably larger than those imposed by vehicles currently in use. The use of higher capacity vehicles could, however, mean significant differences in applied loading.

The key issue to be addressed in a bridge evaluation is to check that none of the structural elements will be damaged under the maximum load effect encountered during the bridge lifetime. Most of the design codes distinguish ultimate limit states, which correspond to failure or permanent damage, and serviceability limit states. The latter correspond to strains that affect bridge operation (*e.g.* traffic safety) but not the stability nor the durability of the structure, and are reversible.

The impact due to the running of a single truck on a bridge increases proportionally with the gross vehicle mass (or axle and group of axle loads for local effects), and with the 3^{rd} to 5^{th} power of the gross vehicle mass (or of axle and group of axle loads for local effects) in fatigue. This increase is less if the length of the vehicle increases. If gross mass limits are increased, vehicle length and the number of axles should be increased at least proportionally. A bridge formula is recommended to provide a useful guide to regulating vehicles to protect bridges from the accumulation of weight on too few axles.

The measure for structural impacts on bridges used in the benchmarking of the trucks was a relative coefficient of aggressiveness with respect to a standard European articulated truck (5-axle 40 t, 16.5 m), based on the true load effects induced in several simple bridges. Results are shown in Figure 8 and depend on the span length. There are significant differences between the different vehicle types. The worst performing vehicles are, on short and medium spans, those with the highest ratio between the gross vehicle mass and the vehicle length, and on long spans, the longest and heaviest vehicles, *i.e.* the higher and very high capacity vehicles.

Figure 8. **Comparison of impacts of trucks on bridges as shown by the relative coefficients of aggressiveness with respect to a reference truck**



For medium and long span bridges (above 50 m), a minimum spacing between trucks that exceed a particular gross mass limit would be useful in order to reduce the risk of bridge damage. For short and medium span bridges, it would be useful to avoid the meeting or overtaking of two very heavy trucks at the worst location along the bridge. Recent research has proposed strategies to manage the access of heavy vehicles to sensitive bridges.

Decisions to grant access for higher capacity vehicles to a road network must be based on a careful consideration including all the factors discussed above. It may be necessary to limit access to parts of the network depending on infrastructure characteristics and any investment required, for instance to strengthen certain bridges. It may also be desirable to limit access to parts of the network where the benefits are largest. Technology is available to ensure compliance with access restrictions.

Opportunities

15. Society expects road transport to be safe, sustainable, efficient and compliant with regulations.

The key to effective utilisation of trucks is to demonstrate to the community and their political leaders that these vehicles comply with regulatory restrictions, deliver high safety and environmental outcomes and recover the costs associated with their use of the network. The tools to deliver these requirements are available. The challenge for regulatory agencies is to implement an integrated and effective approach to the regulation of trucking.

Truck performance in terms of productivity, safety and mitigation of environmental impacts can be improved through innovation in vehicle technology and design and improvements in logistic and operational management. The economic and technological environment in which freight transport operates is dynamic and a variety of initiatives are necessary to release this potential in full. These include voluntary or semi-mandatory accreditation and certification schemes, compliance support, shared responsibility for on-road outcomes and more responsive regulation. In particular, a flexible and performance-based approach to dimension and mass limits and related regulations is needed with periodic renewal to maintain relevant standards. A number of countries have innovated in this direction with demonstrated benefits.

NOTES

1. Higher capacity vehicle (HCV) is the term used in this report to describe vehicles with weights and/or dimensions outside that permitted in conventional regulation. This term embraces European 'Longer and/or Heavier Vehicles', North American 'Long Combination Vehicles' and Australian 'Higher Productivity Vehicles'. The term higher productivity trucks is also used synonymously in this report.

2. Workhorse vehicle is employed to mean the most commonly used truck configurations for long distance transport.

3. Excess braking capacity can be a problem for unloaded vehicles but this is avoided by the use of ABS and load-proportionate braking systems, which are mandatory or will shortly be mandatory in most OECD countries.

4. These factors were accounted for in the Canadian studies.

5. Electronic kilometre charges have been effective in providing incentives for consolidating loads and achieving higher load factors.

6. *i.e.* a 10% decrease in cost per vehicle km would result in an 8% increase in vehicle km travelled.

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Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability

CHAPTER 1. TRENDS IN ROAD FREIGHT TRANSPORT

Abstract

This chapter introduces the role of road freight in the economy and highlights the perspectives and issues considered by this report. It summarises the main trends in the development of road freight policies in OECD/ITF countries and gives an overview of the road freight industry and its development. It describes the global evolution of freight volume and the relative share of road transport. It gives a general overview of the relevant features of the transport sector, describing the demand side (the stakeholders involved, their position in the supply chain, and emerging trends in logistics) and the supply side and its performance.

1.1. The role of road freight transport

The transportation of goods is a prerequisite for almost all local, regional and global trade and production. The transportation of these goods by road is an indispensable element of the freight task except in the limited circumstances where freight that can be transported from door-to-door by rail or water alone.

Depending on the distance travelled and the nature of the goods carried, a transport operation may consist of a series of components involving different transport modes, which together form a logistics chain. The road transport mode may be used throughout, from the point of origin to final destination, or it may serve at various links in the chain, and almost always serves as the first and last links. The characteristics of a particular road transport task will determine the optimum size and capacity of the vehicles; smaller and lighter vehicles are generally preferred or required for urban operations, *i.e.* goods transport between locations within the same urban area, or for scheduled delivery of goods of limited volume. Such vehicles are not considered in this report.

Long distance heavy vehicle transport rapidly became a necessity during the industrialisation era for moving raw materials, fuels, grain, fertilizers, etc. from points of production to points of distribution and for onward delivery to points of usage. Ships, barges and trains naturally play a major role for such transport but during the past 50 years the demand for such transport to be undertaken by road has increased enormously. There are many reasons for this and the main contributors are briefly outlined below:

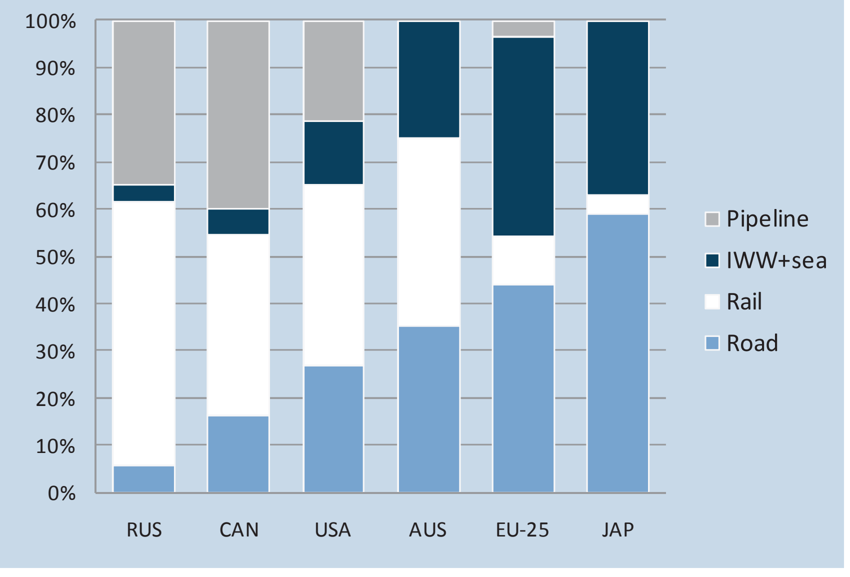
- Road freight transport offers door-to-door collection and delivery, shorter transport times over increasingly long distances and more flexibility than any other surface transport mode.
- Road networks have rapidly expanded, largely to provide for cars.
- Between 1975 and 1995 most developed countries passed legislation abolishing state regulation of prices for road freight transport, prohibiting collusion in setting prices and removing many

restrictions on market entry. This wave of economic deregulation resulted in large reductions in transport prices. Safety and environmental performance continues to be regulated through standards for vehicles, drivers and operators - important concerns for governments and a focus for this report.

- Alongside these regulatory developments, jurisdictional borders have softened or disappeared in most unions of states or nations, leading to greater efficiency for long-distance transport.
- Technological improvements have further helped to increase efficiency, and so the supply of transport services has improved.
- Global trade has been liberalised and manufacturing industries have gravitated to regions of the world with low labour costs. This has substantially increased the distance that goods need to be transported to market. The creation of a shipping container conforming with internationally agreed standards has also helped to facilitate this geographic dispersal of production by standardising shipping conditions and reducing the cost of moving materials and manufactured goods. This has concentrated demand on transport links used for moving containers to and from ports.
- Falling unit transport costs have also driven logistics changes with the centralisation of stocks in fewer, larger warehouses, further increasing the distances goods are transported.

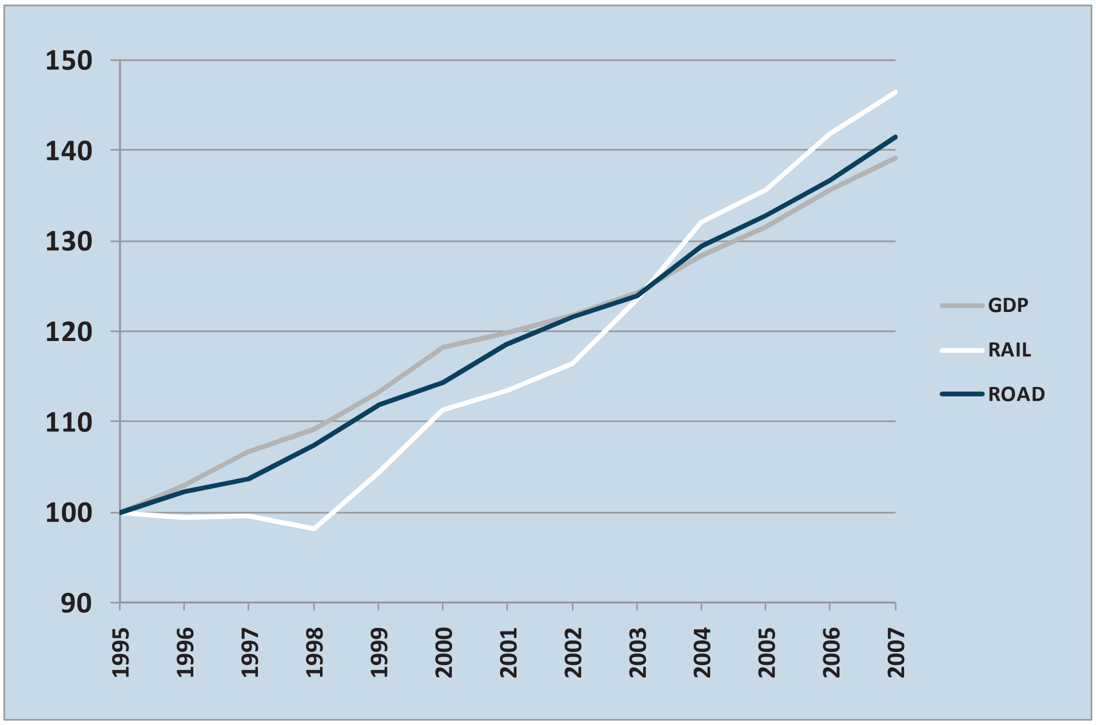
The split between freight transport modes varies enormously between regions as Figure 1.1 shows. Whilst road freight volumes are growing more rapidly than the other modes in most regions rail freight growth has been stronger in the US and Mexico, and especially Russia, over the last decade, as discussed in more detail below. The size of these three rail markets means that rail freight growth has outstripped road growth for the ITF as a whole over the last decade (Figure 1.2).

Figure 1.1. **Modal distribution of inland surface freight transport 2005**



Sources: European Commission; Japan Statistics Bureau; US Bureau of Transport statistics for North America; Federal State Statistics Service, Russia; ITF database.

Figure 1.2. **Rail and road freight (T-km) and GDP in 2005 euros ITF countries**



Source: ITF database.

1.2. Perspectives and issues for this report

Until the recent economic downturn, most forecasts were for continuing growth in freight transport, particularly road freight. Financial market collapse in 2008 and the onset of economic recession change the short term outlook but do little to allay problems of pollution, congestion, resource consumption and greenhouse gas emissions in the long term, or general public aversion to truck operation.

As surface freight transport grows the distribution of freight among transport modes will vary between nations and regions depending on their economies, transport infrastructure capacities and development plans, and the relative productivity of competing transport services. Government policies relating to investment, pricing and regulation of transport infrastructure and operations should aim to maximise socio-economic welfare. This includes reducing the costs of environmental impacts and accidents as well as providing for economic growth. Environmental and safety impacts need to be controlled at source, through regulation and pricing that maximises the net benefit to society for each mode and maximises the returns on any public investments involved. Within such a framework, where transport modes compete for freight, each will develop to carry optimal freight volumes.

The purpose of this report is to provide insights into the development of the heavy road freight transport system to facilitate development of policies to improve its productivity and its social and environmental sustainability. It documents the current situation and identifies realistic short-to-medium term opportunities for improving performance. The report examines how the safety and environmental performance and productivity of this industry can benefit from new technologies. In a highly competitive market such progress cannot be realised without a modern regulatory framework that improves compliance, provides opportunities for improving safety and environmental performance and deters operators from gaining competitive advantages through non-compliance. These complementary roles of regulation are highlighted.

Whilst much of the discussion and analysis in this report covers all heavy freight vehicles (in most countries, heavy vehicles are regarded as vehicles with a gross mass greater than either 3.5 t or 4.5 t), the recommendations and conclusions are focussed on the class of road freight vehicle generally known as "trucks". These are generally considered to be vehicles with a permissible maximum mass greater than 12 tonnes and trailers with a mass greater than 10 tonnes (vehicle categories N3 and O4 as defined by the UNECE Classification and Definition of Power-Driven Vehicles and Trailers, or Class 7 (26 000-33 000 lbs) and Class 8 (33 001 lbs and up) trucks in North America). The many goods vehicles with a permissible maximum mass less than 12 tonnes, which are typically used for a variety of transportation tasks in urban areas, are not specifically considered here, although they present many of the same policy challenges. The report is aimed at the situation in the developed, industrialised economies of the OECD/ITF member countries, although many of the observations are certainly also valid in countries with developing economies. The time perspective of the report is the short to medium term future, *i.e.* the ten years to 2020.

Most of road freight's share of the expected overall increase in freight transport will be carried by heavy trucks, typically on highly-trafficked and often congested highways. Considering the performance of current trucks, the disbenefits to society of this trend are easily foreseen: more noise and pollution, more CO_2 emissions and fuel consumption, more congestion and a slowing of recent crash reduction trends. The key finding of this report is that improved productivity and performance of trucks has the potential to offset or limit these undesirable consequences of increased road freight transport and reduce transport costs at the same time.

1.3. Features of the history of trucking

Road transport by motorised vehicles has a history that goes back to the beginning of the 20th century. The logistic demands of two world wars had a profound influence on this technology as well as on many other transport modes. In the 1950s modern diesel engines started to replace and soon completely eliminated the gasoline engine in heavy road freight vehicles. Engine power in the 200 hp range became available and allowed heavier loads to be transported over longer distances. Extensive use was made of the expanding networks of new motorways, which were developed to be high speed links between population and industry centres within and between regions, states and nations. Thus, heavy goods vehicles soon became the primary mode of long distance transport in industrialised countries where the economy relied on private industry.

Figure 1.3. **Evolution of trucks**

A predecessor of today's heavy goods vehicles:
66.7 ton GVW truck-trailer combination from 1936

Source: Anhängertechnik Teil 1: 1990-1980, Erich Hoepke. In: ATZ Automobiltechnische Zeitung 108, 2006.

B-double operated in Australia in 2009

Recent decades have seen the development of comfortable and more crashworthy driver environments in close cooperation with driver advisory groups. New suspension systems provide better protection for cargo and road pavements from excessive impact forces, especially those resulting from vehicle interaction with poor and uneven road surfaces. Coil suspension of the cab now protects the driver against suffering the kind of back ailments that were frequently seen as an occupational hazard. Engine technology has developed continuously, enabling engine power to reach the 300 hp range in the 1980s with only marginal increases in fuel consumption.

The early 1990s witnessed the introduction of drag reducing aerodynamic profiles and panelling, resulting in aerodynamic improvements of up to 40% and a reduction in fuel consumption of about 20% compared with the preceding generation of trucks. Cross country fuel economy runs in the US showed that heavy trucks, then with engines in the 400 hp range, could be driven under realistic conditions with an average fuel consumption corresponding to 8 miles per gallon (mpg) or 29.4 l/100 km.

At the turn of the century many information technology (IT) systems started to find their way into trucks with the aim of increasing both the safety and productivity of the vehicle. Today's vehicles are offered with service intervals of 40 000 kms, and engines have continued to grow in power and efficiency, reaching the 600 hp range with the capability of transporting loads in excess of 100 tonnes.

The annual production of heavy trucks by the 10 largest manufacturers in Western Europe, the United States and Japan in 2005 was 847 000 vehicles as shown in Table 1.1. The competition between manufacturers involved in HGV production is fierce, and companies invest heavily in long term research aimed at significantly increasing engine efficiency and reducing environmental impacts.

Driving the large trucks of today requires little physical effort by the driver. In fact, the ease with which these heavy vehicles are controlled may leave the driver with a sense of safety that in some conditions is not in accordance with reality. How to mitigate the dangers of this complacency and reduce safety and environmental costs while fully exploiting the productive capabilities of these high-tech transport machines is one of the main considerations of this report.

Table 1.1. **Largest manufacturers in 2005 in Western Europe, the U.S. and Japan of trucks over 16 tonnes GVW by number of units**

Make	Units
Daimler AG (Mercedes-Benz, Freightliner, Sterling, Unimog, Western Star, Fuso)	241 515
Volvo (Volvo, Mack, Renault, UD Nissan Diesel)	177 106
PACCAR (DAF Trucks, Kenworth, Peterbilt, Leyland Trucks)	124 406
Navistar International Corporation (International,Workhorse)	61 066
MAN	53 379
Scania	53 365
Hino Motors (Toyota Group)	44 494
Iveco (Iveco, Magirus, Astra, Seddon Atkinson, Yuejin)	43 364
Nissan Diesel	25 852
Volkswagen	22 684
Total	**847 231**

1.4. Public perception and amenity

Surveys from OECD/ITF member countries across the world (Sofres, 2000), Beirness *et al.,* (2002), Austroads (2007), often show concern by the general public over the influence of trucks on safety and the environment and support for measures to reduce the risks of crashes due to truck driver fatigue and driver errors. The same public wishes to have easy access to consumer goods and live in societies with developing economies and welfare, for which road transport is indispensable and unavoidable.

Concerns are stronger and more frequent in relatively densely populated areas, such as some central European countries, whereas neighbours to truck roads in Australia do not consider trucks as serious threats. Americans express support for tougher truck standards and willingness to pay more for freight shipped in trucks in exchange for that. Canadians are generally trusting in the professionalism of the truckers although they have reservations with respect to trucks with two or more trailers.

1.5. Trends in road freight policies

The following is a snapshot of recent and planned policies in the European Union, North America and Australia.

European Union

In the European Union political initiatives regarding road transport are proposed by the European Commission and decided upon by the Council of Ministers in agreement with the European Parliament. Current policies build on the White Paper "European transport policy for 2010: Time to Decide" and a mid-term review of this White Paper "Keep Europe Moving – Sustainable Mobility for our Continent". The 27 nations of the Union are responsible for domestic policies related to truck regulation but are required to allow trucks that meet European Union standards access to their road networks.

Road transport carries 45% of the goods traded within the EU. Competition between road hauliers has increased with expansion of the Union and better transport services have been provided to customers. Nonetheless problems remain, for example in relation to access to the profession and the market.

Different, sometimes unclear or burdensome administrative and legal requirements can still have a negative impact on the operators, leading to distortion of competition in this market. For instance, despite a large increase since its liberalisation in 1998, road cabotage still only accounts for about 1% of total road transport in the EU, although the figure varies nationally (almost 3% in France and Belgium) and is higher around ports and some borders.

The increasing momentum around issues such as climate change, resource scarcity, sustainability and pollution brings to light critical challenges that the transport by road will face in the coming years. For companies, the greening of logistics not only has an environmental dimension, but is also a question of efficiency. Logistics are estimated to account for 10-15% of the final cost of finished products and businesses are increasingly seeking to cut costs by reducing fuel consumption and time spent in transit. In terms of energy consumption, transport as a whole accounts for over 30% of the total energy consumed in the European Union (Eurostat figures for 2004) and within that 83% is attributable to road transport. On the roads, around 40% of CO_2 emissions are attributable to lorries.

In 2007, the European Commission adopted a Freight Transport Logistics Action Plan, as part of a package of measures including proposals concerning logistics, a rail network giving priority to freight and serving ports, as well as two documents on a barrier-free European maritime transport area and the motorways of the sea. The Action Plan suggests a range of actions in areas such as electronic information on freight, training and quality indicators, simplification of processes, vehicle sizes and loading units.

Legislation that limits the maximum size and weight of trucks (Directive 96/53/EC) together with provisions for Combined Transport operations (Directive 92/106/EEC) are being re-evaluated with the view to making more efficient use of infrastructure capacity and distribution logistics. This includes potential wider use of European Modular System (EMS) vehicle combinations 25.25 metres long. These vehicles are in regular use in Sweden and Finland, with trials underway in some other member states (Netherlands, Denmark and some northern German States). The Commission is conducting preparatory studies to assess options for, and implications of, possible revision of the rules in force to facilitate wider use of EMS vehicles. Further analyses will be carried out before any decision can be taken by on the merits of amending the Directive.

Key elements of the policy on which regulatory decisions are based in the EU are:

- The principle of co-modality, (the efficient use of different modes on their own and in combination) has been adopted as the approach to achieve optimal and sustainable utilisation of resources.

- European-wide standardisation of various conditions of road freight transport, such as driving licensing, working conditions and easing of administrative burdens.

- Establishment of national electronic registers for infringements of Community legislation for road freight transport and interconnection of these registers so as to obtain harmonisation of sanctions for such infringements.

- A Directive on road charging for heavy vehicles that seeks to prevent discrimination, or charging monopoly rents, by requiring charges to be based on road expenditure but allows nations to charge some of the external costs associated with road transport in congested and polluted areas.

- A target to produce 20% less CO_2 by 2020 for the EU as a whole, across all sectors of the economy, compared to a 1990 baseline.

- Substantial funding of the GALILEO project to provide road transport with accurate positioning data for advanced road charging and driver support systems.

United States

In the United States, current federal commercial motor vehicle size and weight limits reflect a balance of safety, infrastructure preservation, and vehicle productivity. Increased attention to the related issues of climate change and energy conservation could add two additional policy considerations to this balance. As those policy considerations are resolved, federal and State authorities continue to work cooperatively with the private sector to research new technology to improve vehicle productivity, and to integrate established and emerging technology into enforcement protocols. These efforts seek to improve the efficiency and fluidity of freight movement on the transportation network and significantly improve the effectiveness and allocation of law enforcement resources. The following are several examples of efforts in this area:

- Freight Performance Measures – Clearly understanding system performance from the perspective of freight movement is integral to focusing and targeting resources to optimise system fluidity. The federal government is working cooperatively with numerous private truck carrier fleets to share information to quantify system performance. The private carriers provide validated but anonymous GPS transponder data to the federal government through a neutral third party. That data is then aggregated to provide travel speeds and travel time reliability on major freight corridors of the US Interstate System.

- SmartRoadside – Operational and fixed asset resources for both the public and private sector are expensive and need to be optimised. To improve the utilisation of existing resources, SmartRoadside seeks to evaluate commercial motor vehicle compliance with safety, weight and driver credentials at highway speeds. It utilises weigh-in-motion, vehicle to infrastructure communication protocols, and electronic integration of over dimensional permits into the Commercial Vehicle Information System and Networks (CVISN) programme. This better targets law enforcement efforts on the violators while improving the efficiency and speed of legal and safe operators.

- SmartPark – Adequate commercial motor vehicle parking capacity on the highway network is a challenge. The truck parking programme seeks to better manage existing capacity and expand where possible. This programme pursues corridor level solutions or scalable/replicable projects that can be leveraged across the system. In addition to building more parking facilities, the United States is exploring information technology solutions to enhance efficient use of all available truck parking through the SmartPark programme. The U.S. Department of Transportation has partnered with the private sector in the SmartPark research programme, where Federal and State government agencies are working with the telematics and trucking industries to provide dynamic truck parking availability information to truck dispatchers and drivers across a multi-state region, or along a corridor, so tired drivers can find a safe and legal area to rest. Current efforts include projects on two major north/south corridors – one on the east coast and one on the west coast.

- SmartWay – The U.S. Environmental Protection Agency has partnered with the private sector in the implementation of the SmartWay^{SM,}, an innovative brand that represents environmentally cleaner, more fuel efficient transportation options, where the brand identifies products and services that reduce transportation-related emissions.

- SAFETEA – The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) was enacted August 10 2005, as Public Law 109-59. The law authorises the Federal surface transportation programmes for highways, highway safety, and transit for the 5-year period 2005 through 2009. The U.S. Department of Transportation is in the process of identifying reauthorisation initiatives that could greatly improve highway safety. An important element of this process is the involvement of DOT stakeholders, partners and the general public. To this end, listening sessions have been held across the country. Congress is currently considering an extension of SAFETEA-LU to continue existing surface transportation programmes for an additional 12-month period to allow more time for the enactment of a new multi-year surface transportation authorisation bill.

Canada

Regulation of trucking is split between the federal government and the governments of Canada's thirteen individual provinces and territories, with the larger role played by the provinces/territories. Despite the sharing of authority, jurisdictional coordination is a feature of trucking regulation in Canada. The Council of Ministers Responsible for Transportation and Highway Safety, a body composed of the federal, provincial and territorial Ministers, oversees a framework of organisations that have, as part of their mandate, to reconcile differences in regulations.

A key feature of trucking productivity in Canada is an agreement on a set of minimum weight and dimensional standards to allow trucks to operate on the main highways across the country. These truck configurations are defined in the Memorandum of Understanding Respecting a Federal-Provincial-Territorial Agreement on Vehicle Weights and Dimensions. Since being signed in 1988, the Memorandum has been amended six times to add truck configurations and adjust standards for existing configurations, most recently in 2009.

The growing emphasis on environmentally responsible trucking has introduced a new variable in the regulatory decision-making process. Trucking associations are requesting changes that will allow them to adopt environmentally friendly equipment without necessarily sacrificing fuel efficiency. In 2008, the length standards of the Memorandum were amended to allow a two foot aerodynamic device on the back of a truck, and increased weight was allowed on wide-based single tyres. Other changes that have been requested are under currently consideration.

The challenges facing trucking, from road congestion to regulatory barriers, are being examined as part of the federal-provincial Gateway and Trade Corridor initiatives. These are long-term, system-based studies being undertaken to promote future transportation systems that allow for efficient, integrated, reliable and sustainable movement of goods and people. There are three initiatives under Canada’s national Gateways and Trade Corridors strategy that collectively span the country from west to east, the Asia-Pacific Gateway, the Ontario-Quebec Continental Gateway, and the Atlantic Gateway.

Sustained system fluidity is a key success factor in Canada’s national Gateways and Trade Corridors strategy. Yet, no systematic national measurement exists to monitor performance and fluidity at key gateways over time, a gap that Transport Canada (TC) is now focusing its attention on. TC is developing a fluidity measurement of the time required for goods to move through our transportation system or in logistics terms: time to market measurement. This approach is predicated on the premise that system impediments or bottlenecks translate in goods spending more time than necessary or planned at those points and ultimately translate into lower productivity and efficiency.

At the macro level, the issue is one of time and overall performance. TC plans to focus on some key city-pair combinations for import and export traffic (*e.g.* Shanghai to Toronto via Vancouver). The indicators will measure the overall fluidity of the North American segment of international supply chains. This will include movements of import and export goods through its multimodal journey along major gateways and corridors and at key border crossing points. The objective of our system-wide analysis is to capture data measuring the fluidity of a movement to and from these points.

Australia

In Australia there are several key policy reform agendas in play.

- Greater focus is being given to national transport outcomes through the creation of Infrastructure Australia – a national body advising the Australian Government on where and how to get investment in critical national infrastructure. Australia's leaders are also directly engaging and driving transport policy reform through the Council of Australian Governments, particularly in relation to the integration of multimodal transport and land use planning.

- In the road freight area there is a continuing push towards more direct performance based regulation whereby vehicles of non-standard design that meet these standards are granted access to the parts of the network to which the particular standards apply. The standards that apply in high risk areas are considerably more stringent than those that apply in the low risk areas such as Australia's 'Outback'.

- Considerable effort is being applied to pricing heavy vehicle road use correctly. The marginal cost of a truck operating on a low standard road is generally high, whereas it may be low on a purpose built truck road. The present 'one size fits all' approach to pricing leads to under recovery on some roads which can make sea and rail freight transport uneconomic.

- Investigations are under way to closely examine the effects of managing roads in a more commercial manner - like other utilities such as water and electricity. Road authorities would have greater control over their income and expenditure – income through more direct road user charges, and expenditure by way of greater autonomy when it comes to road investment. This approach would align road management practice more closely with the more commercial approaches in freight transport modes such as rail and sea and could lead to more efficient national outcomes. It could also encourage asset owners to optimise asset use and invest in the network where the greatest returns could be expected.

- National regulation and licensing of heavy vehicles is to be implemented. Presently this is done on a state by state basis (6 states and 2 territories) and despite the best of intentions there are barriers to operating across state borders.

1.6. Evolution of freight transport in OECD and ITF countries

Freight transport has both enabled, and had to adapt to, many economic changes: the dispersal of production, just-in-time operation, increasing internationalisation of trade and the extensive use of new technologies. The quantity of both national and international goods movements have increased substantially. In response to the liberalisation of trade, the transport offer (services and number of companies) has expanded and competition in transport activities has become increasingly fierce.

This chapter briefly presents major worldwide developments in the volumes of freight transported and the logistic organisation of freight transport. It discusses the factors that determine the costs and productivity of road freight transport and some of the factors that influence modal choice.

***Important remark**: A choice was made regarding the unit selected to describe the quantity of goods transported. Two units are traditionally used to measure flows of freight transport: the tonne and the tonne-kilometre. We will use tonne-kilometres (*t-km*) in this report, except where full data in tonnes are available. However, the share of dense, heavy products (coal, steel, etc.) in the volume of transport has decreased and the share of manufactured products, with a higher financial value but of lower density, has increased. These changes directly affect the economy of a country but are not measured by the traditional units (Savy, 2007). The volume of freight transport measured in m^3 and, consequently, in m^3-km may well become the reference in future, on account of the increasing relevance of volumetric constraints.*

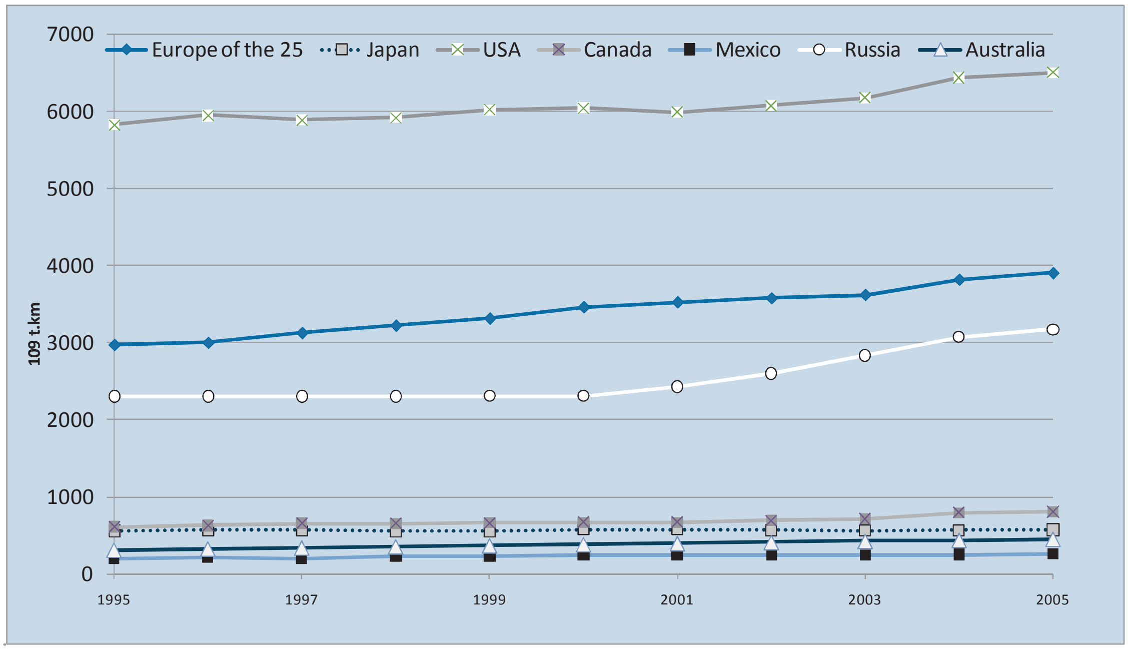
Globally, the quantity of goods transported has increased almost continuously. This growth in both quantities transported and distances travelled can be explained by a multitude of factors:

- The dispersal of production and distribution structures: some producing enterprises have elected to decentralise their production sites, among other things to reap the benefits of cheap labour.
- Living habits and emphasis on consumer choices: any consumable good is now available any time of year. This advantage for consumers often results in goods being carried from very distant countries.
- Stock management: to save costs, enterprises tend to produce goods "just in time" while minimising their stocks. This results in a so-called "rolling store" mode of transport.
- E-commerce: this system enables each citizen to order with a simple mouse click a variety of goods which he would like to receive rapidly. This type of commerce has been booming since the beginning of the 21st century. Transporters have been forced to adapt themselves to this new form of commerce among other things by strengthening their delivery capabilities.

Many of these changes have been enabled by a relatively low cost of goods transport. However, the resulting increase in freight volumes may vary from country/continent to country/continent according to their specific economic, geographic, political, social and ecological characteristics.

To illustrate these variations on a worldwide scale, Figure 1.4 shows how the volume of freight transport (all modes) has changed over time. The volumes shown in Figure 1.4 are expressed in tonne-kilometres of domestic freight. Domestic freight was chosen in order to identify the trends within each region and to allow those trends to be compared at the global level.

Figure 1.4. **Worldwide evolutions of the volume of domestic freight transport (in billion tonne-km)**



Sources: European Commission, Directorate-General Energy and Transport, Japan Statistics Bureau, Transport statistics in North America, Federal State Statistics Service (Russia), ITF, Bureau of Transport and Regional Economics (Australia).

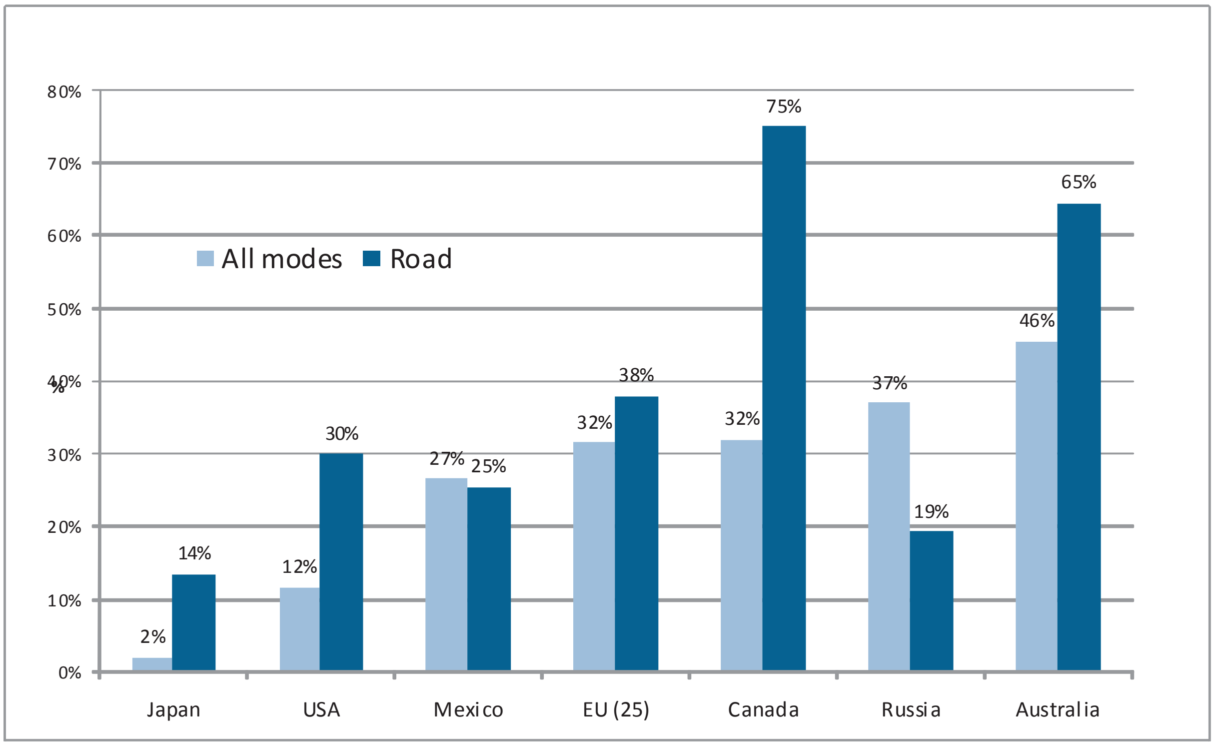
Figure 1.4 shows that the United States transport the highest quantities of freight with a total volume of 6 500 billion tonne-kilometres in 2005. Despite these high quantities, US freight growth as a relatively modest 11.5% over 10 years. (However these data do not include container freight that is shipped inland without being opened and repackaged at the port.) The EU-25 and Russia recorded freight volumes of 3 900 and 3 173 billion tkm respectively in 2005. Over the 10-year period, Europe exhibited a much higher growth (32%) in domestic freight transport than the US. The annual average growth rate for Europe was 3.15% between 1995 and 2005, but this masks considerable variation in different Member States. For example, in 2006 the Czech Republic, Estonia, Hungary and Poland showed respective growth rates of 12.8%, 7.5%, 7.4% and 10.5% (ITF, 2008). These high, and in some cases record, levels of growth were strongly influenced by adhesion to the European Union during this period, which considerably increased economic growth.

Russia shows a growth of 37% over 11 years. This growth is connected to the economic recovery of Russia after the fall of the Soviet Union in 1991, which caused a substantial decrease of domestic freight transport between 1991 and 1995.

Canada, Japan, Australia and Mexico show lower overall quantities of freight (806.6 billion t-km, 570 billion tkm, 453 billion tkm and 259 billion tkm respectively) and very different rates of growth (1995-2005) ranging from 2% in Japan to nearly 50% in Australia.

When demand for transport increases, the additional freight will be distributed amongst the existing modes of transport: road, rail, sea, inland waterway, and pipeline. However, this is not necessarily an equal distribution and an increase in the total volume of freight transport does not always imply an increase in road transport. Figure 1.5 shows a comparison between the increase in volumes of freight transported by road and the equivalent increase for all modes of transport. Except for Russia, where road transport has a low market share, and Mexico the growth in road transport is greater than the growth for freight overall.

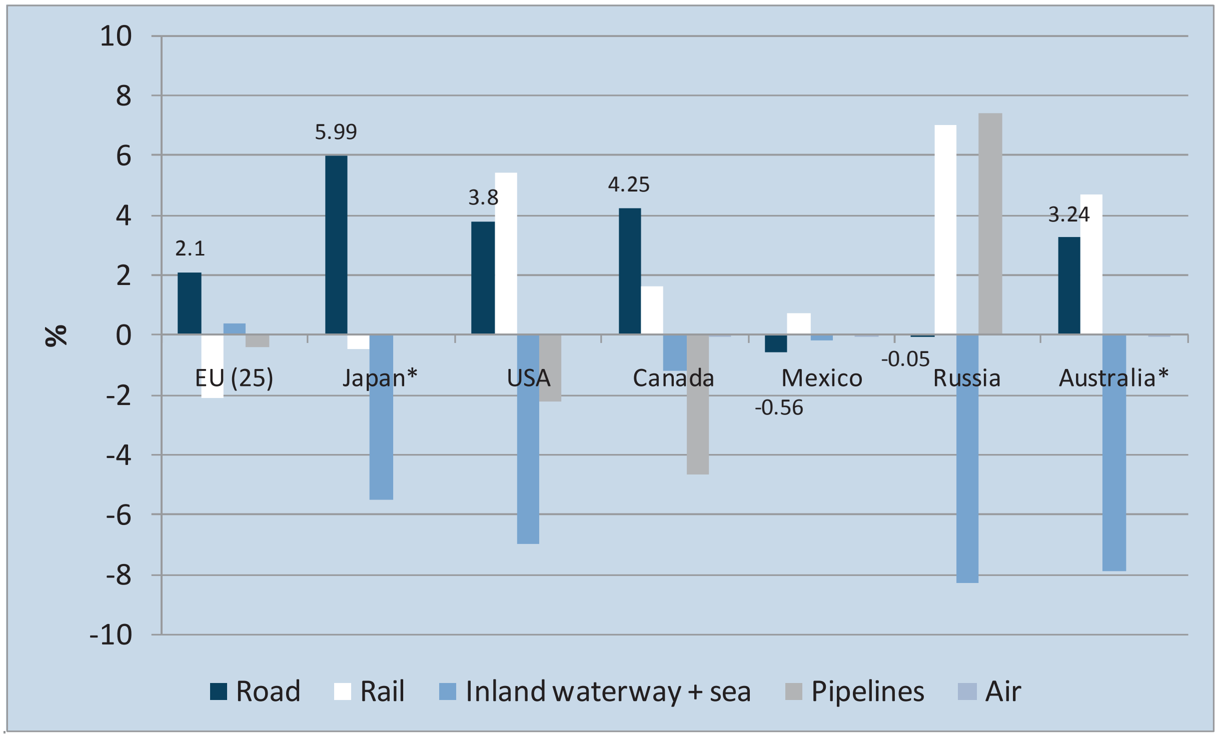
Figure 1.5. **Volume growth for domestic freight transport by road and all modes between 1995 and 2005[1]**



Sources: Calculation based on European Commission, Directorate-General Energy and Transport, Japan Statistics Bureau, Transport statistics in North America, Federal State Statistics Service (Russia), International Transport Forum, Bureau of Transport and Regional Economics (Australia).

Figure 1.6 shows the evolution of the modal shares for freight transport between 1995 and 2005. Except for Russia, where roads market share is very low, and Mexico, where rail is the dominant mode, road's modal share increased between 1995 and 2005 in all the countries analysed. However, it should be noted that figures for the EU-25 mask variations between individual Member States (for example rail increased its market share in the UK between 1995 and 2005). More significantly rail growth outstripped road growth in the USA, Russia and Mexico where rail already accounts for a larger share of overall freight than road. At the same time it should be noted that coal and petroleum, which are poorly suited to road haulage, dominate railway traffic on the world's major railways. These fuels generate between 40 and 50 percent of the tonnes and tonne-km of the traffic on the freight railways of the US and Russia as well as China and India. The EU 10 countries generate slightly over 40 percent of their traffic from coal and petroleum as well. The EU 15 railways are less coal and petroleum-dependent than the larger railways, but still haul about 15% of their output as coal and petroleum (Thompson, 2010).

Figure 1.6. **Evolution between 1995 and 2005 of the modal share for freight transport**



* Data on pipeline transport not available.

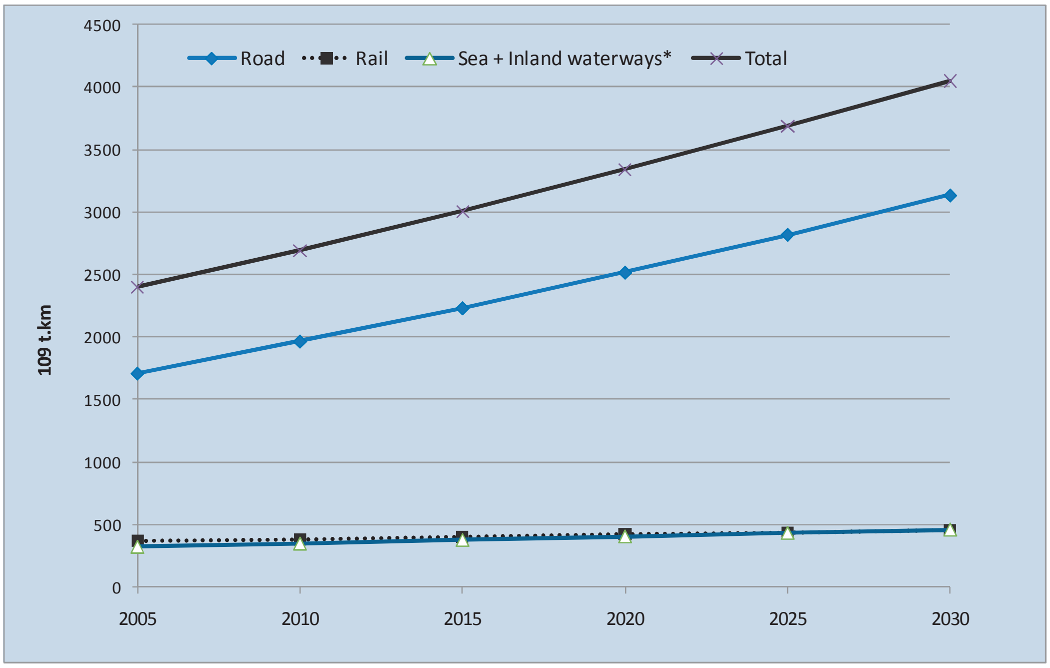
Sources: Calculation based on European Commission, Directorate-General Energy and Transport, Japan Statistics Bureau, Transport statistics in North America, Federal State Statistics Service (Russia), International Transport Forum, Bureau of Transport and Regional Economics (Australia).

The growth of road freight transport has been significant for many years. This trend is evident in most of the countries analysed above, and is likely to resume even if the economic crisis limits growth in the short term. In the United States, for example, it is expected that the volume of road freight (in tonnes) will double between 2000 and 2035 (FHWA, 2008) and reach 22 billion tonnes.

In Europe, the European Commission anticipates that by 2030 the volume of freight transported by road could rise by 83% (tkm) over a 2005 baseline, as shown in Figure 1.7 (European Commission, 2003). In Australia, projections made by the BTRE (Bureau of Transport and Regional Economics) suggest an annual increase of just over 5% for road freight transport, reaching a total of 290 billion tonne-kilometres by 2020.

The structure of freight transport in the EU-25 is atypical for the OECD as a whole, with a much lower and rapidly eroding rail share. In the United States, as well as India and China, rail freight may grow at similar rates to road freight transport, and in Russia the geography of the country implies that rail freight growth is likely to outstrip road freight growth substantially. In all cases, however, the rate of growth of road freight transport will put pressure on the capacity and management of road networks.

Figure 1.7. **Projections for volume of freight transport in the EU-25 by 2030**
billion tonne-km



* Inland waterway and sea transport at the national level only.

Source: European Commission, Directorate-General Energy and Transport.

1.7. Road freight costs

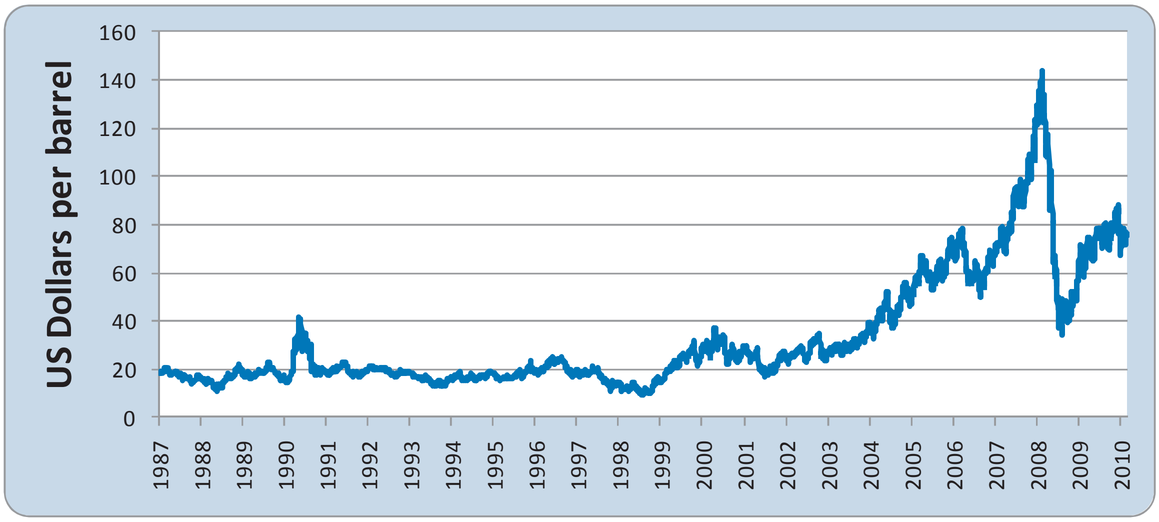
1.7.1. Prospects for road freight transport in the light of rising oil prices

The analysis presented in the preceding section suggests that the leading role of road transport in accommodating growth in the volume of freight transported will persist. Most projections pre-date the large oil price variations of 2007 and 2008 (see Figures below). Early in July 2008, the price of a barrel of crude oil flirted with USD 150. This was 50% higher in real terms than the previous peak of 1979-80. It then dropped sharply to hit USD 33 In December 2008.

Prices rose in the high-growth but unsustainable economic conditions of early 2008, as demand outstripped growth in oil supply. Supply was affected by political instability in parts of the Middle East, Africa and South America and by high materials and labour costs in a generally overheated economy. Collapse of the bubble in financial markets and the subsequent credit crunch and economic recession saw oil demand and oil prices plummet.

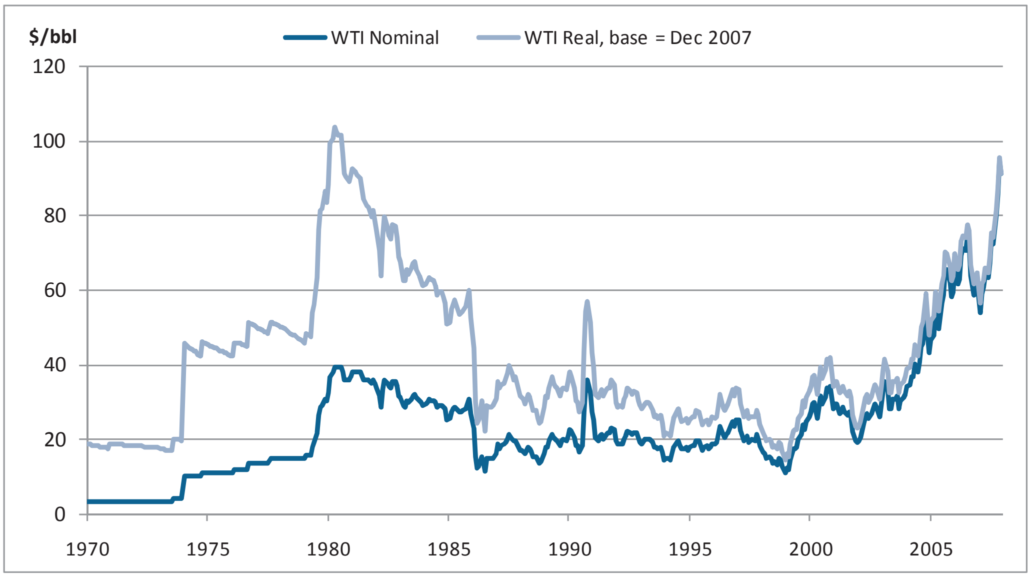
For the longer term, the outlook for oil prices is increasingly uncertain (ITF, 2008-1). OPEC market power is expected to increase as OPEC, and particularly the Middle East, will see its share world oil supply increase because production of conventional oil from other parts of the world has reached a plateau for the foreseeable future. OPEC will therefore be in a strong position to defend high prices against a background of rising demand, particularly from the emerging economies. That is not to say prices can only rise, as the recent economic crisis underlines but the freight transport sector should expect to be faced with generally increasing, but increasingly unpredictable fuel prices in the coming years.

Figure 1.8. **Crude oil prices 1987-2010**
Daily Europe Brent Spot Price FOB



Source: US EIA, http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=D

Figure 1.9. **Spot crude oil price 1970-2007: real and nominal prices**

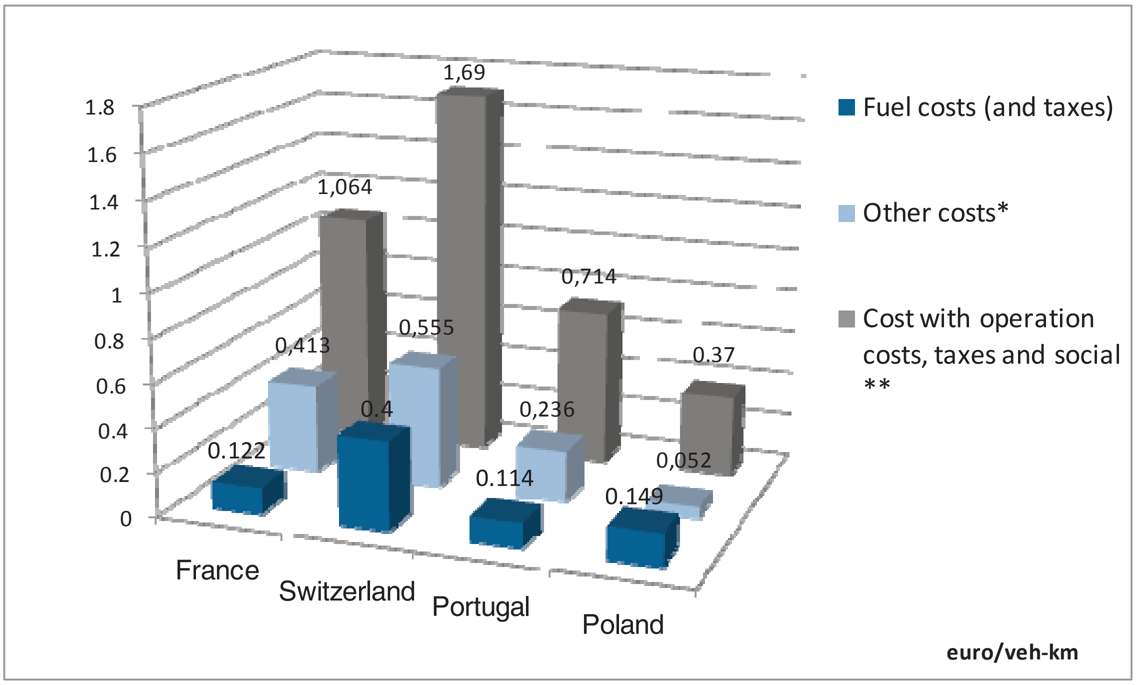


Notes: Price sources: Dow Jones for pre-Jan 1985 data, Platts monthly Cushing spot west Texas intermediate (WTI) crude from January 1985; Deflated taking December 2007 baseline and using monthly OECD consumer price index data.

Source: IEA, published in ITF 2008-1.

Chevroulet (ITF, 2008-2) analysed the importance of oil prices for freight transport costs in several countries, finding that in 2008 fuel prices in Europe account for only a fifth of transport costs on average, although the proportion varies markedly and for example in the UK was closer to one third. Operating costs, wages and taxes make up the remaining share. Figure 1.10 approximately represents the cost structure of a 40 tonne vehicle travelling 100 000 km a year (in 2003).

Figure 1.10. **Fuel (diesel) costs in the total cost of European road freight transport in 2003 (in euros/vehicle-kilometre)**



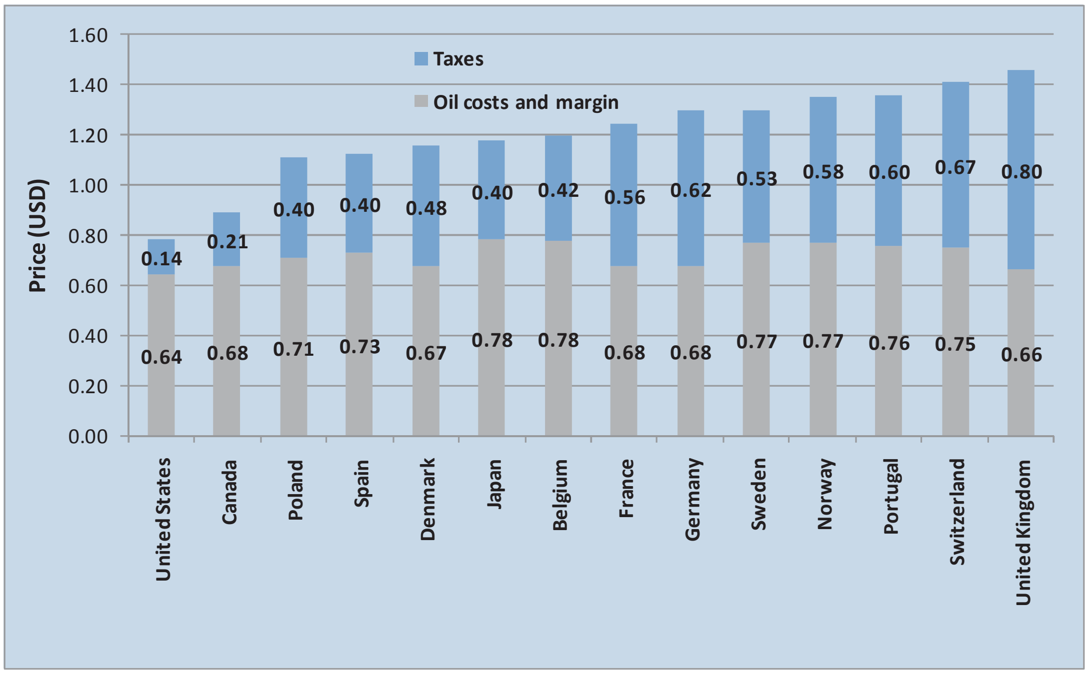
Sources: Chevroulet, ITF (2008-2).

* Includes: VAT, road taxes, vignette, performance-related heavy vehicle fee.
** Includes: wages, vehicle depreciation or leasing, servicing, repairs, tyres.

These data show that fuel cost contributes between 7.6% (France) and 26.1% (Poland) of the total cost of transport (Portugal: 10.7%, Switzerland: 15.1%). Therefore, to double total transport costs the price of fuel would have to be multiplied by 8 on average, with this factor ranging between 4 for Poland and 13 for France. These wide differences are due, to a large extent, to the importance of the fuel tax systems in the various countries. Figure 1.11 presents a worldwide overview of various taxations in force in 2008. It can be seen that, whereas the pre-tax price of fuel is more or less the same across countries, the taxes are very variable ranging from USD 0.14 in the United States to USD 0.80 in the United Kingdom. In Europe, the price of fuel at the pump breaks down into approximately 40% taxes, 50% oil price, and 10% refining and distribution costs.

It can be concluded that the price of crude oil has only a limited effect on the total cost of freight transport by road. To double the cost of road transport at constant taxation, the oil price of 2003 (*approx.* USD 28.5/barrel) has to be multiplied by 14. This multiplication factor is large and implies an oil price of USD 400 to double the cost of road transport compared to the situation in 2003.

Figure 1.11. **International diesel oil prices for commercial use for one litre USD, 4th Quarter 2008**



Source: International Energy Agency (2009).

1.7.2. Transport costs, road freight transport demand and rail/road cross-elasticities

Whereas the link between rising fuel price and the cost of freight transport can be identified, the impact of rising transport costs on freight traffic in general is harder to assess. The economic literature on the price sensitivity of road freight demand is thin, much poorer than for passenger transport, and records a wide range of responses depending on the commodity carried, the methodology used, the geographical area studied and the distance travelled (Graham and Glaister, 2004). The size and the source of the price change for vehicle km travelled is also likely to have a significant impact on the response. The majority of the estimates for the price elasticity of demand for road freight services in the 143 studies examined by Graham and Glaister fell between -0.5 and -1.3, *i.e.* a 10% increase (or decrease) in cost per vehicle km would result in a 5 to 13% decrease (or increase) in vehicle km travelled. The authors caution that this can not be taken as a general guide, because of the sensitivity of the results to the specific circumstances of each market examined, but do conclude that the price elasticity of demand for freight is negative and relatively elastic.

A more recent review of the literature by the consultancies Significance and CE Delft (T&E 2010) comes to similar conclusions. They report that 80% of the 32 studies examined find elasticities in the ranges shown in table 1.2 They note that the values presented are characterised by rather high uncertainties with regard to fuel price changes, due to the limited number of studies that reported estimates for these elasticities, and to a lesser extent this is also true for vehicle kilometre price elasticities. They recommend that practical studies employing elasticities carry out sensitivity analyses to cover the elasticity range, instead of solely relying on mean values. They also recommend detailed modelling of price responses rather than simply using an average elasticity value to estimate impacts on freight transport demand whenever possible.

Table 1.2. **Results from the literature review of own-price elasticities**

Price change	Impact on		
	Fuel use	**Vehicle kilometres**	**Tonne kilometres**
Fuel price	-0.2 to -0.6	-0.1 to -0.3	-0.05 to -0.3
Vehicle kilometre price		-0.1 to -0.8	-0.1 to -0.5
Tonne kilometre price			-0.6 to -1.5

Source: T&E 2010.

A study conducted by the French national institute for transport and transport safety research (INRETS) towards the end of 2007, also assessed the price sensitivity of freight traffic to be within this range (INRETS, 2007; ADEME PREDIT, 2002). The study found that a 10% increase in fuel price reduced truck traffic expressed in vehicle-kilometres by 2.4% (for vehicles with a GVW exceeding 3.5 tonnes) with the demand for road transport expressed in tkm decreasing by about 1%. This difference can be explained, on the one hand, by more efficient vehicle management: fewer empty cargo returns and grouped consignments; and on the other hand part of the traffic shifts to rail. The cross-elasticity of demand for rail[2] with respect to fuel price was estimated at +0.2% (DAEI/SES, 1998, p.21).

One study using a value for average price sensitivity on the trans-European road network modelled the impact of reducing road freight costs 33% through the introduction of heavier (60 t) and longer (25.25 m) trucks (EC 2008). It found an initial reduction in the number of vehicle km driven of 13% as a result of authorising these HCVs for use on the TENt network impact was slightly offset by induced demand and through modal shift, which added 1% to truck vehicle km. Thus the net overall effect was a 12% reduction in vehicle kms driven.

There are limitations to the value of applying average values for price sensitivity across diverse markets. This is illustrated by a study in the UK (TRL 2008). This found that if 60 t, 25.25 m vehicles were to be permitted on UK roads, although the overall effects on freight transport demand were unlikely to be significant, induced demand and mode shift from rail to road could counter the reduction in truck vehicle km to an extent sufficient to cause a net increase in the emissions of CO_2. TRL estimated an overall 8-18% rail to road shift in tonne-km carried if 60 t HCVs were to be authorised across the network, with a very large impact on the deep sea container market. TRL reports lower estimates from studies of the trials of HCVs in the Netherlands, with a shift of 1.4 to 2.7%. This is thought to reflect fundamental differences between UK and Dutch markets, notably the high proportion of international rail freight in the Netherlands.

The impact of the costs of transport on demand for freight transport services varies greatly between market segments. Variations in the cross-elasticity between road and rail freight are particularly large, highly sensitive to the relative size of road and rail freight shares in the market segment of interest and poorly researched. This is reflected in the difference between the EC, DAEI and TRL results. The United Kingdom is far from typical for Europe, differences between European, Japanese, North American and Australian markets are pronounced and the results of these kinds of study are not easily transferable.

1.8. Road pricing for trucks

1.8.1. Pricing principles

An appropriate road pricing regime is seen by many as a key requirement in the development of efficient surface freight transport.

In most countries road user charges are not closely related to road use and the associated infrastructure or social costs. The main charging instruments are some form of fixed periodic charge (*e.g.* vignette or registration charge) and a fuel tax. Revenues from these charges generally accrue to central government funds, although in some countries they are paid into dedicated road or transport funds. In most countries, local government, although responsible for a substantial proportion of road expenditure, receives no revenue directly from charges.

Where cost allocation approaches are used to achieve full recovery of calculated road expenditures (*e.g.* Australia), cost recovery for each vehicle class may still not be achieved (with over-recovery and under-recovery in different classes) and there is little relationship between charges and the costs that individual vehicles actually impose.

Cost allocation involves estimates for the cost of road provision and use for defined vehicle classes. These estimates are based on vehicle characteristics (*e.g.* vehicle length as a measure of road space, fourth power of axle mass as a measure of road wear) and the average distance travelled by vehicles in the class.

Cost allocation systems are based around averages for:

- Mass and distances for vehicles within a class.
- Relationships across road types.
- Expenditure over several years.

Within each vehicle class, averaging tends to under-allocate costs to vehicles which carry lower loads, travel lower distances and travel on higher quality roads and under-allocate costs to other vehicles.

Whilst such cost allocation calculations are undertaken in many countries, in most there is little linkage of road charges with road expenditure, no provision for charging for externalities (environmental, safety and congestion costs) and no hypothecation of charge revenues to road expenditure.

Partial exceptions to this generalisation include:

- Toll roads (where total charging is based on road expenditure), although price differentiation between vehicle classes may not be based on cost allocation.
- Differentiation of registration (vignette) charges on the basis of emissions performance (*e.g.* by type approval emissions class – Euro 3, Euro 4, etc.).
- Electronic charging systems for heavy vehicles using roads in Switzerland, Germany, Austria and the Czech Republic, which charge on the basis of distance driven and differentiate between emission classes.

There is usually no mechanism for transport operators to select higher vehicle or axle masses and elect to pay for the associated higher level of asset consumption, irrespective of the potential productivity benefits.

In the absence of direct linkage between costs and the revenue required to maintain/enhance road assets, many road agencies are reluctant to allow any change in vehicle characteristics that could lead to more rapid deterioration of their assets. In most countries, adoption of a new approach to road pricing for heavy vehicles would need to involve central agencies (*i.e.* Finance Ministries) as well as road agencies, as it cannot easily be separated from broader revenue and funding arrangements.

In order to optimise the efficiency of heavy goods transport, the primary objective of a more refined road pricing system would be to charge more directly link in relation to road wear. Road pricing systems can also be used to improve efficiency in a number of other ways, particularly when they encompass cars as well as trucks. Differentiating km charges and tolls by place and time of day/week can be used to manage congestion, which on busy parts of road networks is the highest external cost of road use. Heavy vehicles are only the chief cause of congestion on small parts of the network, however, and if cars are not covered by a congestion charge heavy vehicles should be charged only part of the cost of congestion they cause[3] in order to maximise overall benefits.

On more lightly used parts of the network charges based strictly on the costs of using roads will not generate sufficient revenues to cover expenditure on road construction. The efficient approach to covering full costs in these circumstances is to recover construction and other fixed costs through a fixed charge, such as traditional annual road access fees (vignettes).

Fixed charges have been replaced with electronic km charges across the network in four European countries with significant transit traffic, partly to ensure foreign vehicles make a contribution to the fixed costs of providing the road network (Switzerland, Germany, Austria and the Czech Republic). Charging according to use avoids some of the issues of discrimination that arise with time based network access charges for foreign vehicles but it adds to political sensitivity over the maximum level of the charge. Variabilising charges in this way provides incentives to use fewer vehicles to move goods with less empty running, through changes in logistic organisation and fleet management, although establishing the level of charge that distributes costs between the road provider and fleet operators most efficiently becomes complicated when the charge for fixed and variable costs is combined.

Better linkage of road use to variable road expenditure (maintenance and renewal) would enable road freight operators to choose and pay for a level of consumption of the road asset and pass that revenue on to road owners for asset maintenance. If road owners were confident that they would receive infrastructure-related road revenues, they would have an incentive to respond to demands for the operation of higher capacity trucks.

In effect, more sophisticated pricing and funding arrangements has the potential to allow some flexibility in the use of prescriptive mass limits applied to vehicle classes and introduce some scope for choice of operating mass by transport operators.

Linkage of road wear and road use would potentially enable attribution of road costs by axle mass, road type and road condition. Attribution of these costs to individual vehicles would mean that they could be factored into route choice, vehicle choice, axle mass and vehicle configuration by transport operators and into mode choice by users of transport services.

1.8.2. Impact of pricing on modal choice

In some cases, heavy vehicles are currently undercharged for their use of the road network and more sophisticated pricing arrangements might then lead to modal shift from road to rail. In some cases, the opposite is true. The effects of class averaging, which leads to under-recovery from the heaviest vehicles and those travelling the longest distances, are generally small relative to total charges and to operating costs. Cost-averaging across road types may lead to over-recovery from the vehicles which use the most durable roads (with the lowest road wear costs), and these are probably the vehicles that compete most directly with rail. Potential charges for externalities would be lowest in non-urban areas, where road and rail compete most directly, and greatest in urban areas where there is little potential for substitution between road and rail transport.

In countries where rail track or rail operations are owned by government, rail access prices or rail service prices respectively are often set at levels which do not provide for full cost recovery. In some OECD countries charges for the use of rail infrastructure do not even cover short run marginal costs (see Charges for the Use of Rail Infrastructure, ITF 2008). This illustrates that it is difficult to generalise about the impact of changes in the pricing of transport infrastructure on modal split. The result will depend on prevailing conditions nationally for each of the modes.

Ensuring equal terms for competition between the modes would require that the same principle for pricing is applied across modes. The principle could be charging according to the long run costs of providing and maintaining infrastructure, or charging the short run costs of using existing infrastructure (wear and tear and maintenance plus charges to internalise environmental and safety costs), or it could be another formula. Clearly, these are not equivalent pricing regimes, and the choice is largely political. Few if any countries currently apply consistent pricing principles to the use of their roads and railways.

In conditions where the full social costs of each freight mode are not addressed by infrastructure charges and regulatory standards, then a shift of freight from rail to road could have a net adverse social impact. Concern that this might be the case has sometimes led to calls for restriction of access to the road network for higher capacity trucks. Conversely, a higher maximum mass can be authorised for trucks operating in intermodal transport to facilitate the transfer of standard containers. This is the case in Europe, where a 44 ton maximum mass limit applies to trucks serving intermodal terminals instead of the standard 40 ton limit.

One option for consideration in attempts to improve the productivity of heavy vehicles, whilst ensuring appropriate terms for competition with rail, is incremental pricing for additional mass and/or length. This would allow road transport operators to pay a supplementary charge for increased mass or network access, in addition to the standard fuel and registration charges. This revenue could be paid directly into a fund dedicated to the infrastructure costs associated with the use of these vehicles (pavement costs for increased mass and other infrastructure costs for increased length). As this option involves retention of conventional road user charging for the existing cost base, it would not require reconsideration of wider funding arrangements.

Where new vehicle classes are under consideration, existing charges could be removed for those vehicles and replaced with charges that depend on distance travelled, road type, social costs and other factors.

Both options would ensure that vehicles allowed additional mass and/or length and new vehicle types fully recovered infrastructure costs and provide a dedicated funding source for infrastructure costs associated with these vehicles. This would address the current incentive for road agencies to focus only on asset preservation, rather than achieving socially optimal levels of consumption.

NOTES

1. US data (all modes) do not include container freight that is shipped inland without being opened and repackaged at the port.

2. Rail transport of goods and passengers, in aggregate.

3. Calculated on the basis of the extent to which car traffic will grow to replace trucks priced off the road by comparing the elasticities of demand and relative values of time for truck and car traffic.

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CHAPTER 2. LOGISTIC CHALLENGES IN THE ROAD TRANSPORT MARKET

Abstract

This chapter gives a general overview of the relevant features of the transport sector. It discusses the issue of payload and volume capacity. It then describes the demand side (the stakeholders involved, their position in the supply chain, and emerging trends in logistics) and the supply side and its performance.

The road transport sector operates in a changing environment. Demand for transport is growing rapidly and shippers require more reliable, customised and responsive transport services, while maintaining or improving the efficiency of transport operations. In the meantime, the price of some parts of transport services (for example labour and energy) is increasing and framework conditions for operating road services (infrastructure, access) are becoming more restrictive. These factors are a challenge to continuing commercial success. The challenge for policy makers is to mitigate the negative externalities of road transport without undermining economic growth or preventing efficiency improvements. Achieving this will require a thorough understanding of how the road transport market functions and its role in the wider logistics chain.

2.1. Loading capacity – Massing out

The loading capacity of a road freight vehicle is limited by weight or by volume and it is the density of the load that determines which will be the case for any particular vehicle. Table 2.1 shows examples of the density of a range of different goods.

Table 2.1. **The density of common commodities (kg/dm³ = t/m³)**

Commodity	Density (tonne/m³)
Water, Milk, Beer, etc.	1
Fuel, Oil, Ethanol, etc.	0.6 – 0.8
Earth	1.3 – 2.0
Concrete	2.2
Briggs	1.9
Alloy	2.7
Steel	7.9
Wood (dry)	0.5 – 0.9
Rubber	1.2
Beer boxes with 20 empty bottles (0.3mx0.3mx0.4m) 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

Volume capacity

It is relatively rare to use single rigid trucks in long distance transport and typically tractor-semitrailer combinations (>50% in Europe) or truck-trailer combinations will be used. In many countries there is a distinction between the types of vehicles that have general access to the road network and the types which, because of their mass and/or dimensions, are restricted to only selected parts of the road network. The characteristics of the two groups of vehicles vary significantly between nations. Table 2.2 illustrates the variation between countries for vehicles with general road access.

Table 2.2. **Typical load unit lengths and volumes for freight vehicles with general road access**

Country/union	Tractor-semitrailer		Truck-trailer	
	Load unit length	Volume	Load unit length	Volume
Europe	13.60 m	100 m^3	7.45 m + 7.45 m	100-110 m^3
USA[1]	16.15 m	113 m^3	8.69 m + 8.69 m	123m^3
Australia[2]	14.60 m	103 m^3	8.3 + 7.3 m	110 m^3
Canada[3]	16.20 m	113 m^3	9.1 + 12,5 m	136 m^3
South Africa[4]	15.50 m	110 m^3	6.2 m + 12.2 m	125-140 m^3
Mexico[5]	15.30 m	105 m^3	7.01 + 7.01 m	80-90 m^3
Russia[6]	13.0-16.6 m	85-110 m^3	7.8 + 6.08 m	80-100 m^3

Example: In Europe the maximum payload (gross vehicle weight minus kerb weight) for both choices of units is about 25 t – 27 t. If one divides 26 t by 100 m³ then a unit will be fully loaded by both volume and weight when the density of the cargo is 0.26 kg/dm³ (or 0.26 t /m³). Data in table 2.1 shows that the transport of empty beer bottles in boxes (0.3 kg /dm³) would overload such a combination if all of the available volume was filled. However, many items carried by road transport have a density of less than 0.26 t/m^3, such as white goods, furniture, single dispatched items, insulating material, etc. In these cases when the volume is filled to capacity, the combination weight will be less than the maximum permitted gross vehicle weight.

Special high volume vehicles with a capacity of up to 125 m³ are available on the market in Europe without exceeding the maximum dimensions. Typically, these are truck-trailer combinations with a low frame obtained by using tyres with very small diameters and so-called “low coupled” trailers[7] to reduce the space between truck and trailer. Another way to increase volume capacity is to replace standard rigid semi-trailer axles by independent suspension at each wheel of the semitrailer. A European example is shown in Figure 2.1 (two floor semitrailer). The volume for cargo is increased by 63% from standard Euro 33 pallets to Euro 54 pallets.

In addition to the loading constraints due to volume and mass limits a third constraint arises when low density cargoes are structurally fragile and therefore cannot be stacked to the full height of a trailer because the mass of the load on top would crush the load at the bottom. In this case the vehicle is full when the load deck is full even though neither volume nor mass limits have been reached. For this type of load double deck increases the capacity. The double-deck or two floor trailer was developed as a solution to this problem.

It is often argued that most road freight transports are limited by the volume capacity rather than the payload capacity. The utility rate (in Europe) for volume is about 80% and for weight about 60%. This often leads to the suggestion that vehicle length should be increased and some European operators have suggested that the maximum length of a semitrailer should be increased from 13.60 m to 15.00 m. This would result in a long rear overhang behind the triple axles if the circular turn test (outer diameter 12.50 m, inner diameter 5.30 m) required by Directive 96/53/EC must still be fulfilled. Compared with existing vehicles this would substantially increase the tail swing that the combination would exhibit when entering a turn. Such a longer semitrailer unit with a GVW of 40 t and a total length of 17.80 m a loading volume of 110 m³ and a storage capacity of EUR 37 pallets runs under special permit in Germany.

Figure 2.1. **Two floor semitrailer with lift, 40 cm ground clearance and 4 m box height, length 16.50 m, single-wheel suspension on semitrailer for volume transports**

If a semitrailer with a longer rear overhang is fully loaded by both mass and volume, then the load on the trailer axles will be very near the limit. This means that if there is any asymmetry in the loading (*i.e.* some of the items at the rear are heavier than those at the front or if items are removed from the front during partial deliveries) then the trailer axles will be overloaded. To prevent overloading, and the resulting increase in infrastructure damage, an on-board axle weighing system can be installed on such longer vehicles, if not on all trucks.

Obviously, the more volume a load unit has for the same GVW, the less the density of the cargo must be. In other words: the risk of overloading increases.

Payload capacity

Trailers or semitrailers for transport of fluids, bulk goods, wood, building materials with a density (tonnes/m^3) that causes the *weight* limits to be reached at less than the allowable *volume* capacity (*e.g.* 0.26 tonne per m³ under European regulations) are usually designed with correspondingly smaller dimensions in length or height. Cylindrical tanks for fluid transport in Europe have only 78% of the volume of a comparable box body. Semitrailers for bulk loads: sand and earth, etc., are shorter and/or lower than maximum limits. For these vehicles, transport efficiency can only be increased by reducing tare weight. So the trend is to use alloy or carbon fibre reinforced plastics (CFK) instead of steel. The potential of these materials is shown by the vehicles in Figure 2.2, where the kerb weight of the tipping semi-trailer was reduced from 7.5 t to 3.6 t and the box body semi-trailer has an unladen weight of only 3.5 t. [*Kaiser/Lange: 7.CTI Forum Nutzfahrzeuge 2/2008*]

A trend to use alloy (for the tractor's frame) and carbon fibre reinforced plastics (for the cabin) can also be seen in future tractor construction. [*Marwitz: 7.CTI Forum Nutzfahrzeuge 2/2008*]

Figure 2.2. **Low weight tipper with CFK body and CFK box body type semi-trailer**

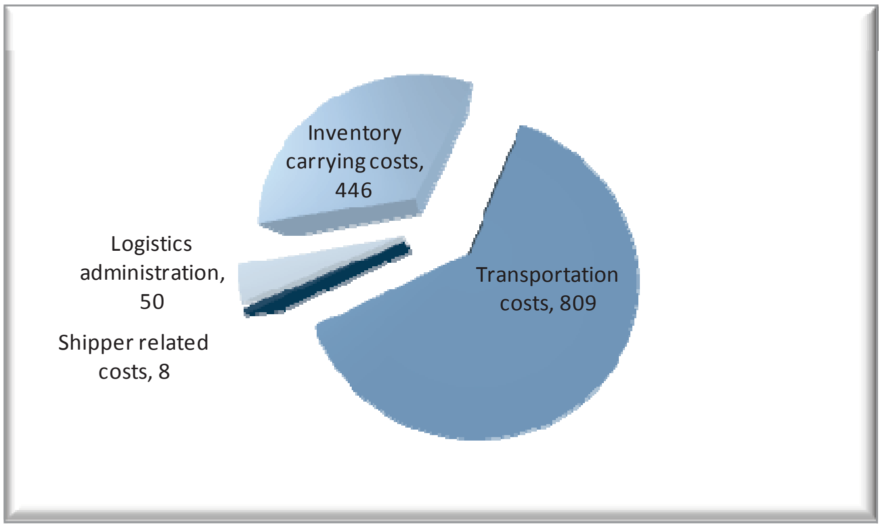
In recent years, conventional drum brakes have generally been replaced by disk brakes, because of their lighter weight and added benefits of reduced cost of maintenance and greater resistance to fading and failure. Similarly, heavy leaf springs have been replaced by lighter air suspensions and twin tyre assemblies on trailers, and semi-trailers have been replaced by wide single tyres.

Where tippers and tankers are shorter than the maximum permitted length, an increase in the permitted GVW would allow length to be increased to the maximum, but an additional axle (for a total of 6) would be required to ensure axle load limits were not exceeded. Such combinations[8] are in operation. However, in some countries, many secondary road bridges and some primary road bridges would not be capable of carrying the additional load (see chapter 8).

2.2. Transport as an element in logistics decision making

It is necessary to understand that the demand for transport services is a derived demand. Transport logistics is part of supply chain optimisation, where logistics structures are being developed in order to fulfil customer requirements in an efficient way, which means optimising the costs of production, warehousing, transport and inventory. The cost of transport is just one element of the total logistics costs, as shown in figure 2.3 (the long haul share of the transportation costs in the figure is USD 432 billion).

Figure 2.3. **Total logistics cost in the US in $billion**



Source: CSCMP (2007).

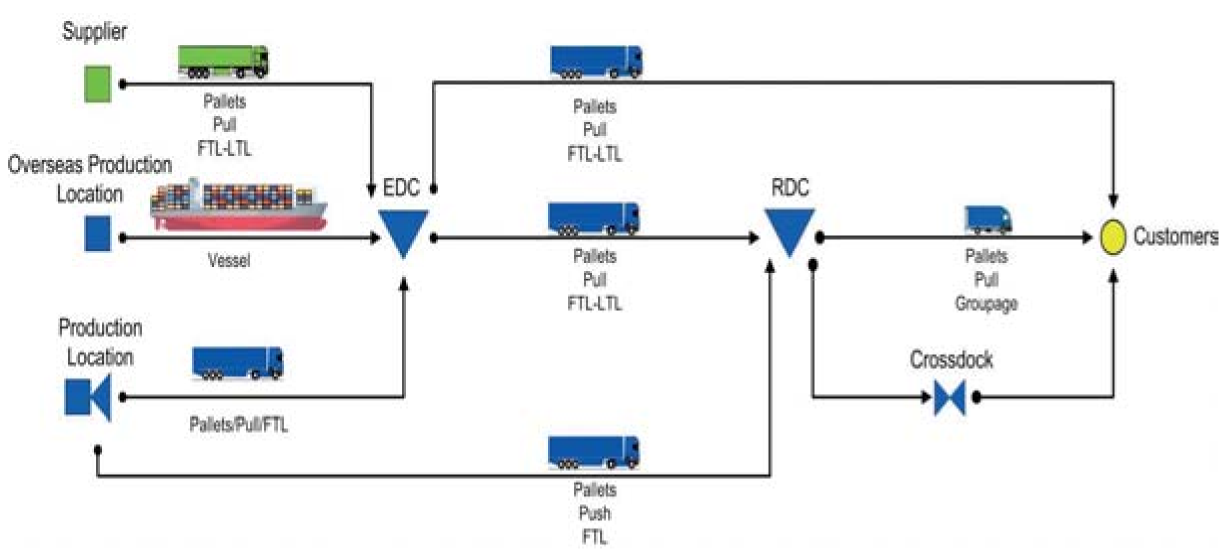
Inventory carrying costs include the cost of warehousing, taxes, depreciation, obsolescence, insurance and interest. The derived demand for transport services follows from specific logistic requirements, available distribution structures and inventory policies. Generally, demand for transport services can be cost driven or service driven. In many logistic transport chains, a service driven approach is dominant when the product lead time and delivery time are crucial requirements for the customer. However, there is a wide array of different logistics requirements in the different product segments and transport markets and there is no single logistics model that fits all requirements.

Many companies strive to become lean, reduce waste and eliminate activities that do not add value to their customers. Key characteristics of lean companies include having a product mix with high volumes and limited variants and a predictable demand pattern. These companies prefer to produce to stock instead of using order driven production. This allows them to keep inventory close to their customers and the distribution networks are designed to minimise logistic costs within these requirements.

Other companies organise their logistics in order to be agile. Agile companies have the ability to adjust to unpredictable events and changing customer requirements without keeping high inventory levels, thus avoiding high logistic costs. The main characteristics of an agile company include the flexibility to produce many different products or variants in smaller series, when reacting to less predictable demand patterns. Build-to-order concepts look promising for such markets as long as they can be achieved in a cost efficient way. The optimum logistics structure is completely different for these markets. Thus, road transport operators need to understand their role in the overall logistic process of their customers and ensure that their propositions add value to their customers.

An illustrative example of a transport chain for electronics products is presented in figure 2.4 (Europe).

Figure 2.4. **Illustrative example of a transport chain of printers and copiers (Europe)**[9]



Source: TNO (2009).

The distribution network shown is an example of the way that many electronics shippers have organised their European distribution. Production facilities can often be in both South-East Asia and Europe and many of them apply a two-tier distribution structure. The first tier involves a European

Distribution Centre (EDC) with good hinterland connections to major seaports in North-West Europe. The EDC can serve a large proportion of the West European market from this one central location. The second tier involves a network of different Regional Distribution Centers (RDC's) that enable them to deliver within reasonable delivery times. Transport between oversea production plants and the EDC often involves maritime transport to a major seaport in the vicinity of the EDC plus hinterland transport to the EDC, either by road, rail or inland waterway. Shipments from seaport to EDC and from EDC to RDC often involve large volumes, using Full Truck Loads (FTL shipments). Outbound logistics from distribution center to the customers often involves smaller shipment sizes. Either Less than Full Truckloads (LTL shipments) are used or the shipments are handled by groupage networks of logistic service providers.

The demand side of the road freight sector generally has two types of clients: the shipper (consigner or consignee) and the logistics service provider. The former increasingly hire the latter to take care of the transport and logistics of their goods. These logistics service providers can originate from traditional transport companies, freight forwarders[10], brokers[11] and storage companies, rental and leasing companies, or they may be information technology providers (4th party logistics service providers).

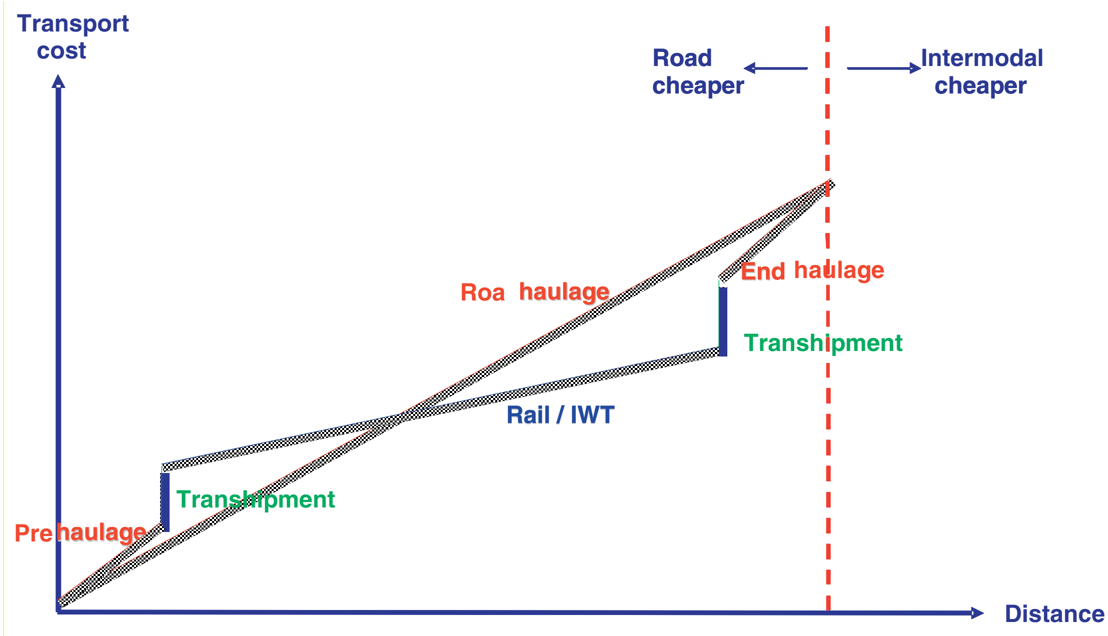
New business models and provider structures such as contract logistics – now referred to as "3PL/4PL" services[12] – are establishing themselves and creating new opportunities for rationalisation, quality enhancement and flexibility in trading and industrial companies. They place no value on having their own extensive resources for operational tasks such as transportation and warehousing. Instead, they prefer to use a "substructure" of logistics providers and their sub-contractors to carry out the work.

2.3. Transport decision making

The service requirements of the customer, the value density of the goods and the volume/weight ratio are all important factors in the transport decision making process. High value goods can bear more transport costs than low value goods. Therefore low value goods are usually transported by low cost transport modes (*i.e.* inland navigation, rail), if available, rather than by road or air.

Cost is, therefore, another important parameter in the decision making process, particularly the comparison between different transport modes. Figure 2.5 provides a generic illustration of a comparison of the costs of road haulage and intermodal transport. Transport cost per load unit kilometer for rail and inland waterway transport (IWT) are generally lower than for road transport, reflected by the steeper red line in the figure. However, rail or IWT often require additional transshipment and road haulage at either end in order to offer door-to-door transport services between origin and destination. These fixed transshipment costs mean that the cost advantage of the rail and inland waterway leg of an intermodal journey only result in a lower total cost on longer distances. On journeys of up to 500 km to 700 km road haulage often prevails.

Figure 2.5. **Cost comparison between road and intermodal transport**



Source: TNO (2009).

Other important factors in the transport decision-making process are speed, frequency, reliability and risk of damage to the cargo. For certain products, *e.g.* food, newspapers, flowers or fashion products, speed is very important. In these cases road transport or (for longer distances) air transport is usually used even if a cheaper alternative is available. If customers want to save costs on stock keeping, the frequency of deliveries will increase and the average shipment size will decrease, which also tends to favour road transport. Similarly, the just-in-time concept has placed a premium on reliability. Thus, the increasing congestion of road networks has reduced the reliability of road and could favour alternative inland modalities (rail, inland navigation). However, the risk of damage increases with an increase in the handling of the cargo. Intermodal transport typically needs more handling than door-to-door transport by road so the risk of damage in intermodal transport is generally considered to be higher than for road transport. On the other hand crash risks are higher for long-haul trucking in comparison with long-haul transport by rail or waterways.

The most important transport decision making factors are summarised in the table below. The scores in the cells refer to the relative scores (1 = best option, 3 = worst option) of the transport modes (road, rail and inland navigation) for each of the factors.

Table 2.3. **Relative scores of transport modes on modal choice factors**

Modal choice factors	Road	Rail	Inland navigation
Speed	1	2	3
Accessibility/network	1	2	2
Bulk transportation	3	2	1
Reliability	1	2	2
Frequency	1	2	3
Security	2	2	1
Flexibility	1	2	2
Risk of damage	2	3	1
Costs	2	2	1
Environmental Sustainability	3	2	1
Transparency	1	2	3

Source: Seals (2009).

2.4. Logistics drivers and trends

Increase in scale and globalisation of production

Recent decades have witnessed a strong growth in transport volumes and a considerable reduction in transport costs and there is a strong correlation between economic growth and growth in freight transport (OECD, 2004). The elimination of trade barriers has further reduced the total costs of moving cargo between production and consumption regions.

The growth of freight transport is expected to continue. The main drivers are: the increasing global population, globalisation and a strong growth in international trade, and the rise of emerging economies leading to new consumer markets.

Value density of goods, product customisation and responsiveness

Mass production is no longer suitable for many segments of the market, where consumers demand individualised products and services. As a consequence, assortment size has grown enormously, making logistics optimisation a complex challenge. Retailers require smaller and more frequent shipments to replenish their inventory levels. In response to the customisation trend, logistic concepts based on postponed manufacturing and mass configuration centres have resulted in value added logistics services enabling mass customisation. In addition, the product life cycle of many high value consumer goods has been shortened, causing a huge increase in the demand for such products.

Customer requirements are changing increasingly quickly and the level of consumer demand is becoming less predictable. The traditional approach to coping with unpredictable demand is produce goods for stock and hold high inventory levels in the vicinity of the market demand. However, for high value products this approach is very expensive. Alternative approaches require distribution structures that combine economies of scale with short lead times to quickly deliver the freight to the receiver. Build to order concepts based on flexible production capacity appear promising for such markets provided that they can be realised in a cost efficient way. Guaranteeing acceptable delivery times in this model is a significant logistics challenge and, as a result, production, inventory and transport are becoming more integrated. Two-tier distribution structures with central distribution centres supported by regional distribution centres support this dual challenge (see Fig 3.1). The fact that different markets have different requirements leads to a range of different supply chain configurations, all well equipped to serve different markets.

Other significant trends

In addition to the key drivers, some other trends are worth mentioning. These include:

- *Importance of reliability*: Reliable transport with predictable lead times is becoming a crucial factor in the optimisation of supply chains and the elimination of unnecessary inventory in the supply chain. Investments in smart Information and Communication Technologies (ICT), track and trace systems and chain visibility systems are important enablers of reliability.

- *Alternative distribution channels*: Internet sales and the resulting increase in home delivery require alternative methods of delivering freight to the final customer. The transport from distribution centre to shops is being replaced by transport from distribution centres to many delivery addresses in urban areas. This has negative consequences for load consolidation and requires a change in the characteristics of the fleet.

- *Environmental awareness*: Society increasingly demands green, sustainable transport with a reduced "carbon footprint". This often goes hand-in-hand with increased transport efficiency, because, for example, reducing vehicle kilometres means less transport cost and less pollution. Measures to control vehicle emissions and to implement road pricing are also likely to have a positive impact on transport efficiency. However, more restrictive measures, like access restrictions for trucks in city centres, might have a negative impact on efficiency.

Table 2.4 summarises the effect of the important trends and developments on the efficiency of transport.

Table 2.4. **Summary of trends in transport logistics and the impact on efficiency**

Trends	Effects on transport and logistics	Influence on efficiency
Increase in scale and globalisation of production	Enables transport operators to develop networks, including (multimodal) hubs	(+) Network developments enable transport operators to consolidate cargo which increases load factors and decreases empty running
	Specialisation causing multi-country distribution of production	(-) More transport movements over longer distances
	Increase in road network use	(-) Cause congestion thus harming reliability and efficiency
	Smaller transport companies become subcontractors to large operators	(+) May lead to better alignment between transport demand and supply which influences efficiency positively (-) May also increase complexity in the supply chain. Without the right coordination and with a lack of visibility, this causes inefficiencies along the supply chain
	Increase in transport distances	(-) More vehicle kilometres
	New integration and communication requirements	(+) Accelerates investments in new communication technologies which can be used to improve alignment between transport demand and supply
	More competition	(+) Transport operators are forced to improve their efficiency in order to remain profitable
Increasing value density of goods (value of goods per tonne or per kg)	Replacement of stockpile production by just-in-time deliveries, maximising responsiveness	(-) Leads to smaller and more frequent shipments, which might lead to decreasing load factors and more empty running
	Increased importance of reliability	(-) Operators opting for reliable delivery in all situations may do that at the cost of reduced efficiency
Developments		
Growing external risks and environmental awareness	Reconsidering transport modal choice	(+) Transport operators will try to further improve efficiency as proof of their 'green' performance
	Network optimisation	(+) Network developments enable transport operators to consolidate cargo which increases load factors and decreases empty running
	More recycling, reverse logistics	(-) Increased transport movement
Shortage of drivers	Drivers wages will increase, which will lead to higher personnel costs	(+) Transport operators are forced to improve their efficiency in order to remain profitable
Regulations on vehicle mass	Tendency towards capacity enlargement	(+) Reduction of vehicle kilometres
Regulations on time windows	Different time windows to enter city centres will lead to sub-optimal transport operations	(-) Transport operators are forced to reconsider number of stops per trip and/or vehicles used

2.5. Organisational structure of the road freight transport sector

This section starts with an introduction to the organisational structure of the sector, the relative market power of the transport suppliers and their clients (shippers) and how this influences price setting and contracting. It goes on to quantify how transport efficiency (*i.e.* load factor, empty running, and vehicle size) has improved as a method of cost saving.

Road transport takes many forms and can be characterised as strongly fragmented, both in the functional sense (from niche monopolies to severe competition in line haulage sector; from independent single driver companies to large professional carriers) and the geographical dimension (different countries with strongly different mixes of size and type of companies, as well as different services). Transport activities can be divided into hire-and-reward and private or own account transport activities. The different geographic transport services include domestic transport, international bilateral transport and cross-border trade (including cabotage)[13].

This market fragmentation has an effect on the power along the supply chain, giving the consignee a strong negotiating position compared with the smaller road haulage companies. The impact this has on market prices and profitability of the sector is described in the next section.

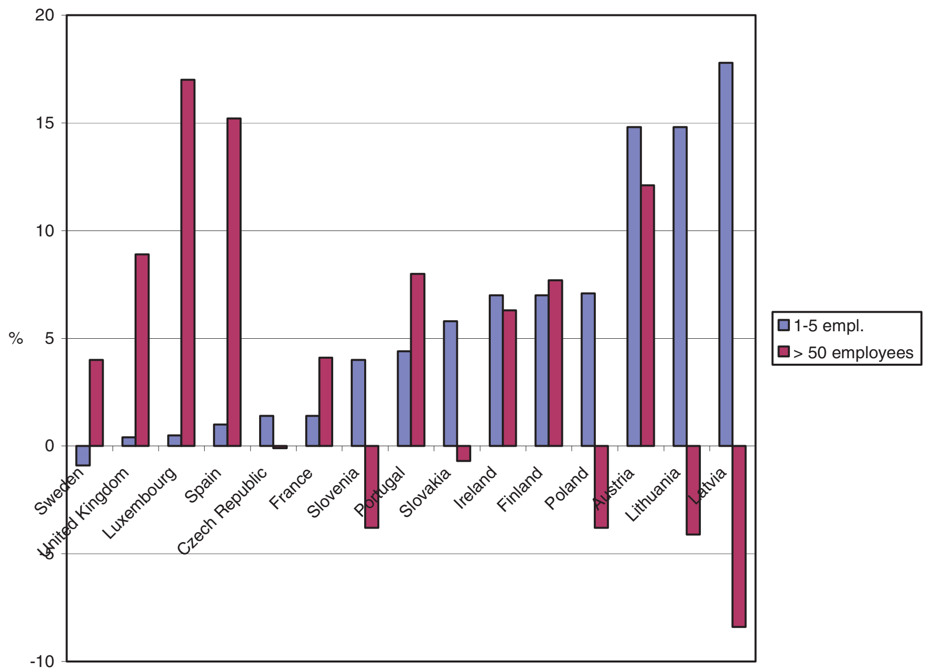
European Union

Some European shippers transport their own goods (own-account transport), but this is relatively rare in international transport. Own account transport has tended to stagnate or even decline over the last decade, while the volume carried by specialist transport companies, for hire and reward, has grown steadily.

In the EU there are approximately 600 000 road freight transport companies. Around 99% of all such companies have less than 50 employees and approximately 80% have less than 5 (including owner-drivers, so-called micro-companies). These small companies often work for large shippers and logistics service providers, which causes an asymmetry in the market.

Figure 2.6 shows that market fragmentation has increased in almost all of the new Member States, whereas consolidation has taken place in most of the older Member States. Consolidation is driven by issues like the continuity of the business, market position or market opportunities. An important driver of fragmentation is the trend towards self-employed drivers, which has been seen in some of the new Member States as a result of the breaking up of former state-owned firms.

Figure 2.6. **Average yearly growth of employment in the EU road freight transport industry in the smallest (1-5 employees) and largest (> 50 employees) firms (1995 - 2003)**



Note: Denmark, Belgium, Germany, the Netherlands, Greece, Italy, Cyprus, Estonia, Hungary and Malta: no data. The years selected may differ for individual countries.

Source: TNO (2006).

Data is available for Belgium, Spain and France, but is recorded differently. However, the patterns and trends are similar to those shown for the older Member States in Figure 2.6. A large proportion of freight is transported by small companies, but the trend is for increasing consolidation and a growing market share for large operators.

Russia

The structure of road freight transport enterprises as characterised by the number of trucks, is shown in Table 2.5.

Table 2.5. **Russia - Breakdown of companies by number of trucks (2006)**

Number of trucks	Share of enterprises (%)	
	In all branches of the economy	In big commercial road transport enterprises
1 – 9	62.0	9.3
10 – 24	22.3	17.9
25 – 49	10.0	20.0
20 – 99	3.9	26.6
100 and more	1.8	24.2
Total	100.0	100.0

The size of the commercial truck fleet in Russia has reduced considerably in the last two decades.

United States

The freight industry in the US has many components, encompassing large and small companies. In 2002, there were about 120 000 (US Census Bureau, 2007) transportation and warehousing establishments with more than half of those primarily engaged in trucking. On average there were 13 paid employees per establishment. During the period 2002-2007, the number of truck transport establishments grew by 6.3% but the number of (paid) employees engaged in truck transport has grown by approximately 5.9%. As a result the average size of trucking companies has decreased marginally.

Australia

In Australia, the vast majority of trucking companies have only one truck (Table 2.6).

Table 2.6. **Number of hire & reward fleets by fleet size and type of operation**

Number of trucks in fleet	Long distance interstate	Long distance intrastate	Short distance	Road freight forwarding	Total
1	3 087	3 824	27 640	367	34 918
2	465	1 177	2 932	87	4 662
3	191	564	925	62	1 742
4	132	172	473	51	829
5 to 9	96	153	223	58	530
10 to 19	159	255	372	96	882
20 to 49	87	158	187	34	465
50 to 99	12	16	26	11	66
100 or more	4	2	10	3	19

Source: NRTC (1998).

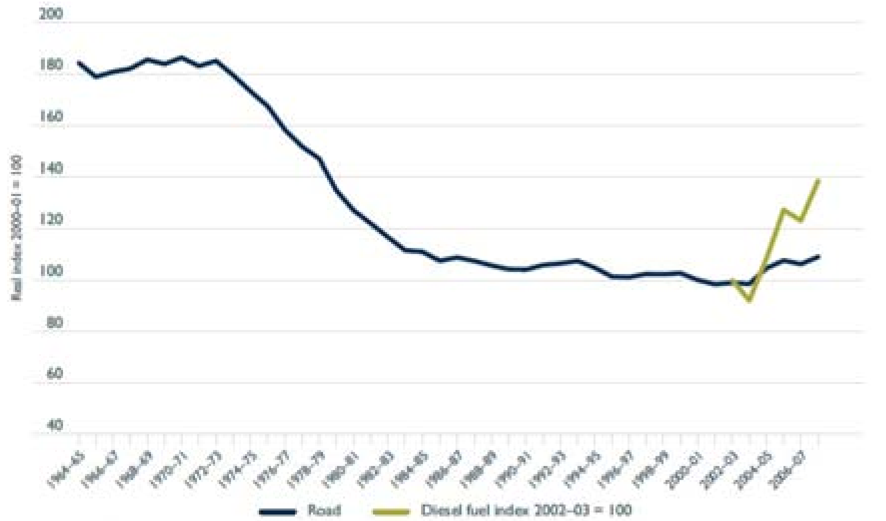
2.6. Development of costs, prices and margins

This section describes the diverging trends between transport costs and prices in different geographic regions. It should be noted that differences in cost level and price level do not automatically enable conclusions to be drawn on the profitability of the sector. Increased efficiency of operation means that not all cost increases need to result in similar price increases to maintain profit margins. However, some general conclusions can be identified.

The cost per unit of goods moved by road reduced substantially between 1970 and the mid '90s but has started to increase again since then. The prices charged for road transport services have followed a similar trend, although the recent increasing trend has been of lower magnitude than the increase in costs.

The drop in price and cost levels from 1970 onwards was achieved mainly by increased transport efficiency. The utilisation of vehicle assets has improved substantially because of an increase in average speed, increases in maximum vehicle weight, migration of loads to heavier vehicles, increased average daily operating hours and a reduction in empty running. However, these improvements in transport efficiency have now ceased and this has combined with substantial increases in unit costs such as fuel and wages to reverse the decline in transport cost and price. An example of this trend is shown in Figure 2.7 below.

Figure 2.7. **Development of road freight rates in Australia (1965-2007)**



Note: The basis of the road rates is full container load (FCL) door-to-door (that is, includes local pick-up and delivery). Road rates do not allow for truck under-utilisation including empty running. Where significant empty running would result in higher rates.

Sources: Bureau of Transport and Regional Economics (2002), Australian Bureau of Statistics (2008a), Transeco (2008), Australian Automobile Association.

The performance of trucks in terms of tonne-kilometres per truck per year reached its peak at the end of the last century and stabilised or even declined in regions with congestion problems. Further reductions of empty running are likely to be difficult to achieve because of fundamental imbalances in many long distance freight relationships.

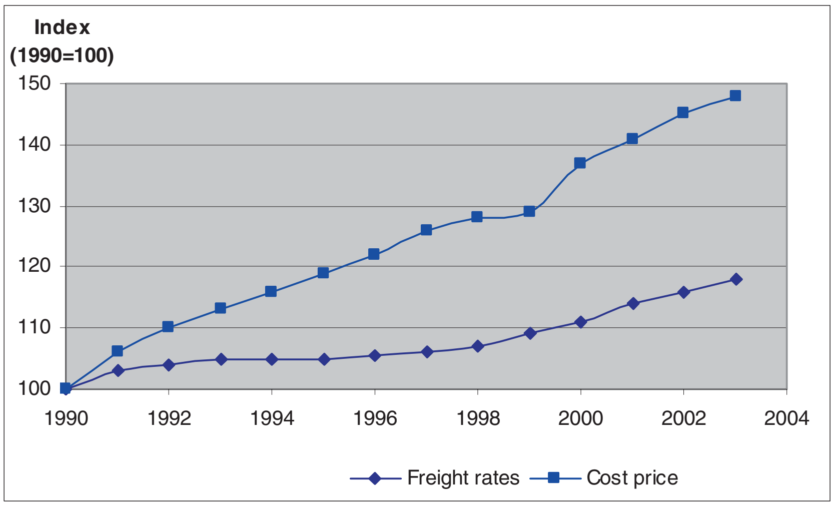
The consequence of these changes is that profit margins are under pressure, particularly for smaller transport companies involved in long distance transport. Larger transport companies appear to compensate by offering value added logistic services like warehousing, which generate better margins. The pressure on profitability has a negative effect on innovation in the transport sector and most logistics innovations are now initiated by shippers.

Only limited information on profitability of the transport sector is available in international terms, but low profitability is recognised as a widespread problem[14] in the industry. In The Netherlands, where margins on national transport services are monitored yearly (NEA, 2008), the margin on national transport was +1.0% in 2007 and only companies with a fleet size of more than 50 trucks generated margins of 5% or more. Dutch transport companies also generate negative margins on international transport: an average of -1.2% in 2007. These margins have been negative for more than seven years and this is mainly a consequence of cost increases.

A business model based on international transport services only might not be sustainable in the long run for small hauliers. However, this does not automatically mean that the profitability of the sector is under severe pressure. Many road haulage companies involved in long distance transport offer also additional services like groupage[15], warehousing and other value added services. It is often the margins on these activities which enable them to compensate low or even negative margins in transportation. Also, transport of specialised cargo could generate better margins.

Figure 2.8 illustrates the pressure on profitability by comparing the changes in costs and prices.

Figure 2.8. **Index of costs and freight rates for Dutch road hauliers**



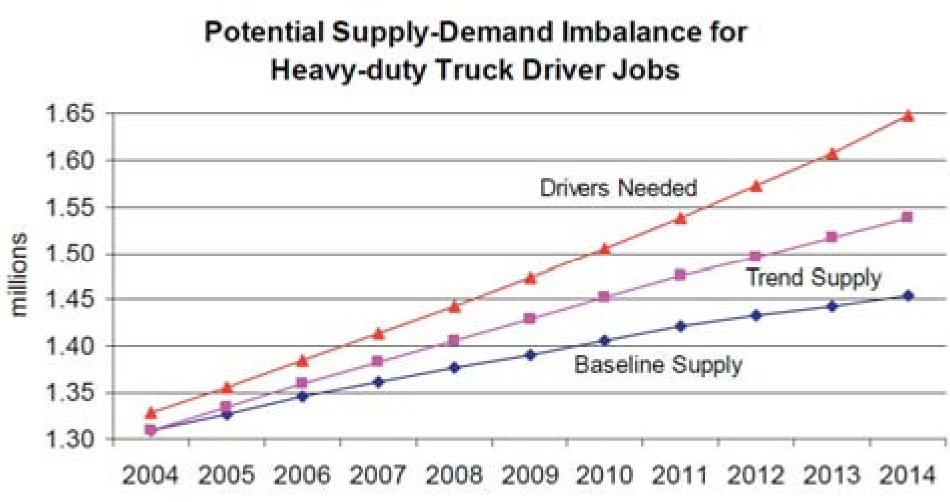
Source: TLN (NL).

The same trends can be seen in French data (costs up 17%, prices up 5%, 2000-2005) and Belgium (ITLB).

2.7. The availability of skilled drivers

In the early part of the 21st century, the increased demand for road transport has greatly increased the number of truck drivers required. This trend is illustrated by data from the USA which is presented in Figure 2.9 below.

Figure 2.9. **Potential supply-demand imbalance for heavy-duty truck driver jobs in the United States (2004-2014)**



Source: Global Insight (2005).

This trend is not restricted to any particular region and the conclusions in Canada (Canadian Trucking Human Resources Council, 2003) are broadly consistent with the USA and in Europe, the introduction of the Working Time Directive, which reduced the hours each driver could work, exacerbated the concerns (TNO, 2006).

It is expected that this problem will shrink or even be reversed as a result of the economic downturn that began at the end of 2008 because of a reduction in transport volumes and this is supported by data from Canada where 30 000 truck drivers have reportedly lost their jobs in 2009 (Today's trucking, 2009). However, this is expected to be a short-term reverse as economies return to growth and freight demand increases once again.

One of the causes of the shortage of drivers is their average age. Australian data presented in Table 2.7 (Australian Trucking Association, 2003) shows that employees in the trucking business are typically older than for other occupations. Again, this is a common problem supported by Canadian data showing that in 2004 truckers aged 55 and over outnumbered those under 30 for the first time, and only 25% were between the ages of 15 and 34.

Table 2.7. **Age profile of road freight transport occupations (average 2001)**

Occupation	Age-range (% share)			
	15-24	25-44	45-54	55 and over
Supply and distribution managers	2.0	54.6	28.4	15.0
Truck drivers	6.9	54.5	25.3	13.3
Delivery drivers	17.5	44.1	23.5	15.0
All occupations	18.4	49.0	21.8	10.8

Source: Australian Trucking Association (2003).

2.8. The efficiency of road freight transport

In order to remain competitive or to improve their profitability transport operators try to increase transport efficiency by improving load factors and the utilisation of assets, reducing empty running or adapting their fleet to better meet transport demand. Improving load factors and reducing empty runs can be achieved by consolidation of cargo (*i.e.* various transport operators working together in order to consolidate their cargo through a distribution centre), advanced planning tools with real-time information and other innovations.

This section analyses the performance of road transport operators, focusing on key performance indicators like the evolution of the vehicle fleet and the evolution in efficiency ratios (load factor and empty runs). Finally, the performance in terms of delivering quality and added value in the overall supply chain is discussed.

Evolution of the vehicle fleet

Generally, larger vehicles are more cost-efficient in terms of cost per tonne-kilometre, assuming they are well utilised. However, other logistic trends have meant that frequent and quick replenishment of inventories has become more popular which has reduced consignment sizes and can mean that smaller vehicles are required. The combined result of this is that there has been a migration of loads both to heavier vehicles and to smaller trucks and vans. In long distance transport, the use of larger vehicles has increased allowing more payload per vehicle. The trend for larger vehicles is illustrated by the data from the USA, shown in table 2.8, below, where the proportion of trucks of between 11.8 tonnes and 27.2 tonnes average mass decreased substantially while the proportion with in excess of 27.2 tonnes increased.

Table 2.8. **Trucks and truck miles by average weight in thousands United States (1987-2002)**

Average weight (tonnes)	1987				2002			
	Number	**Share**	**Miles (mio)**	**Share**	**Number**	**Share**	**Miles**	**Share**
11.8-15.0	377	20.6%	5 411	7.6%	437	16.9%	5 845	5.4%
15.0-18.1	209	11.4%	4 113	5.7%	229	8.8%	3 770	3.5%
18.1-22.7	292	16.0%	7 625	10.6%	318	12.3%	6 698	6.2%
22.7-27.2	188	10.3%	7 157	10.0%	327	12.6%	8 950	8.3%
27.2-36.3	723	39.5%	45 439	63.4%	1 179	45.5%	77 489	72.0%
36.3-45.4	28	1.5%	1 254	1.8%	69	2.7%	2 950	2.7%
45.4-59.0	8	0.4%	440	0.6%	26	1.0%	1 571	1.5%
>59.0	4	0.2%	185	0.3%	6	0.2%	329	0.3%
Total	**1 829**	**100.0%**	**71 624**	**100.0%**	**2 591**	**100.0%**	**107 602**	**100.0%**

Source: U.S. Department of Commerce, Census Bureau (2002).

Again, this trend is also evident in a number of countries:

- *EU* – 74% of tkm by trucks >30 tonnes in 1999 increasing to 77% in 2003. Average load carried by all goods vehicles grew by 6.5% from 2000 to 2005.
- *Russia:*
  - Trucks >9 tonnes payload up from 20% in 2002 to 22% in 2005.
  - Trucks < 3 tonne payload up from 16% to 19%.
  - Mid-sized trucks between the two down from 52% to 47%.
- *Canada:* Maximum length of articulated vehicles increased from 7.5 m in 1940 to 25 m today (and up to 38 m for certain longer combination vehicles (LCVs) in four states).
- *Australia* has seen substantial increases in average gross mass:
  - Three-axle truck plus trailer from 24 tonnes in 2000 to 30 tonnes in 2005.
  - Triple road trains from 83 tonnes in 2000 to 86 tonnes in 2005.
  - Mid-size vehicles have stabilised or decreased.

The utilisation of vehicle assets

The utilisation of vehicle assets can be evaluated using a number of different performance indicators, such as:

- Load factor is the ratio between the average load (when laden) and the maximum load and can be expressed in either mass (average loaded mass/maximum payload mass) or volume terms (*e.g.* average M3 carried/maximum possible M3 or average number of pallets/maximum number of pallets). This is a measure of how often the vehicle is typically filled.

- The number of tonne-kilometres (or pallet kilometres) per truck per year is a combined measure of how close to full the truck is usually run combined with for how much of the time each year it is used.

- Empty running is the proportion of all vehicle kms travelled where the vehicle is empty. Sometimes expressed as the proportion of all vehicle journeys (irrespective of distance) run empty.

It can be seen that at least two of these indicators can be expressed in relation to either the mass or the volume of goods transported. Traditionally, most national data sources measure freight by mass only. However, this typically results in an underestimate of the actual loading efficiency, and thus the productivity of the vehicle, because many loads are constrained by the available volume and are thus "full" even if carrying a mass lower than the maximum permitted.

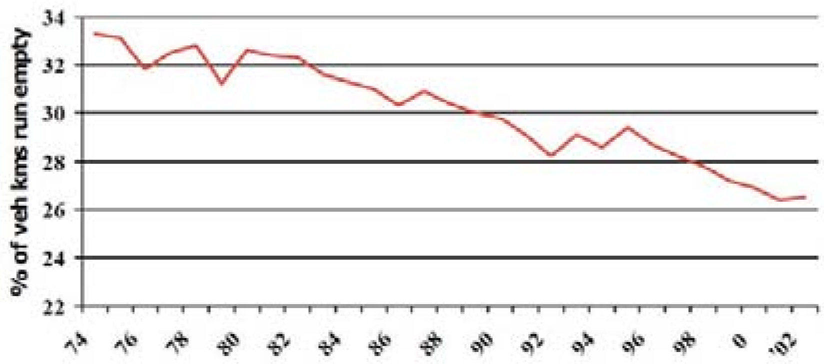
Completely empty journeys are often seen as wasteful and inefficient but in many cases they are unavoidable because of fundamental imbalances in the directions of freight flows. In some applications it is simply not possible to find a return load. For example, in urban fuel distribution a tanker delivers fuel from a depot to an urban fuel station but there is never a requirement to carry fuel from the urban area back to the depot. Also, the tank vehicle required cannot easily be used to carry another liquid let alone any other type of commodity. So, while it is possible to reduce empty running it is not possible to eliminate it entirely and this is true, at least to some extent, in all transport modes.

In general, the utilisation of vehicle assets has improved substantially since 1970 but has stabilised in the last decade.

European Union

Empty journeys account for 40% of all journeys in the European Union and for 23% of the distance travelled in 2003, indicating a higher efficiency in long distance transport. However, empty running has declined sharply, as exemplified by the UK data shown in Figure 2.10 below.

Figure 2.10. **Decline in empty running of trucks in the UK: 1974-2003**

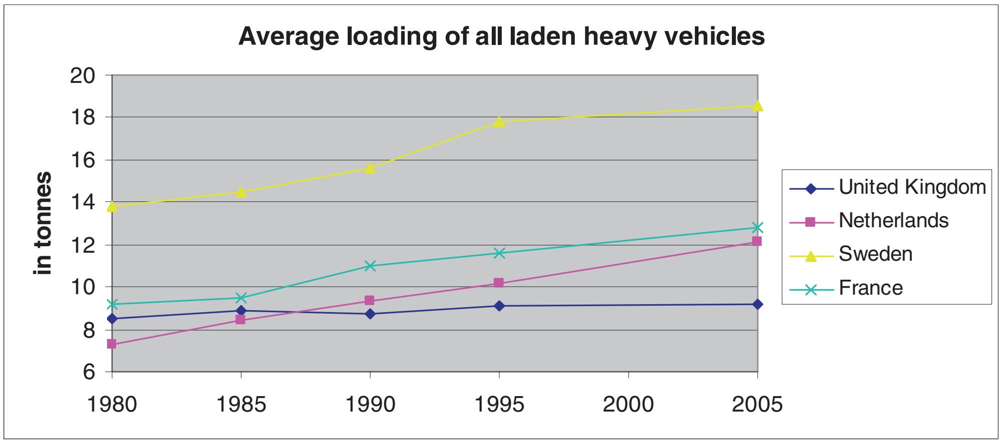


Source: UK Department for Transport (2006).

In Spain around 18% of the domestic heavy trucks run empty, whereas in Belgium this is slightly higher at 20%. In Spain the level of empty running is more or less stable, whereas efficiency by Belgian hauliers has further improved from 22% in 2003 to 20% in 2005. Empty running by trucks over 20 tonnes decreased significantly from 30% in 2003 to 24% in 2005.

The average payload on laden trips has increased everywhere in the past twenty-five years, albeit to various extents: by 8.2% in the United Kingdom, 34.8% in Sweden, 39.1 % in France, and 65.8% in the Netherlands (Figure 2.11). The average figures obtained are directly related to the maximum heavy vehicle masses permitted in each country. Sweden, which allows trucks of up to 60 tonnes, has the highest average loading and The Netherlands, which allows 50 tonnes, is catching up with France, which allows only 40 tonnes. The average load (when laden) for goods vehicles in all countries of the European Union was 13.1 tonnes in 2005 (15.9 tonnes for international transport, 12.1 tonnes for national).

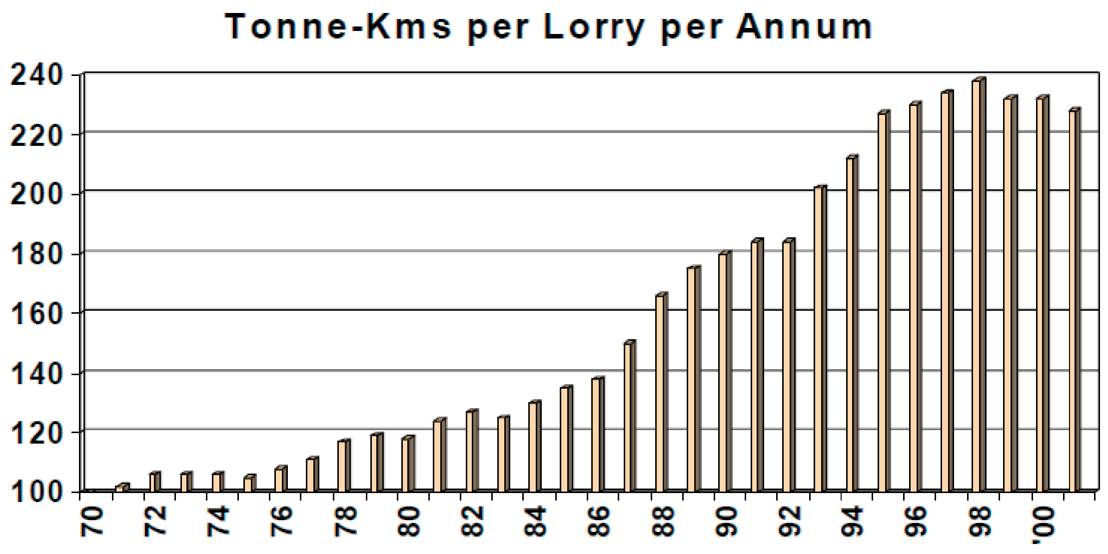
Figure 2.11. **Evolution of average payload of all laden heavy vehicles (National and international transport)**



Source: MTETM, Eurostat (2007).

Figure 2.12 shows a very large increase in total truck utilisation in the United Kingdom when considering the total tonne-kilometres per truck per year.

Figure 2.12. **Average yearly performance in tonne-km per truck per year (index 1970 = 100)**



Source: McKinnon (2003).

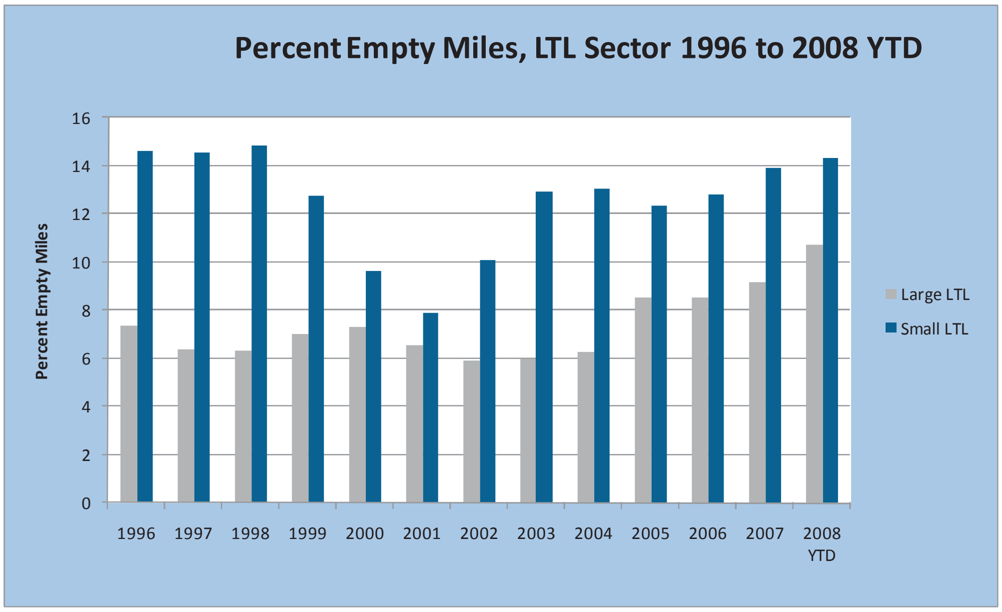
Analysing the data for the United Kingdom shows that the performance of a truck (tkms per year) has doubled between 1980 and 2000, whereas the average payload of heavy trucks increased by much less. This means that the efficiency gain in truck performance was mainly as a result of reduced empty running, migration of loads from smaller to heavier trucks and increasing the time for which the truck was in operation during the year.

United States

Figures on the average payload by distance travelled and the gross vehicle weight shows higher average payloads on longer transport distances. The average payload for vehicles with a gross vehicle weight over 15tonnes travelling less than 50 kilometres is estimated at 13.4 tonnes. For distances over 100 kilometres the average payload is increased up to 18.2 tonnes.

Figure 2.13 suggests that levels of empty running are much lower in the USA compared with the EU at 14% of distance travelled for small operators and just 10.5% for larger carriers in 2008.

Figure 2.13. **Empty miles in the United States** [16]



Source: American Trucking Association (2009).

Australia

In Australia the estimated proportion of unloaded travel in road freight transport is approximately 38% (NTC, 2007).

2.9. Challenges in the market for road freight transport services

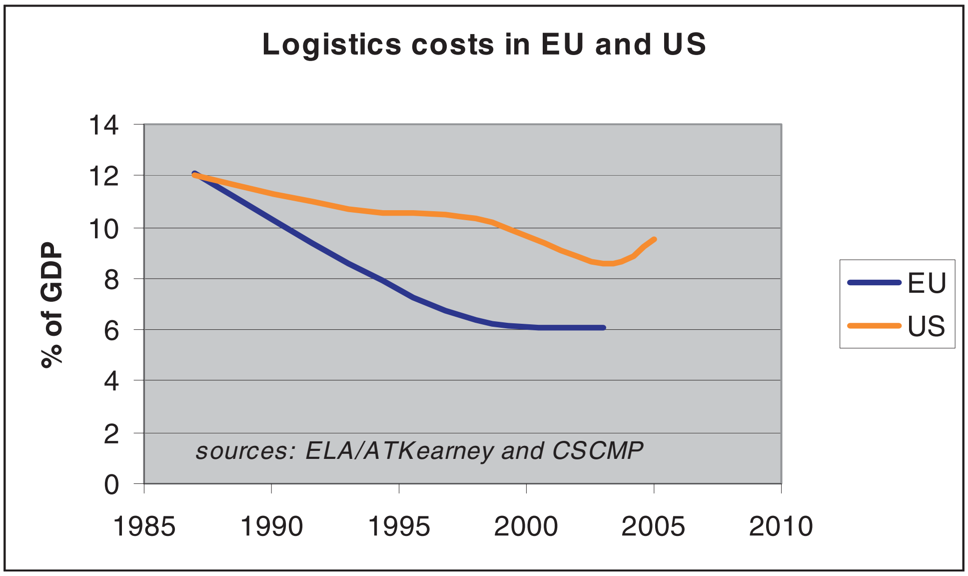
The preceding sections have shown that the road freight transport sector operates within a rapidly changing environment. Demand for transport is expected to grow substantially and shippers require more reliable, customised and responsive transport services. At the same time the cost of transport services (*e.g.* labour, energy) are increasing and framework conditions for operating road services (*e.g.* infrastructure, access) are becoming more restrictive. Until recently, the efficiency of the sector has been increasing steadily, and while profit margins for simple transport services are under pressure, the sector has been able to increase service quality and extend the scope of its services to value added logistics functions, where margins are higher.

The business environment of the road freight sector is changing fast:

- Transport is a derived demand. Changes in logistics will trigger changes in transport requirements. In the future an increase will be seen in the types of supply chains, as a result of the trend towards individualised products and services, and decreasing international barriers to trade and transport.

- Total logistic costs include transport, warehousing and inventory carrying. Total logistics cost as a proportion of GDP has been decreasing but has recently stabilised or even increased again (see Figure 2.14). The effects of external pressures on the road freight industry, such as increasing costs, energy and climate concerns, increasingly congested infrastructure etc, cannot always be compensated by advanced logistic structures with reduced inventory levels. It is, therefore, generally expected that logistics costs in Europe will rise after decades of reduction.

Figure 2.14. **Development of logistic costs in the European Union and the United States as percentage of GDP**



Source: ELA, A.T. Kearney and CSCMP (2007).

The key challenge for the future is to maintain a dual track of improvements, in both efficiency and service quality, under more restrictive framework conditions. The large variety of supply chains makes a general approach difficult. The transport market is highly heterogeneous, so both acceptance of policies and adoption of innovations will occur at very different speeds in different countries throughout the world. The critical factors that will determine how well the sector adapts to the changing circumstances are listed below and described in more detail in the following sections:

- *Further improved efficiency in the present fragmented market*: Developing new business models for freight consolidation using larger vehicles, collaborative services and electronic freight market places.

- *Ability of the logistic sector to reorganise*: Developing new business strategies to increase focus on emerging markets with new performance criteria such as customisation, responsiveness and reliability.

- *R&D investments in new logistics and information systems*: Investing in R&D and the implementation of the latest ICT systems that allow system synergies above and beyond the level of transport services, *i.e.* throughout the supply chains, integrating with warehousing and (flexible) production services (*e.g.* RFID).

- *Communicating effectively with government* in order to foster and implement ideas for intelligent regulation that respects the heterogeneity of the market; putting in place the appropriate financial and infrastructural framework conditions to facilitate the expansion and strategic change of the sector's services.

- *Maintaining a sufficient base of well trained employees,* which can function internationally in a wide array of markets.

Efficiency in a fragmented market

The fragmentation of the market has been described in detail in the supply side section of this subchapter. The many small carriers have the advantage to be able to offer speed and flexibility but efficient transport solutions sometimes require a certain scale in order to optimise the fleet and resources.

For the smaller carriers, developing collaborative business models and implementing (electronic) marketplaces for freight exchange within their own business model are likely to be crucial innovations. Relatively small carriers in international haulage often collaborate to offer joint groupage networks to their customers, not only expanding their scope of services but also generating more volume and attracting more return loads. Electronic marketplaces for the exchange of freight are becoming more and more generally accepted and have the potential to increase the loading factor in long distance freight transport. The resulting increase in market transparency will help hauliers, particularly small ones, to match demand for less-than-full return trips and improve the utilisation rate of their vehicles.

Ability of the logistics sector to reorganise

In long-haul markets with longer transport times, road transport competes with alternative transport modes like rail freight and, in some corridors, with inland waterway transport. Large logistics operators cope with efficiency challenges by offering network services and co-modal solutions in which road transport complements intermodal transport operations.

From perspectives of both shippers and society, intermodal transport solutions for long distance shipments are sometimes preferred to pure road transport solutions. Road transport operators need to understand this and to continue providing added value to their customers. This sometimes means diversification and offering intermodal transport solutions as well as road haulage services. The competitive advantage of road transport compared to intermodal transport on long distances remains its reliability. The transhipment activities in intermodal transport chains increase the complexity of this choice and often conflicts with the ability to offer reliable services. However, the concept of shuttle trains could improve the reliability of rail freight transport and congestion is a threat to the reliability of road transport in some places. The large diversity in the characteristics of shipments and the requirements of shippers means that intermodal and road-only solutions can complement one another. The intermodal solution can be used to transport a core quantity of goods that are sure to be needed while the road only solution can be used to respond quickly and reliably to changes in demand. This strength needs to be understood by the road transport operators in order to offer real added value to their customers.

R&D investments in new logistics and information systems

The automotive sector invests enormously in research and development (R&D). Four car manufacturers are in the top six list of global organisations' R&D spending (UK Department of Trade and Industry, 2006). This is also the case in Europe, where the European road transport sector represents 30% of all EU industrial R&D (ERTRAC, 2008). R&D on improved transport safety and reduction of environmental impact of road freight transport appears to be successful, but is mainly focused on passenger cars.

The R&D investment in new logistics and information systems is of special relevance to the road freight transport industry but there is very limited information available about such investments. In the Netherlands (Commissie van Laarhoven, 2006), innovation on supply chain activities appear to be primarily initiated by shippers, receivers, and non-traditional supply chain partners (like ICT service providers, banks and consultants). Producers and brand owners can achieve huge benefits through logistics innovations but often do not recognize, or underestimate, the impact that this could have.

Logistics service providers and transport operators play an important role in the implementation of innovations, but find it difficult to initiate them. Also some innovations require a certain scale of operation, which is an obstacle for small hauliers (Commissie van Laarhooven, 2007).

Increasing the investment in new logistics and information systems could attract substantial benefits. Electronic document exchange and information systems integrating RFID and satellite navigation could improve supply chain visibility substantially, improve the efficiency of logistics operations and also facilitate legitimate and secure trade without affecting operations along the supply chain.

Develop intelligent new regulations

New regulations for internalisation of external costs, cabotage, working times, standardisation (weights & dimensions), supply chain security and electronic waste will all have a considerable impact on the business of transport logistics. Some of these will have an impact on the competitiveness of road transport in relation to other transport modes, others will require supply chain adjustments. Road transport operators need to be proactive, understand the impact of these regulations for their own business as well as the implications for the supply chain solutions of their customers and act accordingly.

2.10. Public interventions in logistics processes

This section focuses on the potential measures that could be initiated, or influenced, by policy makers. Introducing measures in the road transport sector to improve operational efficiency and service quality cannot be successful without understanding the features of the transport system that can influence implementation; that is why the previous sections first described the transport market characteristics and its challenges. The question about what is within the bounds of possibility for policy makers is a matter of political choice. In the past three decades a number of logistics trends (increase of transport distances, decrease of shipment size, less stock keeping, just-in-time deliveries etc.) have caused an increase in road freight transport. To a certain extent these developments contribute to economic growth, but they also contribute to the negative effects of road freight transport that society wants to reduce: carbon footprint, greenhouse gases, noise and other emissions, but also road accidents and congestion.

A number of lessons can be learned from the previous attempts of policy makers to reduce negative effects by influencing the function of the transport system, as listed below[17]:

- Companies are well prepared to invest in new technology and systems innovations if everyone has to do the same. There could be a serious economic disadvantage for an individual company where they are the first adapter.
- Companies do not invest in public interest and will only invest in new technology or systems innovations if there is an evident self-interest.; American research (MIT, 2008) suggests that the majority of the 110 European and American Chief Operating Officers[18] that were questioned said that they would only take sustainability measures if the government forced them to do so and they certainly would not go any further than the rules required them to.
- Purely technology driven measures carry the risk that they fail to properly account for the complexity of road freight transport.
- Measures directed at improving cooperation within the supply chain have to account for the persistent distrust between companies that arises from fierce competition. The asymmetry of power in the transport sector means that the negotiating position of companies or logistics managers can be too weak to enable them to invest in new technologies or innovative systems.

Public intervention measures can be divided into five clusters:

- Measures involving traffic management, infrastructure network and spatial planning. Their purpose is to improve access to economic centres and to improve the cross modal connections within the transport system.
- Encouraging companies and logistics managers to innovate.
- Encouraging collaboration between the different actors of the supply chain.
- Measures in the field of information and communication technology.
- Measures intended to improve efficiency by smart employment of truck drivers.

Improving access

The extent to which economic centres are accessible for goods transport is determined by the quality of the infrastructure and the connections between different networks. Congestion, customs procedures, lack of capacity and other obstacles, reduce the efficiency of road freight transport. Improving the quality of the network contributes to the efficiency of the transport system as a whole.

Securing a quality network of road infrastructure

Establishing an efficient road transport network is a key element of transport policy. It is essential to remove bottlenecks in transport infrastructure and build missing links, as well as to ensure the sustainability of future transport networks.

Removing impeding rules

Improved conditions for efficient transport operations can be achieved by removing impeding rules both in long distance cross border transport, for example cabotage and a lack of harmonisation, as well as in urban distribution, for example lack of harmonisation in access restrictions, enlarging opening hours and time windows.

Regulations and the lack of harmonisation can be the cause of empty running in road freight transport on long distances. Some vehicle types are only allowed to operate within the borders of states or countries, and in Europe, for instance, foreign haulers are limited in conducting domestic transport (cabotage). Easing the regulations and limitations on cross-border transport might foster more efficient logistics.

Public authorities can also impose restrictions on the time windows of deliveries for example to limit noise. On the other hand the requirements of the shipper and the receiver of goods determine the needs of the delivery. As a consequence the haulier may then have to drive at peak hours or use a greater number of smaller vehicles. Better alignment of the processes within the supply chain, and a more cooperative attitude from the receiver of goods and the local authorities can create more flexibility in delivery times for the road freight transport companies. Other decisions earlier in the supply chain can also reduce the time pressure at the end of the chain.

Deploying intelligent transport systems on road networks (e.g. dynamic traffic information)

Construction of new transport infrastructure is often too expensive to meet growing demand. This emphasises the importance of using existing infrastructure better, which can also help to enhance the safety and service quality on the road network. Improved use of infrastructure can be achieved by measures such as dynamic traffic management, variable message signs, ramp metering and other telematics applications. Intelligent Transport Systems and Services (ITS) are seen as an effective tool in fighting congestion, increasing road safety and reducing the environmental impacts of transport.

Improving connections between modes

For the entire distribution system to work effectively, inland terminals need to be fully integrated into the supply chain. Easier transhipment of goods between modes can be achieved by improved connections between the different transport modes and better intermodal facilities. The optimisation of these transhipment capacities, terminal services and processes will greatly improve the performance of hinterland transport as well as allowing a faster throughput of containers at sea ports. Developing seamless interfaces between transport modes requires advanced planning supported by data exchange and enhanced ICT systems enabling supply chain visibility.

Logistics parks for urban distribution

There is a lot of resistance to heavy goods vehicles entering densely populated areas. Many European cities impose access restrictions on heavy goods vehicles. To enable the delivery of goods in densely populated areas, logistics hubs can be established on the edge of city centres. These hubs decouple the national and interregional transportation from local distribution. In doing so, inner city distribution can be organised in an efficient and sustainable way using dedicated electric or low emission vehicles with dimensions suitable for the purpose of inner city distribution. However, retail companies have often optimised their logistics organisation and the use of a logistics hub can be very inefficient from their individual perspective. This relates to the ownership and the administration of the logistics park for which many models exist but are not always effective. A wide variety of facilities and services can be offered by logistics parks, including for example, transhipment or temporary storage of goods. The further development of such logistics park is the subject of ongoing research[19].

Encouraging innovations

As mentioned above, there are several impediments to innovation in the organisation of transport and logistics. The purpose of the measures below is to take away those obstacles. All measures can be applied on a voluntary or obligatory basis. In general, measures to improve the efficiency of road freight transport will provide benefits to both society and the freight companies directly involved. However, this is not always the case. For example, measures to reduce the number of transport links in a supply chain or to reduce the transport distances by supporting regional production can offer benefits to society as a whole but could commercially disadvantage, some of the companies involved.

Supporting innovation by mitigating commercial risks for early adopters of innovative ideas

The barriers to innovation, such as the lack of power of the logistics manager or the risks associated with being the first adapter, can be overcome in a number of ways ranging from initiating a prize for the best idea to covering the start-up costs of a new development. However, in all cases the cost effectiveness of the initiative for both business efficiency and societal goals should be demonstrated.

Certification and accreditation

There are a lot of criteria with which to describe good company behavior, depending on the subject. This has led to a wide variety of certification schemes, some national, some international, and some worldwide. Being a certified company can be a reason for customers to do business with this company. However, certification and accreditation are based on voluntary participation, the number of different systems and organisations leads to a lack of clarity, and too many schemes generate an excessive administrative burden for companies. Policy makers should support harmonisation and explore the possibilities of combining or adapting existing certification systems.

Setting ambitious standards and quality labels

Ambitious standards can encourage industry to achieve for improvements. For example, in the Japanese Top Runner Program the company that produces the most energy efficient appliances sets the standard for other companies that make the same kind of appliances. Thus, the programme provides competition on energy-saving between companies. This type of concept could be adapted for transport and logistics services.

Many companies are waiting for the authorities to encourage them to take measures. To make consumers aware of the environmental costs, labels on products could inform them of the carbon footprint of production and transport of the products. This can be accompanied by a Carbon Audit, a screening of the business processes of a company or a supply chain, on the use of fossil fuels and with that the emission of GHG.

Government as launching customer for innovative logistics concepts

Some innovative logistic concepts require considerable investments and carry a serious risk of not generating enough revenue to justify that investment. The first customers to launch an innovative logistic concept run the risk that the concept is unsuccessful and not adopted by the rest of the market. It can, therefore, be difficult to find a customer willing to take these risks. In some cases, governments can step in to act as a customer willing to launch new innovations, for example, in innovative business cases concerning the deployment of Radio Frequency Identification (RFID) technology in certain logistic chains such as those involving the supply of school books or hospital equipment.

Inventory of the Best Practices

Companies are constantly seeking ways to improve efficiency and reduce costs. Each company develops its own solutions. Some solutions appear to work and are successful, others fail. Companies could learn from these best practises and failures but competition will act against such exchanges. In the UK the Department for Transport has launched a special website to spread best practices for improving efficiency in transport and logistics (*www.freightbestpractice.org.uk*). A series of guides, case studies and checklists are freely available to freight companies.

Supply chain efficiency scan / Company efficiency scan

A carbon footprint provides information about the parts of the business process that are the most damaging to the environment, but it does not provide information on business processes that can be organised more efficiently. Different tools may be offered in cooperation with industry associations to screen business processes. A checklist or more extended questionnaires can be made for self-use. More labor-intensive and cost-intensive is the use of specially trained people to screen supply chains or companies or the hiring of consultants.

Encouraging collaboration

In general, collaboration within supply chains and between transport companies rarely occurs spontaneously. There is a lot of resistance caused, for example, by fear of losing a market position to, or creating profit for, rival companies. From the point of view of public interest collaboration could significantly contribute to a more efficient road freight transport system.

Initiate and support Vertical and Horizontal Collaboration

Collaboration within the supply chain can take place in different ways. Vertical collaboration takes place when different players like producers, wholesalers, logistics service providers, transport companies or the receivers of goods, work together to improve the efficiency of the whole process. It is, however, not customary that the different players align their individual business processes to each other. It is rather more common that the most powerful organisation in the supply chain optimises their own business process and then expects the other players to adapt.

Horizontal collaboration takes place when companies that are direct competitors work together, for example, to achieve higher load factors. There are several examples on the Internet of cargo exchange systems. Policy makers can propose collaboration between private actors, invest in joint facilities and support the development of park management and co-sitting concepts.

Promote the reconsideration of Just-in-Time

The Just-in-Time principle is often presented as sacrosanct but derushing supply chains can in some cases be implemented without harming the requirements of customers. The principle of delivering fast if necessary and slower if not has unexploited potential and obvious public benefits. Policymakers can increase awareness of this principle among supply chain partners and disseminate best practices.

Improving communication and information technology

Over time supply chains and logistics have become more and more complex and globalisation has created complex international networks. A solid data exchange system is vital to keep control. The world of data and communication systems is very dynamic: once implemented, a system is often already outdated because of the appearance of new applications. The potential benefit of data and communication systems is that they make processes more transparent and enable interventions aimed at improved efficiency and service level. However, the availability of such data often results in a wish for more data.

Several ICT systems and applications in road freight transport support efficient freight and fleet management, improve the control of transport chains, and provide better visibility in the supply chain. These systems include truck-specific navigation systems, tracking and tracing systems, journey and route planning systems, company and supply chain performance measuring systems, e-marketplaces for freight exchange, supply chain visibility systems based on exchange of real time status messages, as well as collaborative planning, forecasting and replenishment systems. Public policy can encourage and support the deployment of these systems by developing harmonisation and standardisation, supporting R&D to further improve such systems and stimulating investments in such systems.

Truck-specific navigation and route planning systems

In truck-specific navigation systems the driver is able to enter the characteristics of the vehicle. Based on these parameters the system calculates a suitable route to the destination. The development of truck-specific navigation systems is very complex because it depends on the availability of detailed information on the infrastructure. Some systems are already on the market. The next steps are to integrate preferable routes from the point of view of public interest and to link with real-time traffic information to enable dynamic route planning.

The growing complexity of supply chains and increasing traffic volume and congestion has made it more difficult to plan journeys and routes. Although distribution (multi-drop) operations will probably obtain the most benefits from advanced planning systems, they can also offer benefits to long distance transport. Smarter planning of journeys and routes will reduce transport kilometers.

Tracking & Tracing (T&T) systems offering supply chain visibility

With T&T systems transport planners have real time information on the exact location of a truck. If a truck is running empty, the back office can decide to redirect the vehicle to a nearby location to pick up some cargo. This improves efficiency and can also offer benefits to other parties in the supply chain. Unforeseen delays to the journey result in an update of the estimated time of arrival at the destination. Downstream activities (by shippers, receivers, terminal operators) can then be rescheduled based on this information, resulting in more efficient utilisation of their resources. Also advanced supply chain inventory reduction concepts based on floating and running stock can generate efficiency gains along the supply chain. This requires transparent information on the actual location of the cargo along the whole supply chain.

E-marketplaces for freight exchange

Electronic marketplaces for freight exchange bring together shippers and carriers. The main function is to better match shippers demand (freight consignments) with truck supply (spare capacity). Some marketplaces have a specific focus on national distribution or international transports; others serve a specific stakeholder group, either shippers or transport operators. The internet has made electronic marketplaces easy to integrate in 'traditional' transport planning. Special websites provide hosting services that link available truck capacity with transportation service requests. These internet posting sites provide truckers (often independent owner-operators) with an opportunity to identify available loads that will allow them to avoid empty backhauls. When the US Congress passed the Motor Carrier Act of 1980, limited privileges were given to private carriers to allow them to conduct dual operations (for-hire operations along with their private carriage) as a way to lower their empty backhaul miles. Vehicle utilisation can also be increased by adding pallet consignments to less-than-full truckload (LTL) consignments on similar routes. In future, advanced matching algorithms offer the potential to fully integrate ad-hoc opportunities with existing transport planning processes.

2.11. Conclusions

In many countries, most road freight transports are limited by the payload volume capacity rather than the payload mass capacity, therefore load volume rather than mass (weight) now often determines the number of trucks required. This has implications in the options to improve road freight transport productivity.

Establishing the right framework conditions to allow the external impacts of freight transport to be reduced without harming the ability of the transport sector to efficiently deliver service quality is a substantial challenge for policy makers. Meeting this challenge will require a thorough understanding of the nature of derived demand, the logistics requirements for transport, and the way in which the sector functions.

The road transport market is strongly fragmented, both functionally (from niche monopolies to severe competition in line haulage sector, from independent single driver companies to large professional carriers) and geographically (different countries with strongly different mixes of sizes and types of companies). Although the shippers can demand changes, the large variety of supply chains makes a general approach difficult and the acceptance of policies and adoption of innovations will both occur at very different speeds in different countries around the world.

Public policies can have a positive influence on the conditions for road transport by improving the quality of road infrastructure, the access to economic centres and the connections within and between modes. Impeding market rules and regulations on access to economic centres may serve other policy objectives but have a negative impact on the efficiency and quality of transport operations. Intelligent application of these regulations, based on dialogue with the sector, can mitigate the negative impacts.

Innovations in transport logistics are necessary to maintain efficiency and deliver service quality under worsening conditions. The readiness of companies to invest in innovation is limited by the risk of losing competitiveness, particularly for early adaptors. Governments can remove such obstacles by providing proof of the efficiency of proposed measures and inventorying best practices for transport companies. The commercial risks inherent in the implementation of innovative concepts can be mitigated when Governments act as a launching customer or provide financial support or subsidies.

NOTES

1. In the United States, some states are limited to 14.63 m in semitrailer length; some states are limited to 8.53 m in trailer length.
2. Recent statistics (2007) had 74 343 articulated trucks, 392 837 rigid trucks and 2.2 million light commercial vehicles. Articulated trucks carried 78% of road freight tonne-kilometres, rigid trucks did 18.4% (with only a small fraction carried by truck-trailer combinations) and light commercial vehicles 3.6%.
3. Figures are based on the most common tractor-semitrailer combination with a 16.2 m. semitrailer length, but for national transport a MOU also allows 25 m. double trailer semi combination with a 20 m maximum box length as well as truck-trailer combinations with maximum box lengths of 20 m (from front of truck box to rear of trailer box).
4. B-doubles are far more common than truck-trailers on the roads of South Africa, but they have similar volume capacities.
5. Tractor-semitrailer dominates interurban road freight with nearly 70% of the loads moved, while the truck-trailer configuration is insignificant with a share of less than 1% of the fleet.
6. Russia: with approximately 250 000 units, tractor semi-trailers are assumed to constitute 5-6% of the vehicles used in road freight. They account for 7-8% of all freight vehicle distance travelled and it is assumed that they carry 13-15% of the ton-kilometres.
7. The hitch (low) is located behind the rear axle of the truck instead of the standard (high) hitch location at the rear cross beam of the truck.
8. The UK allows 44 tonnes on 6 axles with semitrailer length of 13.6 m.

9. Cross-docking is a practice in logistics of unloading materials from an incoming semi-trailer truck or rail car and loading these materials directly into outbound trucks, trailers, or rail cars, with little or no storage in between. This may be done to change type of conveyance, to sort material intended for different destinations, or to combine material from different origins into transport vehicles (or containers) with the same, or similar destination.

10. The party arranging the carriage of goods including connected services and/or associated formalities on behalf of the shipper or consigner.

11. An intermediary between the shipper and the carrier. The broker arranges transportation for shippers and represents carriers.

12. 3PL: "solutions" providers of individually tailored logistics products integrated in the processes of companies in trade and industry. 4PL: new multi-tier vertical collaborative structures are developing between logistics service companies. Those at the top of the structures view themselves as "supply-chain architects" or "navigators," also known as "4PLs" or "Lead Logistics Service Providers (LLP)" (Source: SEALS-project, 2008).

13. Domestic transport: transport performed by a road motor vehicle in country A by hauliers registered in country A.

    International bilateral transport: transport performed by a road motor vehicle between two countries A and B by hauliers registered in country A or B.

    Cross trade: transport performed by a road motor vehicle between two countries A and B by hauliers registered in country C.

    Cabotage: domestic transport performed by a road motor vehicle in country A by hauliers registered in another country.

14. The International Road Union sees the low financial performance of the international road freight sector as the most important problem of the sector.

15. Consolidation of cargo.

16. Large LTL carriers are carriers that earn more than USD 300 million in annual revenue, small LTL carriers earn less than USD 300 million in annual revenue.

17. Different sources mention critical factors to innovation within the transport sector, one of them: *Delivering A Sustainable Transport System: The Logistics Perspective*, UK Department of Transport, London (2008).

18. The Chief Operating Officer (COO) is responsible for operations management (OM).

19. For example, in the U.S. the National Freight Cooperative Research Program (NCFRP) Project No. 23 is studying, "Economic and Transportation Factors for Locating Freight Intermodal and Warehouse Distribution Facilities".

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Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability

CHAPTER 3. REGULATION OF ROAD FREIGHT TRANSPORT

Abstract

This chapter describes the purpose of road transport regulation and the current regulatory framework for heavy duty vehicles in relation to safety, sustainability and infrastructure assets.

3.1. The regulatory framework

Road freight transport is regulated to ensure it is compatible with road infrastructure and minimise adverse impacts on road safety and the environment. A supplementary objective is to ensure that industry participants who breach legislative requirements do not achieve competitive advantage over those with higher levels of compliance. Regulation is necessary because there are no in-built mechanisms to ensure road users take account of the impact of using their vehicles on the costs borne by road agencies and the broader community. In most countries, these objectives are achieved by regulations for:

- Technical vehicle standards, including new vehicle safety standards (*e.g.* for brakes, suspensions, lighting, under-run protection and emissions) and emissions standards.
- Technical vehicle in-service fitness standards (*e.g.* for tyre and brake condition).
- Vehicle weights and dimensions, including axle mass, gross vehicle mass and internal and external dimensions (length, width, height, axle-spacing, and front and rear overhang).
- Vehicle operations, including access conditions, over-sized vehicles, securing cargo and transport of hazardous materials.
- Drivers, including hours of service, licensing, training, medicals and drug testing.
- Transport operators, including driver monitoring (*e.g.* for hours of service), licensing/safety ratings and cabotage.

Breakpoints for differentiating between regulatory categories of heavy vehicles (referred to as commercial vehicles in North America) are usually based on gross vehicle mass (*i.e.* the legally permitted maximum laden mass). Breakpoints typically used are 3.5 tonnes, 4.5 tonnes and 12 tonnes. In Europe, hours of service regulations, speed limiter requirements and differential speed limits apply to vehicles of over 3.5 tonnes gross mass. In Australia, hours of service and speed limiter requirements apply to vehicles of over 12 tonnes. In the United States, Federal Motor Carrier Safety Regulations apply to vehicles greater than 10 000 lbs (4.536 tonnes) gross mass and the Commercial Drivers License requirement applies for vehicles of greater than 26 000 lbs (11.794 tonnes) gross mass. In Canada, the safety ratings requirements apply in respect of vehicles greater than 4.5 tonnes gross, while the speed limiter requirements in Ontario and Quebec apply to vehicle in excess of 12 tonnes gross.

Trucks of up to a gross mass of between 36 tonnes (80 000 lbs, in the US) and 50 tonnes (South Africa) are subject to various requirements but given access to major roads as-of-right. Vehicles above this mass are provided access only through permits and special requirements. In most countries, vehicles of up to 3.5 tonnes are treated in a manner closer to that of passenger cars.

3.2. Technical vehicle standards

Vehicle technical standards are mandated to improve safety and environmental performance by imposing specific requirements (*e.g.* lighting, seatbelts and brakes, CO, HC, NOx and PM emissions) and/or by imposing consistency between vehicles, *e.g.* bumper bar height. As the cost of development and testing of standards has increased and the motor vehicle manufacturing industry has become more globalised, pressures for regional and international harmonisation of vehicle standards have increased.

In most parts of the world, technical safety standards are based on regulations of the United Nations Economic Commission for Europe (UNECE). UNECE regulations are increasingly based on EU Standards. For many other countries, adoption of UNECE standards provides access to international standards and removes the need for local development of standards. They are widely applied in South Africa, Australia, Russia and the Ukraine.

Canadian and United States standards (CMVSS and FMVSS) are generally aligned, with minor differences reflecting different units and linguistic requirements (Canadian standards require bilingual labelling). Canadian and United States standards are not aligned with UNECE regulations. Mexico has no specific standards in this area and relies on the systems provided by the vehicle manufacturer.

In future, vehicle technical standards are likely to converge because of the development and implementation of global technical regulations under the UNECE 1998 Agreement (see Annex A for details) and progressive harmonisation of existing regulations with these. This trend is likely to apply to both light and heavy vehicles. The trend is likely to be strongest in the European Union and Australia, but will also apply in other parts of Europe and South Africa, with gradual harmonisation also applying through Asia. It is likely that United States and Canadian standards will take longer to align.

Economic considerations in developing technical vehicle regulations

The evolution of HDV technical regulations for environmental protection and improved safety generally follows some form of "best available technology at no excessive extra cost" approach (BATNEEC). Regulations are largely driven by developments in technology, for example innovation in the electronics, information technology and chemical engineering industries, but regulations also drive innovation by setting performance standards that can sometimes be met through alternative technological development routes and competing technologies. One of the keys to developing new regulatory standards is to avoid picking winning technologies or locking technological development into specific paths that might discourage investment in developing alternative and more effective technologies in the longer term. This is difficult. Regulations can be designed to be as neutral as possible, focussing on performance not method, but regulators will naturally be inclined to assess what is currently possible using knowledge of current technologies to determine standards. This is never entirely neutral, if only because of the timing of the new requirement.

The BATNEEC approach is followed in the absence of absolute data on the costs and benefits of changing regulatory standards. The task of cost-benefit assessment is complicated because regulation seeks to make technology only recently developed standard on future vehicles. This is usually before large scale production and often before the technology has fully matured, making it difficult to predict the real costs of the technology once it enters mass production. Early cost estimates are often more than an order of magnitude too high (ITF 2008). Regulatory impact assessments undertaken in support of new regulatory proposals therefore rarely include a conventional cost-benefit assessment and arbitrate between estimates of expected costs from OEMs, component manufacturers and research, accounting for expected scale and learning economies as the technology comes into production and making a judgement as to whether costs are acceptable in comparison to the benefits expected.

Benefits are also rarely quantified in strictly monetary terms, although robust figures for the external environmental and safety costs are available and used in relation to some other transport planning and investment decisions. Benefits are more often assessed in relation to meeting targets – for air quality, for example. Non-attainment of air quality limits has long been a driver of US air emission regulations and is an increasingly important driver of Japanese and European emission standards. Greenhouse gas targets may begin to drive fuel efficiency regulations for HDVs in the future, and crash fatality targets are becoming increasingly central to road safety policy. In developing regulations to meet such targets, cost-effectiveness becomes the key economic criteria in determining priorities and choosing between alternative technologies.

Regulatory standards are only one of the elements to managing freight transport environmental and safety outcomes. When the marginal benefits of new regulations for all new vehicles show declining returns it can be more effective to instead target the worst performing vehicles in the current vehicle fleet. For example, in 2002 Japan introduced retrospective NOx and PM emissions standards for old heavy duty vehicles. These require old trucks and buses to be retrofitted to meet 1997/98 emissions limits, or scrapped. This regulation was introduced to address persistent non-attainment of ambient air quality targets in some major urban areas including Tokyo (DieselNet 2003). Enhanced maintenance and inspection programmes can also be effective, as can scrappage schemes, so long as they are restricted to the very worst vehicles (ECMT 1999).

Contemporary road safety policy, following safe system approaches, emphasises synergies between the full range of potential interventions – regulation of driver behaviour, infrastructure design, vehicle technology, traffic management, fleet maintenance and man management, shipper responsibilities and logistics management. Environmental performance is also conditioned by the combination of vehicle technology, vehicle configuration, traffic management, vehicle maintenance and fleet management, driver behaviour and logistics. Achieving major improvements in performance requires improvement on all fronts. This includes: using the right vehicles for the right tasks, to optimise the number of vehicles used; charging transport services efficiently to reflect external costs and price them efficiently in relation to other logistic costs; and improving load factors both by customising vehicles and setting transport charges to provide efficient prices signals. There is scope for improving the regulatory framework in all of these areas.

3.3. Weights and dimensions

Most countries regulate heavy vehicle weights and dimensions through extensive prescriptive requirements, *i.e.* by direct statement of maxima and/or minima. Regulations are generally set at the national level. In federal countries, states often set the regulations with federal regulations providing nationwide road network access for trucks of standard weights and dimensions.

The UNECE process does not cover weights and dimensions for heavy vehicles. Thus, although there are some specific regional initiatives, there is no broad international process for the harmonisation of heavy vehicle weights and dimensions. Even within federal systems (Canada, United States, European Union), there is limited harmonisation of heavy vehicle weights and dimension requirements across countries/States/Provinces. In general, within each of these systems, there is reasonable harmonisation for rigid trucks and combination vehicles up to 40-45 tonnes GVM, but limited harmonisation above that level. One of the purposes of the Australian PBS process is to achieve harmonisation of performance standards and operating conditions for vehicles currently operating under State/Territory permits.

Maximum width ranges from 2.5 metres in South Africa, Australia, New Zealand, many Asian countries and some countries in Europe and Africa to 2.59 metres (102 inches) in the United States, 2.60 metres in Canada and Sweden and 2.65 metres in the Ukraine. Maximum length for typical long-haul vehicles ranges from 16.5 metres for a truck-trailer in the EU, to 26 metres for a B-double in most Australian states. Maximum height ranges from 4.0 metres in Europe, to 4.6 metres in some African countries. In some countries, no height limit is specified and the practical maximum is set by infrastructure restrictions. In most countries this leads to a maximum vehicle height in the 4.0 – 4.5 m range but in a few, for example, the UK, vehicles can be as tall as 4.9 m.

Maximum mass ranges from:

- Steering axle: 5.5t in Canada to 7.7t in South Africa (many countries, *e.g.* EU, do not separately regulate the steering axle mass).
- Single axle: 9 t in South Africa, Australia and the US to 13t in France.
- Tandem axle[1]: 15.4 t (34 000lbs) in the US to 19 t in Norway.
- Tridem axle[2]: 20 t in Mexico to 27 t in Belgium (depending on axle spacing).

Gross mass of the most commonly used long haul vehicles ranges from 36.3 tonnes (80 000 lbs) on Interstate highways in the US to 45 – 50 tonnes in Canada, Mexico, Australia and South Africa. Many countries allow larger vehicles to operate under permit or similar systems. These vehicles are often subject to route restrictions. Some examples of weights and dimensions in various countries are presented below.

European Union

EC Directive 96/53/EC of 25 July 1996 defines the maximum dimensions and weights for trucks used in border crossing transport in the EU. Member states are obliged for market reasons to respect the same length maxima for trucks in national transport, but may set other limits for height, weight and axle loads.

The EU permits maximum lengths of 16.5 m for conventional tractor-semitrailer combinations and 18.75 m for truck-trailer combinations. Width is limited to 2.55 m (2.60 m for refrigeration containers) and height to 4.00 m. Maximum permissible vehicle mass is 40t, except for intermodal transports using 40-foot containers, which are allowed a maximum weight of 44 t.

Maximum axle weights are 10 t for a single axle and 11.5 t for a driven axle. Maxima for tandem axles and tridem axles on trailers and semitrailers may vary, depending on axle spacing, in the range 11-20 t and 21-24 t respectively; while maxima for tandem axles of motor vehicles may vary from 11.5 t to 19 t depending on axle spacing. There is no specific mass limit for steering axles, but other vehicle design constraints result in an effective mass limit of 8 tonnes for these axles.

Some European countries outside the European Union (*e.g.* Norway, Switzerland, Liechtenstein) align with EU weights and dimensions for heavy vehicles.

Vehicles which diverge from the EU regulations are permitted in national operations. Longer and heavier vehicles are operated under permits and pilot schemes in Norway, Sweden, Denmark and the Netherlands.

United States

In the United States, heavy vehicles using the Interstate Highway System are governed by Federal weights and dimensions requirements, whilst vehicles on other roads are subject to State regulations. Federal regulations permit a maximum mass of 20 000 pounds (9.1 t) on single axles; 34 000 pounds (14.5 t) for tandem axles; and GVM of 80 000 pounds (36.3 t).

National vehicle size standards apply on the National Network of highways. This network includes:

- The Interstate Highway System.
- Highways, formerly classified as Primary System routes, capable of safely handling larger commercial motor vehicles, as certified by states to FHWA.

The total National Network system is about 200 00 miles (322 000 km), of which 47 000 miles (75 000 km) is the Interstate Highway System. Federal commercial vehicle size limits on the National Network provide a minimum length of 48 feet (14.63 m) for semitrailers (longer if provided for by grandfathering rights) and 28 feet (8.53 m) for trailers in a twin-trailer combination. Vehicle width is set at 102 inches (2.59 m).

Canada

Canadian jurisdictions are harmonised with respect to commercial vehicle dimensions (while allowing different maximum allowable weight limits). The maximum allowable length for any combination in Canada is 25 m, allowable height is 4.15 m, and allowable width is 2.6 m.

A federal-provincial-territorial Task Force on Vehicle Weights and Dimensions Policy pursues greater harmonisation of vehicle weights and dimensions regulations within Canada. In Canada, the provinces and territories have authority for establishing vehicle weight and dimension limits on roads within their jurisdiction. A Memorandum of Understanding Respecting A Federal–Provincial-Territorial Agreement on Vehicle Weights and Dimensions (MOU) identifies several vehicle configurations that provinces and territories have agreed will be allowed on their main roads. This offers carriers and shippers a degree of consistency for freight movement across the country.

Finalisation of the MOU required extensive negotiations between the provinces and territories, because there were considerable differences in the trucks used and road infrastructure capability from province to province that required reconciliation. This MOU, the result of a conscious effort by Canadian jurisdictions to harmonise vehicle weights and dimension regulations for trucks, was the first time in North America that performance standards were used as the basis for selecting standards for weights and dimensions. The technical base was provided by studies of truck dynamics and impacts conducted in the 1970s and 1980s, some by individual provinces and others jointly by the provinces and federal government.

The MOU was signed in 1988 by all provinces and territories through the Council of Ministers Responsible for Transportation and Highway Safety (COMT) and has since been updated several times. The current MOU establishes specifications for seven truck configurations and one intercity bus configuration. A key part of the MOU is a list of roads that each province has identified. A vehicle that meets MOU specifications for its configuration can operate on the MOU identified roads (provided all other regulatory conditions are met, such as an appropriately licensed driver and possession of a safety fitness certificate). By signing the MOU, a province commits to handle the MOU vehicles on the MOU roads, but the province is free:

- For vehicles with MOU configurations and dimensions, allow them to operate within the province at heavier weights than defined in the MOU.
- To allow any other vehicle (configuration, dimensions, weights) to operate within the province.

South Africa

Axle and axle unit loads are limited by the minimum of vehicle manufacturer's rating, tyre manufacturer's rating and road damage limits. Road damage limits are: steering axle 7.7 tonnes; non-steering axle (2 tyres) 8 tonnes; (4 tyres) 9 tonnes; tandem axle unit (single tyres) 16 tonnes; (dual tyres) 18 tonnes; tridem axle unit (single or dual tyres) 24 tonnes.

Permissible maximum vehicle/combination mass limited to the minimum of: sum of axle/axle unit permissible masses (as determined above); 240 times power rating of motorised unit in kW; 5 times actual mass on the drive axle/axle unit; manufacturer's GVM/GCM; bridge formula from first to last axle (P=2,1 L + 18); and 56 tonnes.

Australia

In Australia, weights and dimensions of heavy vehicles are controlled by State and Territory governments. However, national processes have led to a high degree of uniformity in weights and dimensions, especially for vehicles of up to around 46 tonnes GVM. Maximum axle mass is: 6.5 tonnes for a steering axle (6.7 t on a road train), 9 tonnes for other single axles, 16.5 tonnes for tandem axles and 20 tonnes for tridem axles. Tandem and tridem axles are permitted an additional 0.5 and 2.5 tonnes respectively if they are fitted with road-friendly suspensions (subject to route restrictions for tridem axles). A six-axle tractor-semitrailer (the most common long haul vehicle) has a maximum length of 19 metres and a maximum mass for of 43 tonnes (6.5 tonnes on the steering axle, 16.5 tonnes on the tandem drive axle and 20 tonnes on the tridem axle) or 46 tonnes (6.5 + 17.0 + 22.5) if the axles are fitted with road-friendly suspensions. For the additional mass on the tridem axle, accreditation under the Mass Management module of the National Heavy Vehicle Accreditation Scheme is also required. Width is limited to 2.5 m and height to 4.3 m, except for livestock trailers and car carriers which are allowed a height of 4.6 m.

Truck-trailer combinations of above 42.5 tonnes are subject to State/Territory regulations, with consequent variations in mass limits. Mass limits for these vehicles range up to 55 tonnes.

B-doubles and larger vehicles (B-triples, double and triple road trains) are subject to the same limits on height, width and axle mass as other vehicles and their access to the road network is restricted. Gross mass and length for these vehicles is:

- B-double (tractor and two B-coupled trailers, 9 axles): 68.5 t, 26 m.
- B-triple (tractor and three B-coupled trailers, 12 axles): 91 t, 36.5 m.
- Double road train (tractor and two A-coupled trailers, 11 axles): 85.5 t, 36.5 m.
- Triple road train (tractor and three A-coupled trailers, 16 axles): 125 t, 53.5 m.

3.4. Trends in heavy vehicle technical standards

In most countries, the current regulatory approach is one of prescriptive control of vehicle weights and dimensions, with a movement towards performance-based standards for most technical safety standards. There is a considerable lack of uniformity of regulation across regions and countries. Many commentators and industry representatives argue that this lack of harmonisation of heavy vehicle regulation imposes both productivity and safety costs.

The major benefit of harmonisation is that it facilitates transport, and therefore trade, between harmonised regions. Where training and licensing requirements are harmonised, the trade in labour and services are facilitated. Harmonisation of vehicle standards reduces costs associated with providing specialised equipment to regions with different standards and facilitates globalisation of the provision of transport equipment.

A disadvantage of harmonisation is that it may lead to greater difficulty in providing equipment and services which are optimised to meet the requirements of particular regions. For example, harmonisation across diverse regions could prevent the operation of longer and heavier trucks in terrain and road conditions to which these vehicles may be well suited. Harmonised regulations which require forms of audit, inspection, accreditation and certification may be more difficult in developing countries with lower levels of workplace skills and weaker institutional arrangements.

One response to these difficulties in harmonisation is to allow exemptions or variations in the application of the harmonised regulations. For example, when Australia applied the UNECE noise regulations, it allowed an additional 3 db for longer combination vehicles (B-doubles, road trains and above).

There is currently a strong trend towards the harmonisation of heavy vehicle technical safety and emissions standards, through the 1998 Global agreement and the UNECE WP.29 process. This convergence in vehicle technical standards will facilitate the supply of heavy vehicles and related equipment at lowest cost. Where adoption of international standards does not reflect local conditions, productivity may be adversely affected. For example, if emissions standards tailored to populous areas are applied in sparsely populated areas, fuel use efficiency may be reduced, with minimal environmental benefit.

Other than in the area of vehicle technical safety and emissions standards, it is likely that variations in requirements will persist indefinitely. This includes requirements relating to drivers, operators and operating conditions including compliance and enforcement. In these areas of regulation, harmonisation between contiguous geographical regions of frequent heavy vehicle travel is of greater importance than any attempt at globalisation. There are strong arguments to allow variations in heavy vehicle size, weight and operating conditions to reflect local geographical, cultural and economic environments, provided that artificial geographical regulatory divergences between areas engaged in trade through land transport can be minimised.

There is generally an alignment of weights and dimensions for 'workhorse' vehicles engaged in cross-border trade in contiguous areas (including within the European Union, the United States, Southern Africa, Canada and Australia). This includes vehicles of up to 40-46 tonnes gross mass and 17-20 metres in length. Many countries, states and/or provinces within these areas allow local operation of higher capacity vehicles.

This situation, however, also has many unfavourable features. For example:

- In the European Union, Canada and the United States, higher productivity vehicles can only be operated locally/nationally.
- In the United States, the most productive vehicles are only permitted to operate on non-national roads, which are generally of poorer quality than interstate highways and other designated national routes.

The greatest variations in vehicle-related regulatory requirements are for mass (both gross and axle), dimensions (length, width and height) and vehicle type. In the short-to-medium term, the greatest problem associated with these regulatory differences is likely to be in the area of vehicle width and front axle mass. Permitted front axle mass is considerably higher in Europe than in North America and Australia. If sustained, this situation will limit potential efficiencies through common vehicle design and manufacture.

3.5. Environmental Standards

The United States, the European Union and Japan have each developed fuel quality standards and exhaust emissions standards for heavy duty vehicles. The emission standards concern carbon monoxide, hydrocarbons, nitrogen oxides (NOx), particulate matter (PM) and a small number of other gases. These emission standards have brought significant reductions in the emission of local pollutants.

Recent developments have focussed on reducing the level of NOx and particulate emissions to very low levels. Future standards will limit the number of particles emitted as well as the mass emitted in order to control the smallest particles that penetrate deepest into the body.

Table 3.1. **EU emission standards for HD diesel engines, g/kWh**

	Date	CO	HC	NOx	PM
Euro 1	1992, < 85 kW	4.5	1.1	8.0	0.612
	1992, > 85 kW	4.5	1.1	8.0	0.36
Euro 2	1996.10	4.0	1.1	7.0	0.25
	1998.10	4.0	1.1	7.0	0.15
Euro 3	*1999.10, EEVs only*	*1.5*	*0.25*	*2.0*	*0.02*
	2000.10	2.1	0.66	5.0	0.10 0.13[a]
Euro 4	2005.10	1.5	0.46	3.5	0.02
Euro 5	2008.10	1.5	0.46	2.0	0.02
Euro 6	2013.01	1.5	0.13	0.4	0.01

The EU standards entering into force at the end of 2012 will mark a convergence of the limits for NOx and particulates in the USA, Japan and Europe. Most other countries follow the EU's "Euro standards" with varying lag times for the entry into force of successive limit values. China and Taiwan follow the US approach and Mexico allows trucks meeting either US or EU regulations into their market.

The UNECE World Forum for Harmonization of Vehicle Regulations is working to improve the alignment of standards worldwide in order to facilitate the functioning of the global vehicle market (see annex).

Table 3.2. **Euro VI emission limits (adopted in 2009 to enter into force at the end of 2012)**

	Limit values						
	CO (mg/kWh)	THC (mg/kWh)	NMHC (mg/kWh)	CH_4 (mg/kWh)	NOx (mg/kWh)	NH_3 (ppm)	PM mass (mg/kWh)
ESC (CI)	1500	130			400	10	10
ETC (CI)	4000	160			400	10	10
ETC (PI)	4000		160	500	400	10	10

ESC = European Stationary Cycle emissions test procedure
ETC = European Transient Cycle emissions test procedure
PI = Positive Ignition
CI= Compression Ignition

Source: EU Regulation 595/2009/EC.

Fuel sulphur content is critical to the performance of many emissions control systems, but fuel quality standards for diesel differ widely. Sulphur limits range from 10 ppm for ultra low sulphur diesel in Europe and Japan (15 ppm in the USA) to between 1 000 and 12 000 ppm in diesel sold across much of Asia, Africa, Latin America and Russia. India, Mexico and a number of other countries limit sulphur to 300-500 ppm. Lower sulphur fuels are available at some pumps in, for example, Russia and in major Indian cities; but the maximum sulphur content of the fuel to which vehicles are likely to be exposed determines which emission control technologies are viable in the market. The control systems available to meet Euro IV standards (applicable in Europe from 2005) are designed for diesel with 50 ppm sulphur or less. The catalysts and filters used to meet the latest round of emissions regulations (Euro VI, US HD07, and Japanese standards for 2009) operate optimally with sulphur levels of 15 ppm or less. Fuel quality and emissions standards have to be developed in concert. Higher levels of sulphur reduce the effectiveness in controlling emissions and increase fuel use (to burn off soot and regenerate filters and catalysers). Exposure to high levels of sulphur can irreversibly damage performance of some emission control systems.

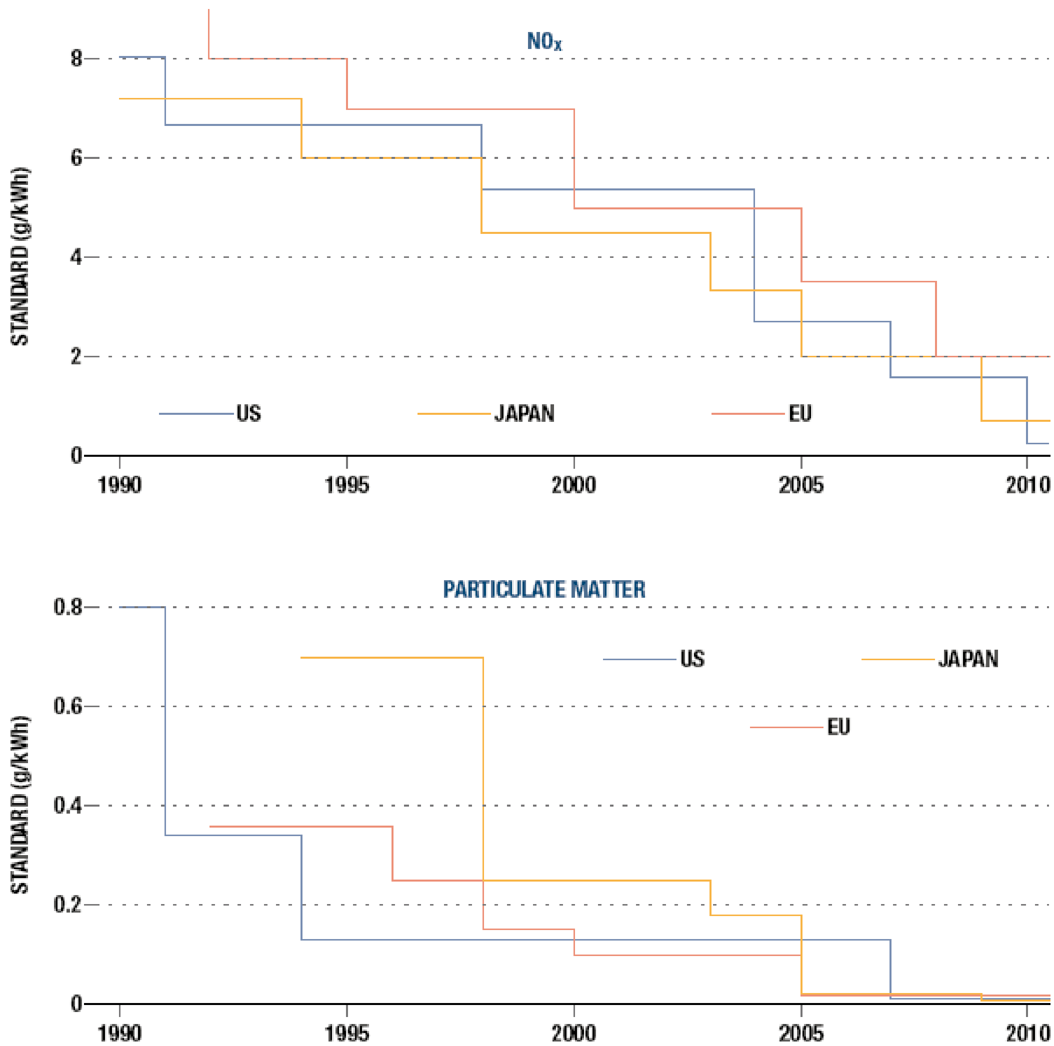
Table 3.3. **Diesel sulphur limits 2009**

Limit	Regions
10 ppm	European Union, Japan, Norway, Iceland, Switzerland
15 ppm	USA, Canada
50 ppm	Australia, South Korea
300-500 ppm	India, Mexico, Chile, Oman, Taiwan, Thailand, Philippines, Papua New Guinea, South Africa, Namibia, Botswana
1 000-12 000 ppm	China, Russia, Rest of Asia, Latin America, Africa, Middle East and Europe

Source: IFQC.

The levels of NOx and particulate emissions permitted for type approval of new heavy duty vehicles in the EU, Japan and the United States have been reduced sharply over the last two decades in a series of steps (Figure 3.1). The latest round of emissions limits are summarised in Table 3.3. Well-maintained vehicles of recent design emit very low levels of these pollutants.

Figure 3.1. **The Development of NOx and PM emissions limits in the EU, Japan and the USA**



Source: ICCT, 2007, modified from Tokyo Metropolitan Government.

Table 3.4. **Latest emission standards for heavy duty vehicles**

	Entry into Force	NOx (g/kWh)	PM (g/kWh)	PM (#/kWh)
EU (Euro VI)	End of 2012	0.4	0.01	To be set in 2010
Japan (NLT)	2009	0.7	0.01	
USA (HD07)	2007 PM, 2010 NOx	0.27	0.013	

Source: ICCT 2007, EU Regulation 595/2009/EC.

Alternative PM and NOx treatment systems available on the market and in development have advantages and disadvantages, with trade-offs to be made between effectiveness, durability, robustness and fuel efficiency. This is a dynamic environment and advances in catalysts, in the design of catalysers, in engine control systems and exhaust system engineering change the relative merits of each approach over time. One of the challenges of designing regulations is to enable these advances and avoid prematurely picking winners that might cut commercial interest in developing the alternative treatment systems.

Although the level of permitted emissions has converged, the test cycles used for approving vehicles for sale differ significantly between the countries. Idling and low-speed crawling figure prominently in the Japanese test cycle to reflect conditions on congested Japanese roads. The European test cycle involves frequent variations in load and speed. The US cycle has a high proportion of high-speed cruising, more typical of conditions on US highways. This makes optimising engine performance to meet all three sets of emissions regulations challenging. The World Forum for Harmonization of Vehicle Regulations is working on harmonisation of test cycles as well as standards to facilitate the design of vehicles for global markets (see Annex A).

As emissions standards evolve it is always necessary to monitor the emergence of unexpected problems: the excess NOx levels resulting from the gap between test and on-road driving conditions, for example, and the increase of NO_2 emissions with the spread of diesel oxidation catalysers. The emergence of new pollutants as a side effect of control technologies has also to be monitored, as with ammonia from SCR. Emissions controls rely increasingly on on-board diagnostics to ensure active control systems are performing as intended. On-board diagnostics are a powerful tool for ensuring on-road compliance with standards, but they have still to mature and prove their reliability. All these factors mean that routes to reducing emissions that do not rely on exhaust control systems, such as reducing the number of vehicles on the road and managing congestion, continue to be of value despite the very low specific emissions levels mandated by current standards (see also chapter 5.1).

Regulating CO_2 Emissions from HDVs

Fuel economy standards were developed for passenger cars by the United States DoT in the 1970s, the CAFE standards. CO_2 emissions standards were adopted for passenger cars in the European Union in 2009. Setting fuel economy or CO_2 emissions standards for heavy trucks is complicated by the great variation in truck configuration and trailer types. The fuel consumption of trucks driven by the same engine with the same design of cab varies enormously with the weight and aerodynamic properties of the trailer they haul and with the configuration of axles and tyres on the trailer. Nevertheless, a standard in terms of litres consumed per kWh of engine output or grams of CO_2 per kWh can be employed, assessed on a test cycle that subjects the engine to a range of loads and typical drive cycles, as used for the regulation of NOx and PM emissions.

It is often argued that concern to reduce fuel costs on the part of truck operators drives manufacturers to develop fuel efficient trucks without the need for fuel economy or CO_2 standards. The market imperfections that standards seek to address are perhaps less pronounced in markets for heavy vehicles than car markets, but some of the same features are present –especially for small businesses operating only one or a small number of vehicles for whom truck purchase decisions are difficult to plan on the basis of long term economic considerations. And in relatively low fuel tax environments there is less concern with fuel efficiency, as the development of SCR technology in Europe rather than the USA reflects (see section on NOx emission controls).

Japan has therefore developed fuel economy regulations for heavy vehicles and, for the time being, is the only country that has truck standards for fuel economy or CO_2 emissions. This was perhaps facilitated by the Japanese approach to developing standards, also employed in passenger car and electric appliance markets, the 'Top Runner' approach. This sets standards for the average performance of new vehicles at a future date on the basis of the current best performing truck in each class of vehicle. Truck standards were adopted in 2006, under the 1976 Energy Conservation Law, setting so-called "New fuel efficiency standards" for 2015 for heavy vehicles above 3.5 t. The standards aim to reduce the average CO_2 emissions of trucks by 12.2% between 2002 and 2015, from an average of 415 g CO_2/km to 370 g CO_2/km (Japanese Agency for Natural Resources and Energy, 2005). Using the top runner approach facilitates standard setting by avoiding the problem of assessing the cost and effectiveness of technologies that are not yet on the market but, by the same token, may provide only weak stimulus for further technological development.

3.6. Truck operations

In most countries a range of conditions are imposed on the operation of trucks. These are designed to improve safety by limiting heavy vehicles to suitable parts of the road network and to minimise the impact they have on the community by restricting their access to more populous areas, particularly at night and on weekends. Restrictions are most severe in parts of Europe where many countries do not permit the operation of heavy vehicles on weekends or public holidays.

Speed restrictions

In many countries, more restrictive speed limits are applied to heavy vehicles.

Countries that apply differential speed limits for heavy vehicles include most European countries, Mexico, and South Africa. Some European countries apply non-urban speed limits that are lower than the maximum speed limiter speed. For example, Denmark, Germany and The Netherlands apply a heavy vehicle speed limit of 80 km/h on motorways. South Africa applies a limit of 80 km/h on all non-urban roads. In Mexico, the non-urban heavy vehicle speed limit ranges from 80 km/h to 95 km/h, depending on road and vehicle type.

Countries which do not generally apply differential speed limits for heavy vehicles include Canada, Australia and the United States. In several Australian States a speed limit of 90 km/h is applied to road trains (tractor and two or three trailers).

In the United States, heavy vehicle speed limits are generally high by international standards (up to 75 miles per hour). Most States do not apply differential speed limits to heavy vehicles.

The break point for more restrictive heavy vehicle speed limits is 9 t GVM in South Africa, generally 3.5 t GVM in Europe, 12 t GVM in Australia and based on vehicle type (rigid, articulated with one trailer and articulated with two trailers) in Mexico.

Cargo securement

This is an area of significant variation. Approaches range from no regulation, to guidelines, to extensive prescriptive regulation.

Canada, United States, Germany and South Africa have specific requirements. Denmark and France have only a general requirement to secure the load. Australia has a general requirement which is supported by a *Load Restraint Guide*. Russia has no cargo requirement but is developing a Technical Regulation.

Canadian and United States requirements were developed in a joint programme.

Transportation of dangerous goods / hazardous materials

UNECE regulation of the transport and handling of dangerous goods is developed through Working Party 15. Many countries adopt these regulations. In Europe, these provisions are adopted through the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR). In South Africa and Australia local requirements are based on UNECE regulations. Australia is moving towards adoption of UNECE regulations by reference. Russia applies UNECE regulations for international traffic but different national Rules of Transportation for national traffic. The local requirements are currently being reviewed to harmonise them with UNECE.

Canada and United States each regulates the transport of dangerous goods through national legislation.

Access conditions

Heavy vehicles which generally have wide access to the road system may face restrictions on some routes or at specific times.

Many European countries (including France, Austria, Germany, Belgium, Italy, Poland, Portugal, Switzerland, Czech Republic, Slovak Republic and Slovenia) do not permit the operation of heavy vehicles on weekends or public holidays. In some cases (*e.g.* Austria) reduced speed limits apply to heavy vehicles operated at night.

In Denmark, national legislation has authorised municipalities to establish environmental zones. Trucks and buses are only permitted into these zones if they have either an engine meeting the Euro III standard, or are fitted with an approved particulate filter. Central areas of Copenhagen city have been established as environmental zones.

Over-dimensional vehicles

There are no EU or UNECE regulations for over-size transports. The carrier undertaking such transports must apply for permission with the relevant authorities in the countries in question.

Most countries have some form of permit system for the operation of oversize or overmass vehicles. In federal systems (*e.g.* Australia, United States, Canada, European Union) there may be regional inconsistencies in weights, dimensions, or operating conditions for these vehicles. Australia is attempting to improve consistency in the operation of over-dimensional vehicles through the development of nationally agreed performance-based standards.

Permit systems generally involve ‘reverse onus’. For most vehicle operations, the right to access the road system is provided unless a serious offence can be proved against the driver or operator. However, under permit systems, the right to operate can often be removed unless the operator can prove compliance with additional operating conditions.

Permit conditions may include a requirement that over-dimensional vehicles be accompanied by pilot vehicles.

Vehicle safety inspections

The most common requirement for periodic safety inspections of heavy vehicles is annual inspections by government inspectorates or licensed organisations (EU, Norway, Russia, Canada, United

States, Mexico, South Africa, some Australian states). Belgium requires inspections every six months and some Australian states do not require any periodic inspections of heavy vehicles.

All countries undertake roadside inspections of heavy vehicles.

In addition to the 1958 and 1998 Agreements, the World Forum for Harmonization of Vehicle Regulations administers the 1997 Agreement on periodical inspection of vehicles.

3.7. Drivers

Driver licensing

In most countries, there is some form of graduated licensing requirement for drivers of heavy vehicles. These take the form of a requirement to hold a licence for smaller vehicle classes before being permitted to take a test to drive larger vehicles. In some countries, specific training is required to drive heavy vehicles or specific classes of heavy vehicles.

In most countries, an applicant for a licence to drive a heavy vehicle is required to undertake some form of medical examination (in addition to an eyesight test) and many countries require a regular medical examination, generally with greater frequency for older drivers.

Drivers of heavy vehicles are usually subject to the same drug and alcohol restrictions as drivers of other vehicles, although some countries apply stricter alcohol standards to drivers of heavy vehicles. In the United States, operators are required to apply drug and alcohol tests to drivers.

There has been little attempt to align driver requirements internationally, except within the EU. Within North America, there is mutual recognition of driver licences between Canada and the United States.

Hours of service

Restrictions on hours of service, working hours, or driving hours are applied in most countries. Regulation applied through labour law or social legislation (EU, South Africa, Mexico, Russia) generally results in more restrictive working hours than regulation applied through transport safety law (Australia, Canada, New Zealand, United States). Hours of work restrictions are difficult to summarise due to the complex interactions of daily and weekly restrictions and, in some cases, the availability of different options. Restrictions on daily work hours range, depending on the circumstances, from eight to ten hours in the European Union, Russia and Mexico; to 12 to 14 hours in Australia, Canada, New Zealand and the United States. Permitted weekly working hours are 56 in Europe (or 90 over a two-week period), 72 in Australia, 70 in Canada and 70 in New Zealand. In the United States, a driver may not drive after 60 hours of duty in seven consecutive days or 70 hours in eight days, depending on the cycle under which he is operating.

In South African transport legislation, there are no restrictions on working hours for truck drivers. However, under an industrial labour agreement, there is a general limitation of nine hours per day and 45 hours per week, with an ability to extend working periods provided rests are also extended to compensate and there is no increase in total hours of work.

Hours of service requirements apply to drivers of trucks of above 3.5 tonnes GVM in Europe, 4.5 t in Canada, New Zealand and the United States (10 000 lbs) and 12 t in Australia.

Canada and the United States have different hours of service regimes and no mutual recognition. Drivers must comply with all applicable regulations while operating in each country.

European regulation of hours of service applies more broadly than the European Union countries. The European Agreement concerning the work of Crews of Vehicles engaged in International Road Transport (AETR, 1st July 1970, commonly referred to as 'AETR Agreement') regulates the work and rest times of drivers. The AETR Agreement has been ratified by 42 contracting parties.

The basic regulation of driver working hours and rest periods for international road transport in Europe is the responsibility of the UNECE under the European Agreement concerning the Work of Crews of Vehicles engaged in International Road Transport (the AETR convention) with the 50 UN Member states in Europe (of which the 28 EU member states are a subset) as contracting parties.

Following a ruling in 1971 by the European Court of Justice, the European Commission has sole responsibility to act on behalf of the Member States to negotiate the AETR regulations, which will eventually become the repository for a single, unified set of rules for the European UN member states.

Hours of service regulations have recently been reviewed in Canada, United States, Australia and New Zealand. The purpose of these reviews has been to improve safety outcomes by better linking regulatory requirements to scientific knowledge of fatigue causation. None of these reviews has led to significant reductions in permitted hours of service.

Trip/event recorders

Currently, trip/event recorders are required only in the European Union, as part of the record-keeping requirements of the working hours regulations. The current requirement for a digital tachograph replaces the earlier requirement for an analogue tachograph.

The digital tachograph is seen as a more secure and accurate recording and storage device than the analogue tachograph. The digital tachograph records all the activities of the vehicle, including distance, speed and driving times and rest periods of the driver. The system includes a printer for use in road side inspections. The driver is issued with a card incorporating a microchip, which he must insert into the tachograph when he takes control of the vehicle. This personal driver card ensures that inspections remain simple. Since 1 May 2006, it has been obligatory to install the digital tachograph in new vehicles having a mass of more than 3.5 tonnes (in freight transport) and carrying more than nine persons (in passenger transport). The European Union regulatory framework for digital tachographs includes specification of processes for issuing driver cards and installing and maintaining tachographs. The specifications of the tachograph performance requirements are included in the UNECE regulatory structure for international road transport in Europe.

In Canada, the United States and Australia, electronic recording devices are permitted as an alternative to paper log books for recording hours of driving and work. In Australia, following consideration of adoption of the European digital tachograph, it has been decided to instead develop performance standards to support electronic record keeping for the new hours of service legislation.

The United States is currently developing a regulation which may mandate trip recorders in heavy vehicles. The U.S. Federal Motor Carrier Safety Administration on January 23, 2009 pulled back its regulation to require some carriers to use electronic onboard recorders (EOBR) pending additional review under a new Presidential administration. One purpose of the review is to determine how the rule may be revised to expand the use of EOBRs on more trucks. In its initial proposal, the EOBR rule would have applied only to carriers that have high out of service rules violation rates in two compliance reviews in a two-year period.

On 19 November 2008, FMCSA rescinded a policy barring use of some driver and operator records for enforcement. FMCSA instituted the policy in 1997 to "encourage and promote the use of technology". The FMCSA considers that this goal has now been achieved, and if a driver has global positioning system (GPS) records showing violation of hours of service rules, then FMCSA will use those records for enforcement purposes.

Many operators are voluntarily installing electronic trip recorders for management purposes.

Speed limiters

Speed limiters may electronically limit the maximum attainable speed of trucks, and are assumed to benefit fuel use and speed-related crashes. Speed limiters are required for all vehicles in excess of 3.5 tonnes in the European Union and some other European countries, and in Australia for trucks with GVM exceeding 12 tonnes.

In Canada, a comprehensive series of studies[3] were completed in 2008 examining the feasibility of mandating heavy truck speed limiters. This included traffic modelling to better understand the safety impact from differential car-truck speeds on highways, quantifying the environmental benefits from fuel savings and reduced greenhouse gas (GHG) emissions, and an assessment of the trade and competitiveness impacts of a speed limiter mandate in both the Canadian and North American context. No national requirement has been supported at this time, but two Canadian provinces, Ontario and Quebec, now require heavy trucks to be equipped with a speed limiter set at 65 mph (105 kph)[4]. This requirement took effect on 1 July 2009, and is retroactive for trucks built after 1995. All trucks entering these two provinces have to comply.

An ongoing survey of the use of speed limiters in the US trucking industry (American Transportation Research Institute, 2007) has so far shown that 69% of the respondents use such devices on their trucks. Of hauliers that employ owner-operators, 25% require them to use speed limiters. The speeds at which the limiters were set vary from 60 to 85 mph, with an average of 69 mph. Fear of compromising safety by breaking the traffic flow with a car-truck speed differential was cited as the reason by 40% of the hauliers who do not use speed limiters.

Alcohol and drugs

Most countries have limits on the permitted blood alcohol content for drivers. These limits range from zero to 0.08%, with 0.05% the most common. In most countries, drivers of heavy/commercial vehicles are subject to the same drug and alcohol limits and testing regimes as drivers of other vehicles. In some countries, more restrictive alcohol limits are applied to commercial drivers.

In Spain, Australia and South Africa the limit for drivers of light vehicles is 0.05%, while the limit for drivers of heavy vehicles is 0.03% in Spain, and 0.02% in Australia and South Africa.

Most countries do not require operators to test commercial drivers for drugs or alcohol. An exception is the United States, which has implemented regulations that stipulate drug and alcohol testing for commercial vehicle drivers. The regulations require motor carrier employees to administer the Federal drug and alcohol testing programme to drivers of commercial motor vehicles. The Large Truck Crash Causation Study analysed the causes of serious crashes and determined that the frequency of drug and alcohol use as a cause is much less for large trucks than that for passenger vehicle crashes.

In Australia, roadside testing for alcohol has been extended to include testing for the presence of some drugs, and is sometimes targeted at drivers of heavy vehicles.

3.8. Transport operators

There is marked variation between countries in the degree and type of regulation imposed on operators of road freight services. In some countries (*e.g.* South Africa, Australia, Russia) there are no specific requirements, whilst in others (*e.g.* EU, Canada, United States, New Zealand) operators of road freight services are subject to extensive licensing and management requirements.

Operator licensing systems have usually evolved from economic regulation, *i.e.* price setting and/or restrictions on the number of operators, which was designed to protect government-owned rail operators from unregulated competition from road freight operators. In most countries, this form of regulation has been removed. In some countries it has been replaced by regulation of transport operators designed to achieve safety.

Operator licensing

Operator licensing generally involves registration of road freight transport operators and a requirement that they demonstrate compliance with technical, safety, financial fitness or other standards set by the regulator. These standards are seen as a means of achieving safety outcomes by ensuring the quality of operators. The specific requirements necessary to comply with operator licence conditions vary between countries.

In 1998, around 80% of OECD countries required firms to obtain a permit, licence or certificate to set up a business supplying road freight services. In most OECD countries, operator licences are required for hire and reward operators, but not necessarily for ancillary (own account) operators. However in the United Kingdom, Spain, Canada and New Zealand, ancillary operators must also obtain a licence or permit to operate their fleet.

In the European Union, admission to the occupation of road haulage operator is governed by Directive 9626/EC as amended by Directive 98/76/EC. Any road transport operator wishing to carry out an operation between Member States must hold a Community Licence issued by a Member State. To obtain a Community Licence, an operator must be of ‘good repute’ and demonstrate financial standing and professional competence.

This is seen as justified for several reasons:

- To halt the proliferation of unscrupulous firms which seek to gain market share by skimping on safety.
- To achieve greater harmonisation of standards between Member States, particularly as regards levels of financial standing required and the standard of professional competence expected.
- To facilitate the right of establishment in other Member States and the mutual recognition of professional status.
- To improve the overall professional standing and quality of road transport.

The financial standing for operators requires them to have capital assets of at least EUR 9 000 for the first vehicle and EUR 5 000 for each additional vehicle. The professional competence is based on an expanded list of practically oriented subjects, with common exam arrangements, marking and certificates. Regular checks at least every five years ensure that undertakings continue to satisfy these three criteria. The rules on admission to the occupation cover hauliers using vehicles of over 3.5 tonnes maximum authorised mass.

The European Parliament has adopted a list of infringements which may lead to the loss of a Community Licence. Whilst the European Union has no formal safety ratings system, national authorities are required to monitor the behaviour of transport operators and intervene if acceptable limits are exceeded. These limits are not formalised and may vary considerably between nations. Driver offences are taken into account in this process. The European Union is planning to introduce a common information system to prevent an operator who has been denied market access in one country from becoming licensed in another.

In the United Kingdom, there is a more rigorous form of regulation of road transport operators. In addition to demonstrating good repute and financial standing, a potential road transport operator must demonstrate knowledge of the industry and regulatory requirements and meet a requirement relating to the location of depots and their impact on traffic and communities. Rights to operate can be curtailed or withdrawn by Traffic Commissioners on the basis of individual offences, or patterns of offences, relating to the operator or drivers employed by the operator.

In the United Kingdom, operator licensing restrictions are also used for environmental planning purposes. 'O' licence applicants must advertise in the local press that they are applying for a licence or variation of a licence and must specify the location of each centre where their vehicles will be garaged and maintained. Local residents may appeal against the granting of a licence on the grounds of noise, pollution, visual intrusion, etc.

Canada, the United States and New Zealand all combine operator licensing approaches with different systems which rate the safety performance of operators.

In the United States, regulation of motor carriers is a function of the Federal Government through the Federal Motor Carrier Safety Administration (FMCSA). Motor Carriers (transport operators, freight brokers and freight forwarders) that are subject to federal regulations must register with the FMCSA within 90 days of starting a service. To register, motor carriers must demonstrate that they have adequate insurance and have agents in all states in which they will operate. They must also register with every state through which they will travel in conducting their operations. Operators must also submit to a safety rating fitness programme.

FMCSA has developed a 'safety fitness rating methodology' which uses data from on-site compliance reviews and roadside inspections to rate motor carriers. A carrier rated as 'unsatisfactory' must improve this rating within a specified time or will be prohibited from operating interstate or across national borders. In addition, the FMCSA has developed Safety Status Measurement System (SafeStat) – an automated analysis system that provides a regularly updated assessment of motor carrier performance. SafeStat ratings are used to guide the deployment of enforcement resources to focus on carriers posing the greatest safety risk and are made publicly available on the FMCSA website in order to assist customers in their choice of transport providers.

In Canada, the approach is applied through various standards of the National Safety Code (NSC) and is administered by the province in which the operator is based. Carrier safety ratings are determined on the basis of convictions for road transport offences which have been recorded against the carrier or its drivers and motor carrier facility audits. Relevant information provided by the United States or Mexico is included in the carrier ratings. If an 'unsatisfactory' rating is assigned, the carrier's right to operate is suspended. Canada and the United States have recently reached agreement on reciprocity in motor carrier safety rating. When operational, this will remove the need for the United States to maintain separate carrier ratings for Canadian operators.

Driver safety records are generally not aggregated in the same way as operator records are aggregated under safety ratings systems. Where drivers commit offences, previous offences may be taken into account in determining a penalty. In countries with demerit points systems (*e.g.* Australia), the driver licence is suspended when the points cap is reached.

In the United States, motor carriers must keep up-to-date qualification files for each regularly employed driver. This file includes:

- The driver's employment application.
- Proof that the employer has investigated the employee's previous employment and driving records.
- An annual review of the driver's driving record.
- A certification from the driver of the number and type of convictions for breaches of the motor vehicle traffic laws during the previous 12 months.
- A copy of the driver's Commercial Drivers Licence.
- Proof that the driver has passed a medical examination in the last two years.

Australia, South Africa and Russia have no form of operator licensing, or even of registration of transport operators.

In Australia, under the recent national compliance and enforcement legislation, action can be taken against both drivers and operators on the basis of 'persistent and systematic offences'. This allows an additional form of aggregation of adverse behaviours. The recent Australian compliance and enforcement legislation also allows courts to impose penalties and interventions similar to those available under operator licensing approaches, supervisory intervention orders, removal of the right to operate a transport company.

There has been little attempt to align operator requirements internationally, except within the EU. The United States and Canada exchange driver and operator information so that events can be recorded in the safety ratings system of the home jurisdiction.

Economic regulation

Many countries (including Australia, the United States and many European countries) previously applied economic licensing to road transport operations, in the form of quantitative restrictions on entry to the market. Most of this 'economic regulation' was removed in the 1980s and 1990s through broader processes of micro-economic reform and reflecting the need for more efficient provision of transport services.

However, international access to road haulage markets is still regulated in many parts of the world, including among countries participating in free trade areas, such as NAFTA and the European Union.

Cabotage, that is purely domestic haulage trips undertaken by a truck registered in a foreign country, is restricted. In the European Union, restrictions on cross-border transport were fully lifted on 1 January 1993 for longstanding members of the Union, but substantial phase-in periods were negotiated with countries joining the Union. Cabotage in the EU is authorised, still subject to certain conditions and restrictions. The motivation for these restrictions is to protect employment and conditions of employment in domestic haulage firms from competition. Countries outside the Union are granted some partial access to the international market so that they are not always obliged to return home empty after an international delivery. The conditions as to how many and what kind of trips (return hauls, triangular international trips, etc.) can be undertaken before returning home are subject to bilateral negotiations between each and every country, creating a complicated web of restrictions in Europe, given the number of parties involved.

To simplify arrangements for part of this international market, a form of regulation through allocation of rights to serve the market was introduced by the former European Conference of Minister of Transport and still undertaken by the International Transport Forum, covering Europe in its widest geographical dimension. Cross-border transport is facilitated by an annual distribution of licences on the basis of a political agreement between these countries. The system allocates a total of more than 6 000 permits to its member countries, on the basis of a weighted sum of quantified criteria and with incentives for the use of vehicles which meet higher environmental and safety standards.

Multilateral ECMT licences allow operating international transport between any two Member countries (cabotage is not allowed). From 1 January 2006, the number of loaded trips not involving the country of registration was limited to three; the driver subsequently has to return to the country of registration. Validity is 12 months; short-term licences for one month can also be obtained.

The purpose of this capacity allocation is to provide broad access to the European transport market to operators from each country in the interests of efficiency and integration. Quality standards were added when the number of licences was expanded in order to provide an incentive for hauliers enjoying this right of access to accelerate the introduction of cleaner and safer vehicles, a *quid pro quo* for access that proved highly effective.

Cabotage

Cabotage is the ability of operators from outside a jurisdiction to pick up and deliver freight within that jurisdiction. Most countries with land borders restrict cabotage to a limited number of freight operations or a limited period of time.

In the European Union, any non-resident carrier who is a holder of the Community Authorisation is entitled to operate, ‘on a temporary basis’ and without quantitative restrictions, national road haulage services in another Member State without having a registered office or other establishment in that State. ‘On a temporary basis’, means that these transports must not be carried out systematically, or continuously, over a long period of time.

The current interpretation of this provision is that a haulier taking a delivery to another Member State may then make three consecutive cabotage operations (*i.e.* collections and deliveries within that Member State) before returning to their home country within seven days.

The European Parliament wants to see these restrictions phased out. In May 2008, it adopted a provision increasing the permitted number of cabotage operations to seven, with effect from two years after the entry into force of the legislation, and then abolishing all restrictions on the number and duration of cabotage operations on 1 January 2014. This proposal was rejected by the Council of Ministers in 2009.

Cabotage is prohibited in Russia.

In the United States, foreign domiciled motor carriers are prohibited from providing point-to-point transportation services, with some exceptions.

Canada does not permit cabotage but allows some exceptions, including the repositioning of empty vehicles, in-transit cargo and domestic movements that are incidental to an international movement.

In countries with no land borders, including Australia and New Zealand, cabotage in road freight is not an issue.

NOTES

1. This applies to countries which offer a single limit. In some countries, the limit is dependent on the axle spacing. For example, in the EU tandem axle mass ranges from 11 t, if the spacing is less than 1.0 m to 20 t, if the spacing is 1.8 m or more.

2. In some countries, this limit is also dependent on axle spacings. In the EU, limits of 21 t and 24 t apply. The Belgian upper limit of 27 t is a local limit that applies to a wider axle spacing.

3. http://www.tc.gc.ca/roadsafety/safevehicles/motorcarriers/Speedlimiter/index.htm
   http://www.tc.gc.ca/securiteroutiere/VehiculesSecuritaires/TransporteursRoutier/limiteursvitesse/index.htm

4. http://www.mto.gov.on.ca/english/trucks/trucklimits.shtml
   http://www.mtq.gouv.qc.ca/portal/page/portal/entreprises_en/camionnage/limiteurs_vitesse

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Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability

CHAPTER 4. EVALUATION OF TRUCK PERFORMANCE

Abstract

This chapter presents the summary results of the performance benchmarking of 39 truck configurations across 10 countries. The benchmarking study seeks to examine the safety and productivity impacts of changes in the configuration of heavy vehicles, including weights and dimensions and articulation. The performance measures examined include vehicle dynamic safety performance, metrics, energy efficiency, CO_2 efficiency and freight transport productivity measures. (Bridge and road impacts are assessed in the chapter on Infrastructure).

The full benchmarking report can be found in a stand-alone report available on the ITF website[1].

Heavy vehicles are regionally unique because their design, axle loading, mass and volume are directly influenced by the regulations (which can differ significantly among most nations). This investigation is to benchmark safety and productivity performance of representative vehicles from participating member countries. The assessment was undertaken utilising well-established and validated computer simulation methods and a set of recognised measures for assessing performance.

This section of the report describes the benchmarking of 39 vehicle configurations across 10 member countries, and provides detail on the methods used and the vehicle performance results. For the most part, the candidate vehicles selected for benchmarking are actual vehicles currently in operation.

4.1. Benchmarking concept

Member countries were invited to submit representative vehicles for evaluation and to provide their technical information. Each vehicle was classified in the following three general categories:

- Workhorse vehicle – the vehicle most commonly used for long haul transport. This vehicle is generally at the upper end of the weights and dimensions that is permitted general or widespread access. Workhorse vehicles were defined in this study as having a gross combination mass (GCM) of less than 50 tonnes and a length of less than 22 metres. Of the 39 vehicles in the study, 21 of these were classified as workhorse vehicles.

- Higher capacity vehicle – This vehicle is typically operated under restricted access conditions, dependant on the suitability of the road network. This vehicle will be heavier and/or longer than the workhorse vehicle. Higher capacity vehicles were defined in this study as having a GCM of up to 70 tonnes and a maximum length of 30 metres. Thirteen vehicles were classified as higher capacity vehicles.

- Very high capacity vehicle – This vehicle typically operates under permit conditions, and often in rural or remote areas. It is heavier and/or longer than the higher capacity vehicle. Very high capacity vehicles were defined in this study as having a GCM of at least 52 tonnes and a length of at least 30 metres. Five vehicles were classified as very high capacity vehicles.

4.2. Vehicle benchmarking method

Each vehicle was examined against vehicle safety performance measures based largely on the Australian National Transport Commission's (NTC) Performance Based Standards (PBS) scheme. The subset of measures used provides an understanding of general vehicle performance in the broader international context. Some of the Australian measures were not used in this analysis because they did not provide distinguishing value for the vehicles examined. The load transfer ratio measure which is widely used internationally but not included in the Australian system was added to the performance measure subset because of its usefulness and value.

The University of Michigan (UMTRI) and JTRC conducted a survey of member countries and compiled the vehicle data. ARRB Group was contracted to conduct the simulations for the PBS analysis, while UMTRI conducted the productivity analysis. For the PBS simulations, a computer model was created for each of the 39 vehicles. Each vehicle model was based upon the characteristics supplied by the member organisations. The computer model was used to simulate the performance of the vehicle for each of the manoeuvres selected for evaluation. Independent replication was conducted using another model developed by LCPC/CETE (France).

4.3. Vehicles

During the course of this investigation, a total of 39 vehicle configurations were analysed and the performance assessed. A brief description of each of the vehicles assessed can be found in Table 4.1.

From the vehicles identified by the OECD member countries, four vehicles were identified as being European Union international traffic vehicles as no member can prohibit the use of these vehicles in international traffic within its territory. These vehicles have been referred to as European vehicles (Europe 1, Europe 2, Europe 3 and Europe 4) in Table 4.1.

Table 4.1. **Vehicles as modelled during benchmarking study**

(These vehicles represent real vehicles. Their lengths do not necessarily correspond exactly to the maximum authorised length.)

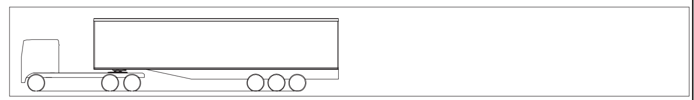
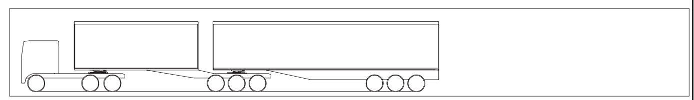
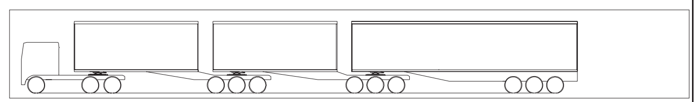
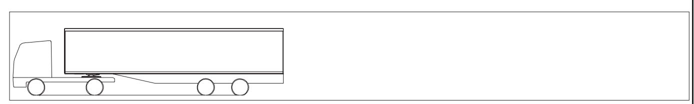
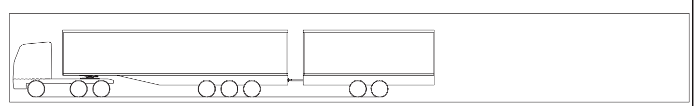
Vehicle origin & identification number	GCM (t) / Payload (t)	Length (m)	Vehicle Classification	Schematic	Vehicle description & vehicle code
Australia 1 AU1-w	45.500 29.000	19.000	Workhorse		Tractor semi-trailer T12b3
Australia 2 AU2-h	68.000 44.500	25.010	Higher capacity		B-double T12b3b3
Australia 3 AU3-v	90.500 60.000	33.310	Very high capacity		B-triple T12b3b3b3
Belgium 1 BE1-w	39.000 25.000	16.200	Workhorse		Tractor semi-trailer T11b2
Belgium 2 BE2-h	60.000 39.300	25.25	Higher capacity European modular vehicle		Tractor semi-trailer with rigid drawbar trailer T12b3a2

Table 4.1. (contd) **Vehicles as modelled during benchmarking study**

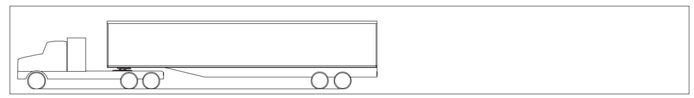
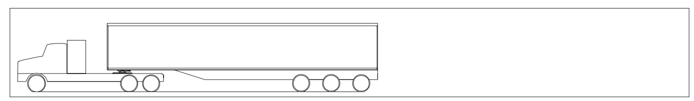
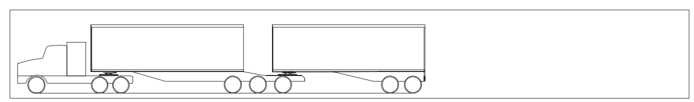
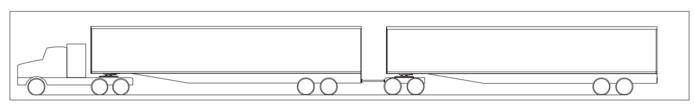
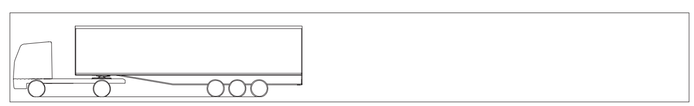
Vehicle origin & identification number	GCM (t) / Payload (t)	Length (m)	Vehicle Classification	Schematic	Vehicle description & vehicle code
Canada 1 CA1-w	39.500 25.300	21.550	Workhorse		Tractor semi-trailer T12b2
Canada 2 CA2-w	46.500 31.300	21.550	Workhorse		Tractor semi-trailer T12b3
Canada 3 CA3-h	62.500 42.300	20.430	Higher capacity		B-double T12b3b2
Canada 4 CA4-v	62.500 37.300	38.330	Very high capacity		A' train double T12b2a2b2
Denmark 1 DK1-w	44.000 30.000	16.480	Workhorse		Tractor semi-trailer T11b3

Table 4.1. (contd) **Vehicles as modelled during benchmarking study**

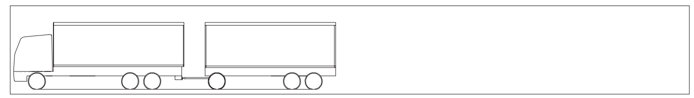
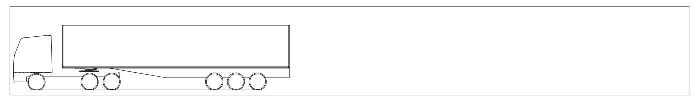
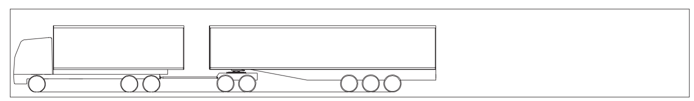
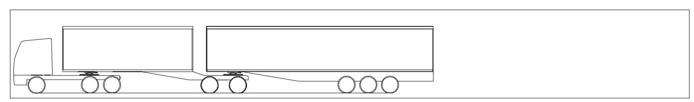
Vehicle origin & identification number	GCM (t) / Payload (t)	Length (m)	Vehicle Classification	Schematic	Vehicle description & vehicle code
Denmark 2 DK2-w	48.000 32.000	18.750	Workhorse		Rigid truck trailer R12a1b2
Denmark 3 DK3-w	48.000 32.300	16.500	Workhorse		Tractor semi-trailer T12b3
Denmark 4 DK4-h	60.000 40.700	25.250	Higher capacity European modular vehicle		Truck trailer R12a2b3
Denmark 5 DK5-h	60.000 38.000	25.100	Higher capacity		B-double T12b2b3
Europe 1 EU1-w	38.000 24.000	16.500	Workhorse		Tractor semi-trailer T11b2

Table 4.1. (contd) **Vehicles as modelled during benchmarking study**

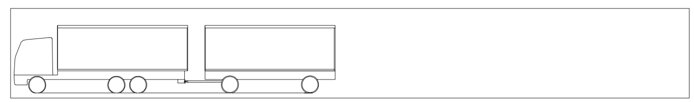
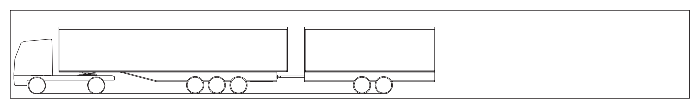
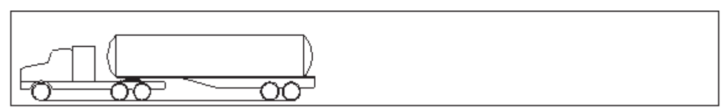
Vehicle origin & identification number	GCM (t) / Payload (t)	Length (m)	Vehicle Classification	Schematic	Vehicle description & vehicle code
Europe 2 EU2-w	40.000 26.000	16.480	Workhorse		Tractor semi-trailer T11b3
Europe 3 EU3-w	40.000 27.000	16.895	Workhorse		Truck trailer R11a1b2
Europe 4 EU4-w	40.000 21.900	18.750	Workhorse		Rigid truck with rigid drawbar trailer R12a2
Germany 1 DE1-h	40.000 20.800	25.235	Higher capacity European modular vehicle		Tractor semi-trailer with rigid drawbar trailer T11b3a2
Mexico 1 MX1-w	41.500 26.650	16.950	Workhorse		Tractor semi-trailer T12b2

Table 4.1. (contd) **Vehicles as modelled during benchmarking study**

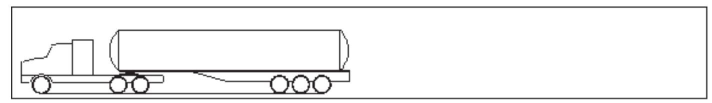
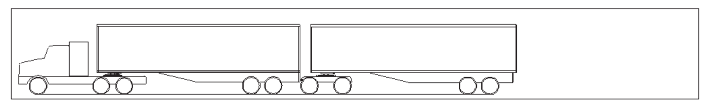
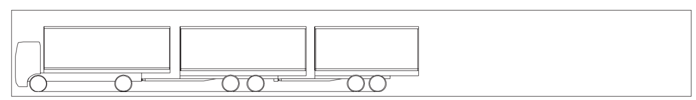
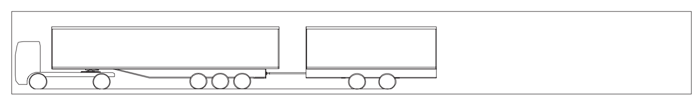
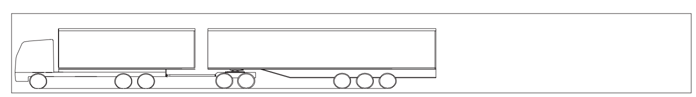
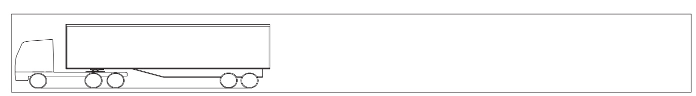
Vehicle origin & identification number	GCM (t) / Payload (t)	Length (m)	Vehicle Classification	Schematic	Vehicle description & vehicle code
Mexico 2 MX2-w	48.500 31.850	19.250	Workhorse		Tractor semi-trailer T12b3
Mexico 3 MX3-v	66.500 42.849	30.730	Very high capacity		'A' train double T12b2a2b2
Netherlands 1 NL1-h	50.000 33.410	24.200	Higher capacity		Rigid truck with two rigid drawbar trailers R11a2a2
Netherlands 2 NL2-h	60.000 37.702	25.200	Higher capacity European modular vehicle		Tractor semi-trailer with rigid drawbar trailer T11b3a2
Netherlands 3 NL3-h	60.000 39.720	25.240	Higher capacity		Rigid truck trailer R12a2b3
South Africa 1 ZA1-w	43.500 28.140	15.313	Workhorse		Tractor semi-trailer T12b2

Table 4.1. (contd) **Vehicles as modelled during benchmarking study**

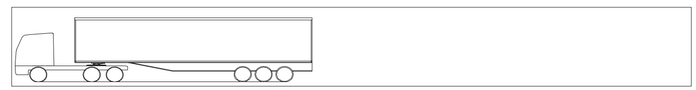
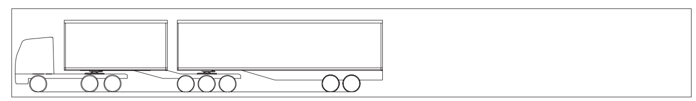
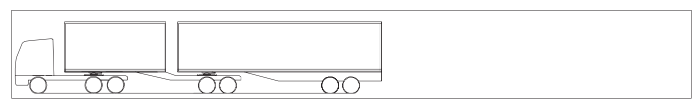
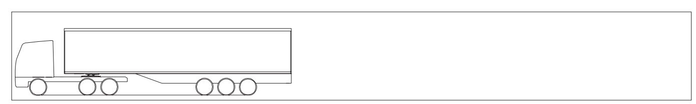
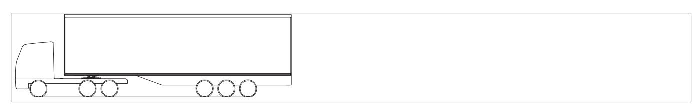
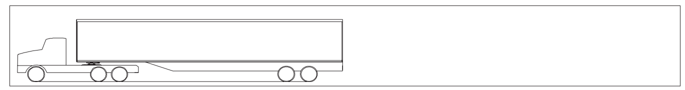
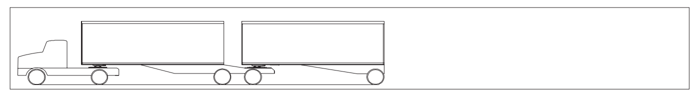
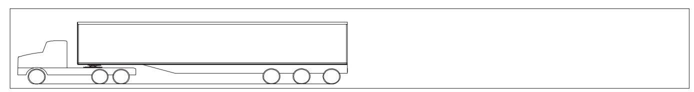
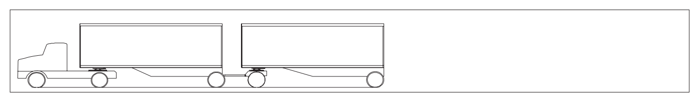
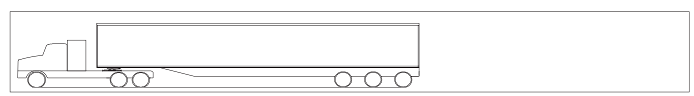
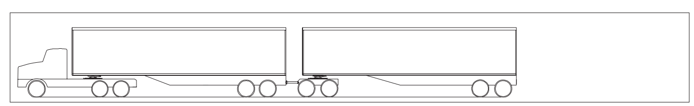
Vehicle origin & identification number	GCM (t) / Payload (t)	Length (m)	Vehicle Classification	Schematic	Vehicle description & vehicle code
South Africa 2 ZA2-w	49.300 31.900	17.745	Workhorse		Tractor semi-trailer T12b3
South Africa 3 ZA3-h	56.000 33.800	21.972	Higher capacity		B-double T12b3b2
South Africa 4 ZA4-h	56.000 34.240	21.983	Higher capacity		B-double T12b2b2
United Kingdom 1 UK1-w	44.000 29.109	16.500 height = 4.0 m	Workhorse		Tractor semi-trailer T12b3
United Kingdom 2 UK2-w	44.000 26.130	16.500 height = 4.90 m	Workhorse		Tractor semi-trailer T12b3

Table 4.1. (contd) **Vehicles as modelled during benchmarking study**

Vehicle origin & identification number	GCM (t) / Payload (t)	Length (m)	Vehicle Classification	Schematic	Vehicle description & vehicle code
United States 1 US1-w	36.350 (80 138 lbs) 21.150 (46 628 lbs)	19.770	Workhorse		Tractor semi-trailer T12b2
United States 2 US2-w	36.360 (80 160 lbs) 23.460 (51 720 lbs)	21.980	Workhorse		B-double T11b2b1
United States 3 US3-w	41.900 (92 374 lbs) 26.700 (58 863 lbs)	19.770	Workhorse		Tractor semi-trailer T12b3
United States 4 US4-h	36.360 (80 138 lbs) 23.586 (51 998 lbs)	22.060	Higher capacity		‘A’ train double T11b1a1b1
United States 5 US5-h	44.100 (97 224 lbs) 28.900 (63 714 lbs)	25.120	Higher capacity		Tractor semi-trailer T12b3
United States 7 US7-v	57.040 (125 751 lbs) 32.840 (72 400 lbs)	30.960	Very high capacity		‘A’ train double T12b2a2b2

4.4. Performance measures

About Performance Based Standards

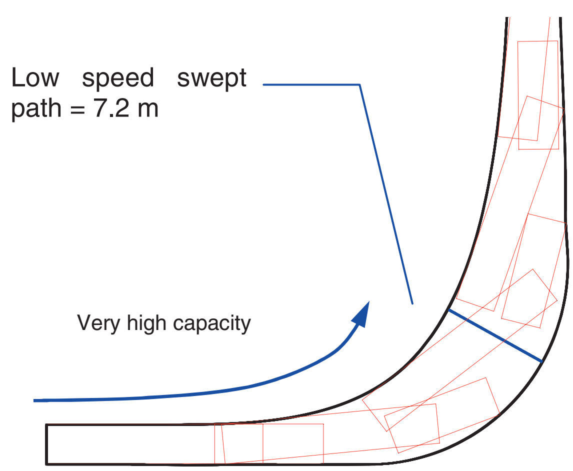
Performance based standards for heavy vehicle safety were first introduced by the Canadian Heavy Vehicle Weights and Dimensions Study in 1986. Australia has further refined PBS and is acknowledged as the leader in the implementation of PBS. The PBS scheme examines the actual performance of the vehicle on the road, rather than the approximation of a vehicle's behaviour through the enforcement of prescriptive standards. PBS allows for vehicles to be physically tested or simulated, with the performance of the vehicle compared to the performance levels for each standard to determine the hierarchy of the road that the vehicle may safely travel upon.

In Australia, the Performance Based Standards scheme uses 16 safety standards and 4 infrastructure standards to assess non-standard vehicles. Five safety measures were selected as well as the load transfer ratio (LTR), which is a well-established international PBS measure that was not adopted in Australia. A description of each measure is provided below.

Low speed swept path (LSSP)

The low speed swept path is the maximum width of the swept path of a vehicle simulated driving through a 90º turn of 12.5 m radius at a speed of 5 km/h. Figure 4.1 shows an example output of a LSSP simulation for a tractor semi-trailer. The outer path of the vehicle is shown by the solid bold line. The maximum swept width is indicated. Note – This manoeuvre is not intended to apply universally and represents a less severe test than the EU directive. However it does allow a relative comparison of vehicle performance in the context of this study.

Figure 4.1. **Example output of LSSP manoeuvre**



Static rollover threshold (SRT)

Rollover stability is a significant safety issue, and arguably the most important performance measure for heavy vehicles because it has been strongly linked to rollover crashes. The measure of rollover stability is static rollover threshold (SRT) which is the level of lateral acceleration that a vehicle can sustain without rolling over during a steady state turn. The SRT is expressed as a fraction of the acceleration due to gravity in units of 'g', where 1 g is an acceleration of 9.807 m/s^2, corresponding to the force exerted by the earth's gravitational field. High values of SRT imply better resistance to rollover.

To determine the SRT the vehicle must be driven along a specified circular path at an initial speed that is at least 10 km/h slower than the speed at which the rollover instability will occur. From the initial speed, the driver must increase the speed of the vehicle at a slow, steady rate until the point rollover is reached. The vehicle should reach a level of not less than 0.35 g during this manoeuvre.

Yaw damping coefficient (YDC)

An important consideration in the stability and handling of heavy vehicles is how quickly yaw or sway oscillations take to 'settle down' or decay after a severe manoeuvre has been performed. Vehicles that take a long time to settle increase the driver's workload and represent a higher safety risk to other road users and to the driver. The yaw damping coefficient (YDC) performance measure quantifies the rate at which yaw oscillations decay after a short duration steer input (pulse input) at the hauling unit. The intention of the yaw damping response test is to provide a steering input that will excite the rear unit of the combination into a yawing motion. A higher YDC means better performance. This manoeuvre is more relevant to the safety of multi-combination vehicles with more than one articulation point.

Rearward amplification (RA)

A lane change manoeuvre is the method used to measure the rearward amplification (RA), high-speed transient offtracking (HSTO) and load transfer ratio (LTR) of a vehicle combination. The intention of the lane change manoeuvre is to produce a known lateral acceleration at the steer axle, at a given frequency, and to record the lateral acceleration experienced at the rear unit. The ratio of peak lateral acceleration at the rear unit to that at the steer axle is the RA of the vehicle. RA generally pertains to heavy vehicles with more than one articulation point, such as rigid truck-trailers and road train combinations. RA describes the tendency for the trailing unit(s) to experience higher levels of lateral acceleration than the hauling unit during a dynamic manoeuvre. It is a serious safety issue in rapid path-change manoeuvres, as it can lead to rear-trailer rollover. Lower values of rearward amplification indicate better performance. Higher values of rearward amplification imply higher probabilities of rear-trailer rollover.

High speed transient offtracking (HSTO)

High speed transient offtracking (HSTO) is measured during the same lane change manoeuvre as described above. During the manoeuvre, the lateral displacement of the rear end of the last trailer of an articulated vehicle may overshoot the final path of the front axle of the hauling unit. The lateral overshoot may interfere with overtaking or passing vehicles and thus represents a safety risk. HSTO measures this lateral overshoot.

Load transfer ratio (LTR)

Also measured in the lane change manoeuvre, the load transfer ratio is the proportion of load on one side of a vehicle unit transferred to the other side of the vehicle in a transient manner when undergoing the manoeuvre. The LTR value returned is the maximum LTR achieved during the manoeuvre. A value of 0 means that the vehicle is evenly balanced on both sides of the vehicle, while a value of 1 means that all the vehicle load is on one side of the vehicle, wheel lift-off has occurred, and rollover is imminent. Therefore, the LTR measure provides a clear indication of the proximity of rollover for any vehicle unit during the lane change manoeuvre. Although not used in Australian PBS system, the LTR measure was included in this study as it gives an easily conceptualised measure of vehicle performance during the lane change manoeuvre. Based on international experience a ratio of 0.6 is the maximum level of load transfer considered safe during the lane change manoeuvre.

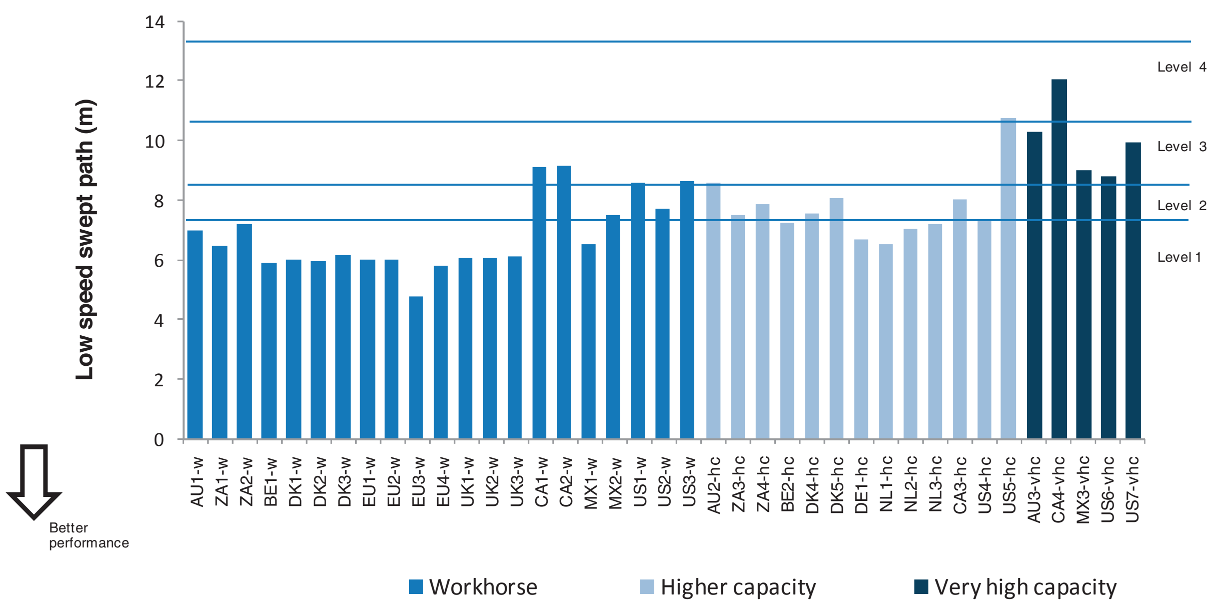
4.5. Results

The simulation of the 39 vehicle configurations generated a large volume of results. This section of the report presents the results of each vehicle for each performance measure.

4.5.1. Low speed swept path

Figure 4.2 shows the LSSP performance results for each vehicle separated by classification. The European vehicles generally achieved a better LSSP result, which corresponds to the higher prevalence of 'A'-type couplings which tend to give better low-speed manoeuvrability, though poorer high-speed dynamic performance. All of the vehicles pass PBS Level 4, while all but two of the European vehicles pass PBS Level 1 for LSSP.

Figure 4.2. **Low speed swept path performance**



A total of 20 of the 39 vehicles pass PBS Level 1 for LSSP, of which 16 are from the European vehicle pool of 18 vehicles.

Best performers – the best performing vehicles comprise vehicles with short vehicle units with 'A' type couplings to help in the low speed manoeuvres.

Worst performers – the worst performing vehicles comprise longer vehicles with long vehicle units making it difficult to pass around tight corners.

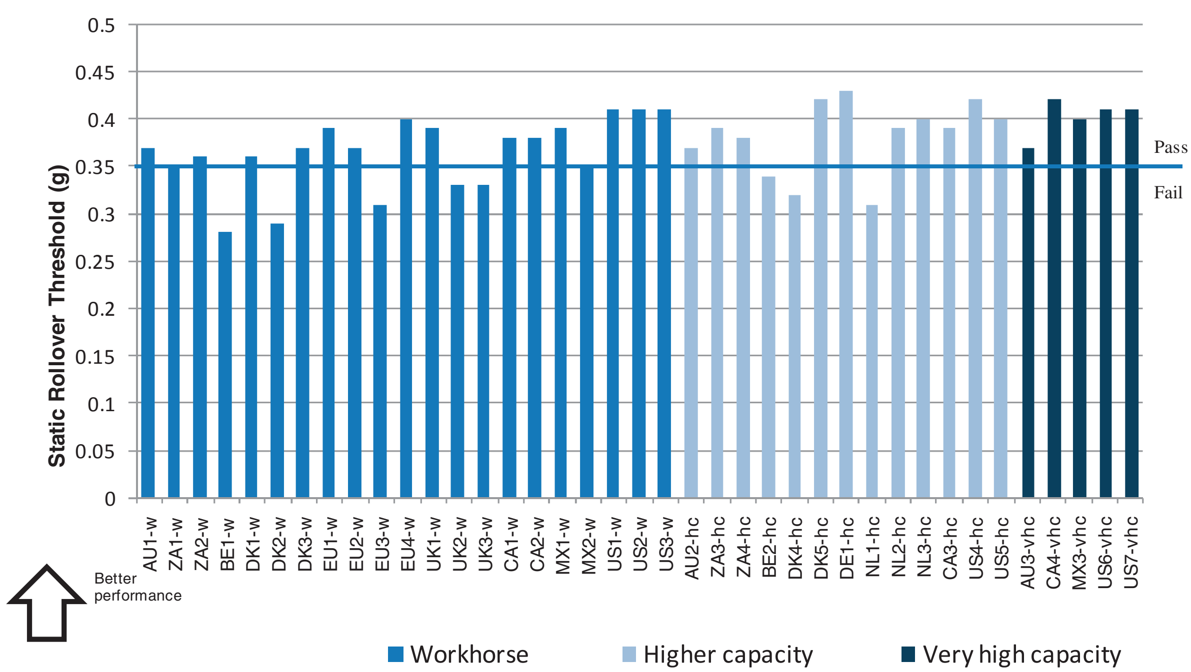
Figure 4.2 shows a worsening in performance (an increase in low speed swept path) with increasing capacity. Though there is little difference between the LSSP of the workhorse and higher capacity vehicles, the very high capacity vehicles are noticeably poorer performing, with four of the five worst performing vehicles coming from the very high capacity category. None of the very high capacity vehicles satisfied the Level 1 (general access) requirement for low speed swept path.

The result of this analysis showed that the very high capacity vehicles achieve the worst low speed swept path result. This result is expected as these vehicles are typically long vehicles (greater than 30 m) with long trailers. It is expected that the low speed swept path of these vehicles would improve considerably if fitted with steerable axles or active steering systems. Steerable axles and active steering systems enable the axles and/or wheels on trailers to steer as the vehicle turns, this reduces tyre scrubbing and increases manoeuvrability.

4.5.2. Static rollover threshold

The SRT performance values are presented in Figure 4.3, which shows the performance of the vehicles grouped by classification. All seven Australian and South African vehicles pass the SRT performance measure. The majority of the 14 North American vehicles pass the PBS performance level of 0.35. Of the 18 European vehicles, only 10 of the vehicles pass the SRT requirement.

Figure 4.3. **Static rollover threshold performance**



Best performers – the vehicle dimensions and layout did not affect the SRT measures as much as the loading of each axle. The better performing vehicles had low payloads per axle and low standard axle repetition counts.

Worst performers – conversely, the poorly performing vehicles had high payloads per axle and high standard axle repetition counts.

Analysis of the results showed that the median value of SRT increases slightly (better performance) as the capacity increases. This indicates that the vehicles in this study have increased rollover stability as the capacity increases from 'workhorse' to 'higher capacity' to 'very high capacity' vehicle classification.

At first, this result may appear counter intuitive – as the 'very high capacity' vehicles were shown to have the best roll stability. However, this is a 'static' low speed measure of rollover, hence the total number of vehicle units does not influence roll stability *i.e.* the SRT of any combination vehicle is equal to the SRT of the least stable vehicle unit in the combination. Typically the 'very high capacity' vehicles comprise more axles for the increase in capacity and coupling types that improve roll stability. Therefore, in isolation the units that comprise the 'very high capacity' vehicles were shown to have a higher rollover threshold than the units of the other vehicle categories.

The distinction between 'static rollover threshold' and 'dynamic roll stability' should be clarified. Static rollover threshold is the amount of the lateral acceleration required to produce total rollover of a vehicle or roll coupled unit in steady state conditions. Rollover occurs when the lateral acceleration exceeds the vehicle's rollover limit. When a vehicle undergoes a dynamic manoeuvre, such as lane change manoeuvre, the effect at the rear trailer is amplified, and this results in increased lateral acceleration acting on the rear trailer. This in turn increases the likelihood of the rear trailer rolling over under some circumstance. For example, a semi-trailer such as UK 2, with a poor SRT of 0.33, is unlikely to rollover during a lane change manoeuvre. However, the United States six triple road train, with a superior SRT of 0.41, may rollover during the same lane change manoeuvre, as the lateral acceleration experienced by the road train's rear trailer is greater (amplified).

The measures rearward amplification (RA) and load transfer ratio (LTR) address this safety issue. The RA measure considers the SRT of the vehicle, and the vehicle is deemed to pass if the RA is no more than 5.7 times the SRT unique to that vehicle. The results from the RA and LTR measures are presented in Sections 4.5.4 and 4.5.6 respectively.

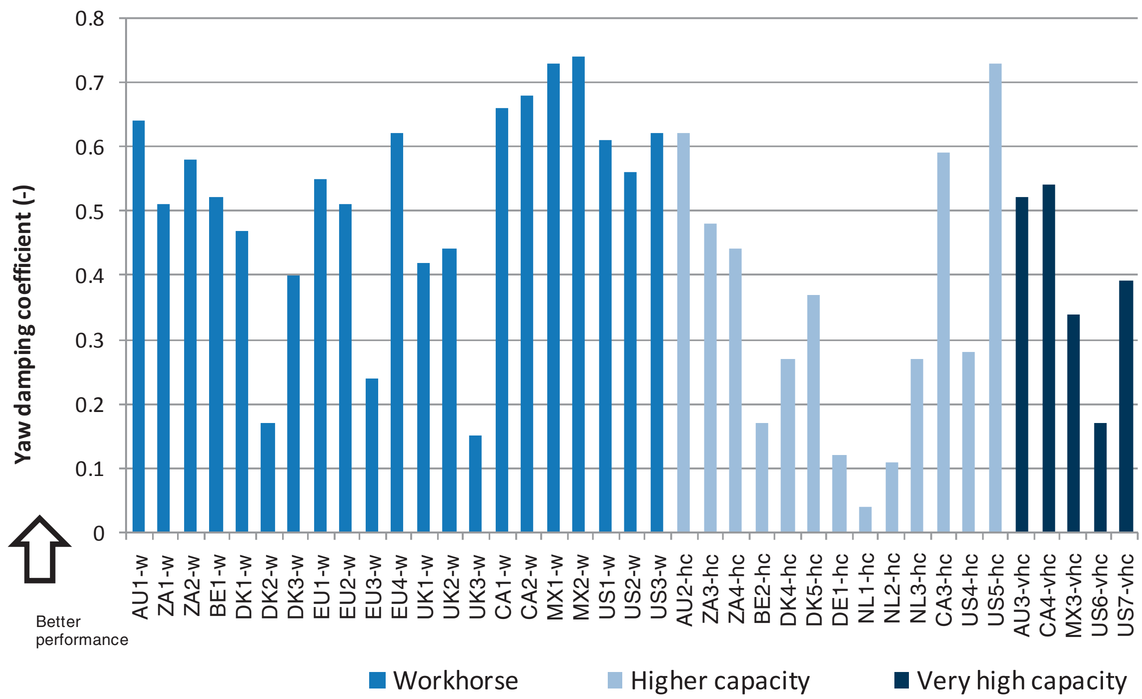
Vehicles shown to have a high static rollover threshold are not necessarily less prone to rollover during a dynamic manoeuvre.

4.5.3. Yaw damping coefficient

Figure 4.4 shows the YDC measure results grouped by classification. Only three vehicles, all of which are from Europe, do not meet the PBS performance level required to pass this measure. The three vehicles to fail YDC were Germany 1 (a tractor semi-trailer and rigid drawbar trailer), Netherlands 1 (a rigid truck and two rigid drawbar trailers) and Netherlands 2 (a tractor semi-trailer and rigid drawbar trailer).

These three vehicles along with the poorly performing Belgium 2 (tractor semi-trailer and rigid drawbar trailer) and United Kingdom 3 (rigid truck and rigid drawbar trailer) are the vehicles which have the 'A'-coupled rigid drawbar trailers. These vehicles, while performing reasonably well on the LSSP measure, do not perform as well on the high-speed dynamic performance measures.

Figure 4.4. **Yaw damping coefficient**



The yaw damping performance measure generally pertains to heavy vehicles with more than one articulation point, such as rigid truck-trailers and road train combinations, hence the YDC results for these vehicles are more relevant than those obtained for the semi-trailers included in this benchmarking study. Of the three vehicles that fail the YDC requirements, all were classified as 'higher capacity' vehicles.

Best performers – the six best performing vehicles are the semi-trailers, which are completely roll-coupled throughout the vehicle. Australia 2 (B-double) is the next best-performing vehicle after the semi-trailers and is also completely roll-coupled.

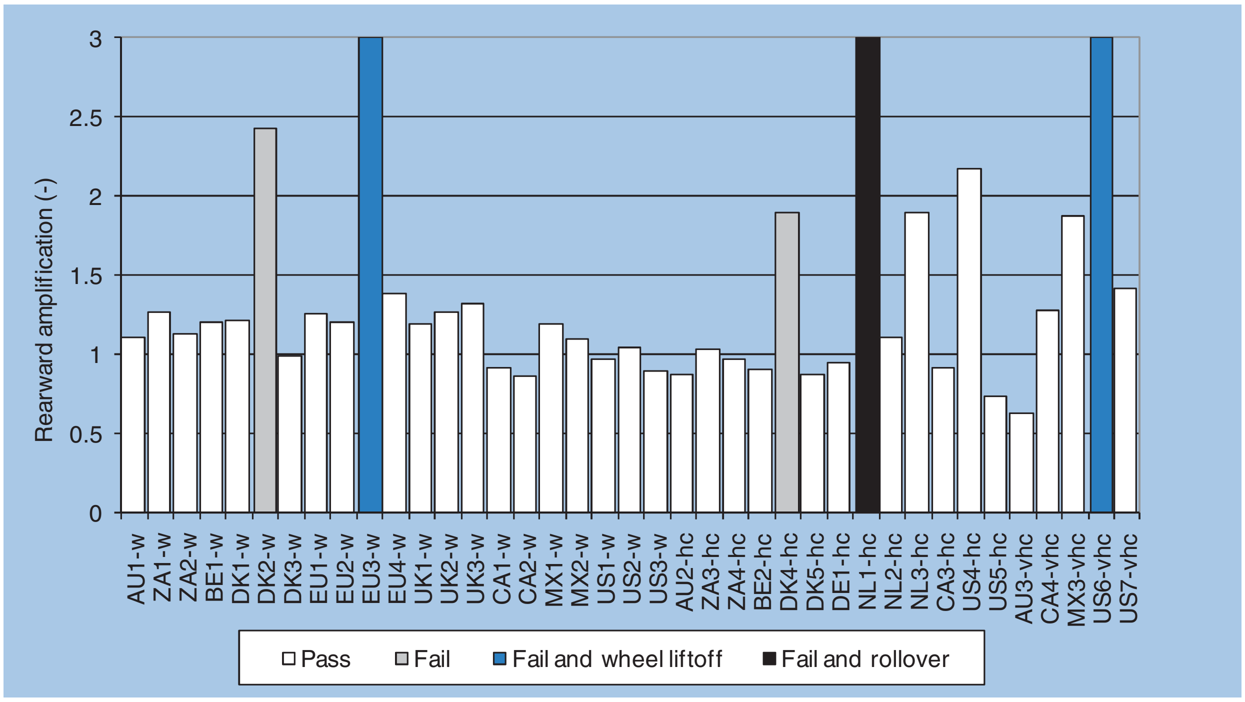
Worst performers – the four worst performing vehicles all have rigid drawbar trailers, while the worst has two rigid drawbar trailers. Rigid drawbar trailers perform poorly when damping yaw oscillations.

4.5.4. Rearward amplification

Rearward amplification, high speed transient off-tracking, and load transfer ratio are all calculated from the lane change manoeuvre. The RA performance values are presented in Figure 4.5. During the lane change manoeuvre, three vehicles displayed critical instability (*i.e.* experiencing wheel lift or rolling over completely). These vehicles were a European rigid truck trailer (EU3), the Dutch rigid truck and two rigid drawbar trailers (NL1) and the United States 'A' train triple (US6). As the performance level required to pass PBS for the RA measure is dependent upon the SRT of the vehicle, the requirement for RA is unique to each vehicle. Therefore, in Figure 4.5, vehicles that pass the RA requirement are shown in white, vehicles that fail are shown in grey, vehicles that fail and experienced 'wheel lift-off' during the manoeuvre are shown in blue and vehicles that rolled over during this manoeuvre are shown in black.

The five vehicles that failed the RA measure, were the two Danish rigid truck trailers (DK2 and DK4), as well as the aforementioned EU3, US6 and NL1.

Figure 4.5. **Rearward amplification performance**



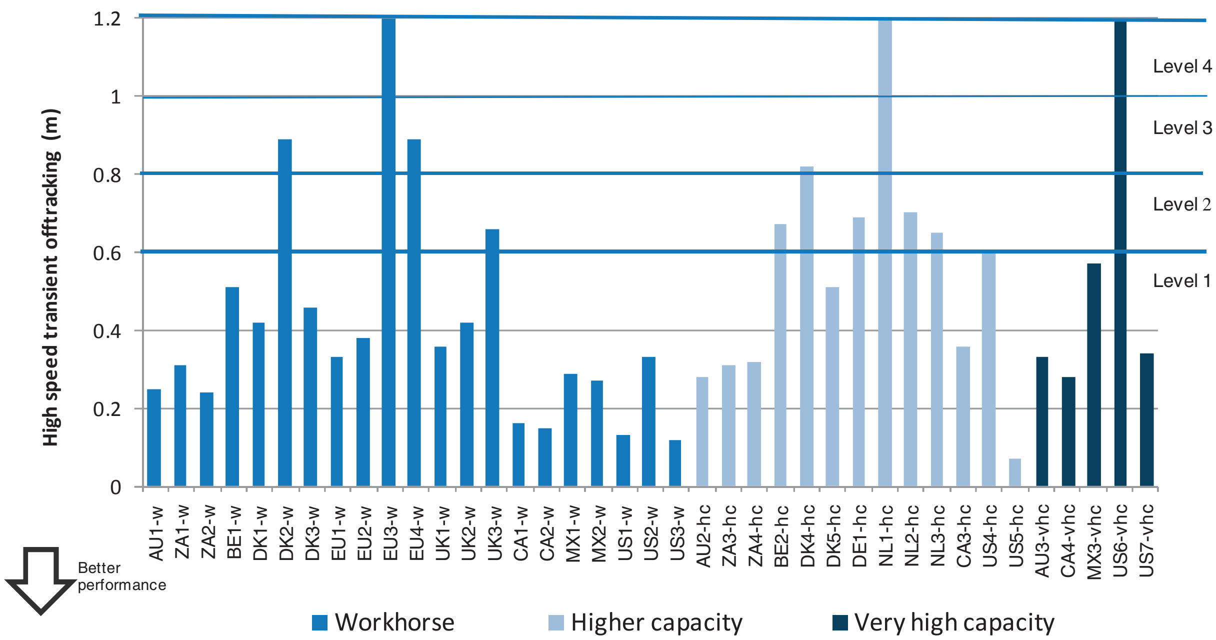
Best performers – both of the best-performing vehicles comprised purely 'B' type, roll-coupled units. All of the top six performing vehicles in the RA manoeuvre had only 'B' type couplings.

Worst performers – the poorer performing vehicles all had at least one 'A' type coupling, which does not provide roll coupling through the connection. While the United States 6 vehicle did have a number of 'B' type couplings, it also had the largest number of vehicle units in the simulation study (six in total) which amplified the yaw oscillation affect. The Europe 3 rigid truck trailer was also found to be unstable and performed poorly in this manoeuvre, similarly to all the rigid truck trailers in this study.

4.5.5. High speed transient off-tracking

The HSTO performance values are presented in Figure 4.6. The majority of vehicles pass PBS Level 1, with all Australian and South African vehicles, as well as all but one North American vehicle, passing HSTO PBS Level 1 (general access to the entire road network). Out of the 18 European vehicles, eight pass PBS Level 1, five pass PBS Level 2, three pass PBS Level 3 and two do not pass HSTO at any level.

Figure 4.6. **High speed transient off-tracking performance**



The three vehicles (EU3, US6 and NL1) which showed a high level of instability during the lane-change manoeuvre are shown, in Figure 4.6, as having a value of 1.2 – though no true value could be obtained due to the instability of the vehicle during the manoeuvre.

Best performers – both of the best-performing vehicles were semi-trailers comprising purely 'B' type, roll-coupled connections. All of the top seven performing vehicles in the HSTO manoeuvre had only 'B' type couplings.

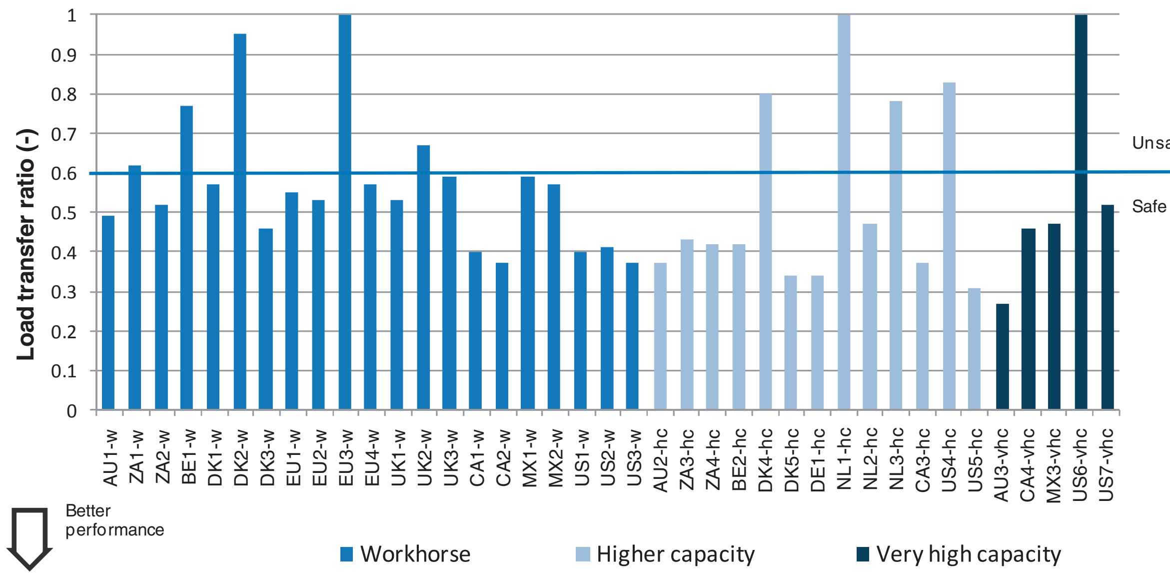
Worst performers – the poorer performing vehicles both had a number of 'A' type couplings, which do not provide roll coupling through the connection. While the United States 6 vehicle did have a number of 'B' type couplings, it also had the largest amount of vehicle units in the simulation study (six in total) which amplified the oscillation affect. The Europe 3 rigid truck trailer was also found to be unstable and performed poorly in this manoeuvre, similarly to all the rigid truck trailers in this study.

The results showed there is no linear relationship between HSTO performance and capacity. While the performance worsens when increasing capacity from workhorse to higher capacity vehicle, the performance then improves when increasing capacity from higher capacity to very high capacity. This, again, is likely due to the higher occurrence of rigid drawbar trailers present in the higher capacity vehicle category, and the link between rigid drawbar trailers and poor HSTO performance.

4.5.6. Load transfer ratio

The load transfer ratio performance values are presented in Figure 4.7. The results showed the majority of the vehicles passed the safe LTR of 0.6, with generally similar performance across the three vehicle categories. This result indicates that very high capacity vehicles perform similar to workhorse vehicles in this measure. Again, the vehicles with more 'A'-type couplings performed worse for this measure, with the worst eight performing vehicles having at least one 'A'-type coupling. Of the three worst-performing vehicles reaching an LTR of 1, there was one vehicle from each classification, implying that very high-capacity vehicles perform similar to workhorse vehicles in this measure.

Figure 4.7. **Load transfer ratio performance**



Best performers – both of the best-performing vehicles comprised purely 'B' type, roll-coupled units, showing that the 'B' type couplings provided a greater level of stability than the 'A' type couplings. The best-performing vehicle was a very high capacity vehicle.

Worst performers – the poorer performing vehicles both had a number of 'A' type couplings, which do not provide roll coupling through the connection.

4.6. Influences on performance measures

An investigation of the simulation results was performed in order to determine the major influences on each of six performance measures. The most influential vehicle characteristics were those with a high correlation, as well as having a steeper gradient in a linear line of best fit plotted between the characteristic and performance result. Table 4.2 summarises the vehicle characteristics which influence performance measures.

Table 4.2. **Influences on performances measures**

• Low speed swept path	The greatest influence on the LSSP results was vehicle length. As the vehicle length increased, so did the LSSP value (poorer performance).
• Static rollover threshold	A factor found to influence the SRT results was the payload divided by the number of axles. The analysis showed that as this ratio increases, the SRT value decreases (poorer performance).
• Yaw damping coefficient • Rearward amplification • High speed transient off-tracking • Load transfer ratio	The greatest influence on these three measures was the coupling ratio factor. A higher ratio of B-couplings to A-couplings results in better high speed dynamic performance in each of YDC, RA, HSTO and LTR measures.

4.7. Results summary

Low speed swept path – Results showed the highest correlation between vehicle category and the LSSP measure of any of the measures. All workhorse vehicles from Europe, Australia and South Africa passed the Level 1 requirement, which is the most demanding level in the Australian standard. The workhorse vehicles from Canada and Mexico did not meet these requirements. Vehicles from the North American region typically required more road space to perform these low-speed turning manoeuvres. None of the very high capacity vehicles passed the Level 1 requirements; this was the only performance measure in which no very high capacity vehicles were able to meet Level 1 requirements. This implies that low-speed manoeuvrability would prevent these vehicles from accessing the entire road network, including inner urban and city areas. However, it is expected that the low-speed swept path of these vehicles would improve considerably if fitted with steerable axles.

Static rollover threshold – Results showed that very high capacity and higher capacity vehicles were able to achieve better performances than workhorse vehicles in most instances. Typically, the very high and higher capacity vehicles comprise more axles for the increase in capacity and have coupling types that improve roll stability.

High speed dynamic performance during a lane change – Rearward amplification (RA), high-speed transient off-tracking (HSTO) and load transfer ratio (LTR) are assessed via the lane change manoeuvre and relate to the dynamic stability of the vehicle. The results were similar for all vehicle categories, indicating that very high capacity vehicles can perform equally, or better, than some common workhorse vehicles. There was one vehicle from each of categories (workhorse, higher capacity and very high capacity) that reached critical instability (experiencing wheel lift off, or rollover) during this manoeuvre.

4.8. Productivity and efficiency benchmarking

The following section derives simplified measures of productivity and efficiency that will allow a comparative analysis of the diverse candidate vehicles evaluated by this study. The analysis does not consider driving cycles, given that a single cycle cannot be applied uniformly across the international fleet because of topography, operational and speed limit variations. The primary variables influencing energy consumption for large trucks are vehicle mass, aerodynamic drag and tyre rolling resistance. These variables are highly influenced by size and weight regulation, while other components – such as the engine and driveline – are more universally similar. Therefore, this study only examined the energy consumed to overcome rolling resistance and aerodynamics by the vehicles at a steady state speed of 90 km/hr on level ground with no wind effects. Other universally consistent energy losses, such as drive line, the engine and auxiliary loads, were applied equally to all vehicles using a constant of 225 kWh, thus providing approximate values of total energy use. There are operational, regulatory and manufacturing factors which influence the vehicle and the amount of energy consumption. A summary of these considerations follow.

4.8.1. Operation factors

Large trucks exist to do work, and to do it efficiently. Their worth and function are tied directly to work performance in exchange for money. This mode of operation is very different from passenger cars. The tasks that commercial vehicles perform are highly varied, and vehicles are purposefully designed to reflect task specific requirements. For example, vehicles designed to transport goods between cities are very different to those designed for deliveries or within urban areas. They can perform special purpose tasks, such as picking up garbage, or maintenance functions, such as occurs with utility vehicles used by electric companies.

Generally, competitive forces within the transport industry provide strong incentives to encourage the efficient use of fuel. However, there are segments of the industry that are less sensitive to fuel use optimisation, given the priorities of the operator, or the nature of the freight task or work function.

Freight tasks vary, as do the weight and shape of cargo transported, therefore vehicle duty cycles and fuel consumption varies for a given cargo and vehicle task. For long-haul transport in particular, the nature of goods transport can be volume limited, mass limited or, for low density goods that cannot be stacked to full vehicle height, limited by the available deck area. Fuel efficiency for volume-limited freight tasks requires a different evaluation metric than that of a mass-limited freight task.

A vehicle having low fuel consumption is not necessarily a vehicle having good fuel efficiency. Fuel consumption references fuel used to move a vehicle. Fuel efficiency refers to the fuel used to accomplish a specific freight or work task. For road freight transport, fuel efficiency is the preferred performance metric.

4.8.2. Regulatory influencing factors

Basic aspects of truck design, such as the length, wheelbase, width, height, axle loads, axle spacing and GVW, are influenced and limited by size and weight regulations. Since many of these factors directly influence fuel consumption, it can be concluded that fuel consumption and fuel efficiency are directly related to size and weight regulation. Size and weight regulations can exist at both the state, provincial, regional, national or international level. In general, each country has its own unique set of regulations governing vehicles using their highway network. Some aspects of these regulations, such as vehicle width and height, are largely harmonised within international regions; however vehicle weight (a first order factor affecting vehicle fuel consumption) is highly variable.

4.8.3. Manufacturing factors

For a given heavy truck purchase, the customer exercises choice (particularly in North America) for major components used in the assembly of the vehicle, such as engine, transmission, drive axles and suspensions. The customer also specifies the vehicle GVW, suspension and axle load rating, the vehicle wheelbases, and drive axle spread. In some cases, components such as engine, transmission, drive axles and suspensions are supplied by a third party to the manufacturer as plug-in components which are fully compatible within the truck manufacturing industry. The customer may have a choice of three or four different engine manufactures and corresponding model subsets, as well as different transmissions and drive axle assemblies sourced from separate manufactures. In addition, final drive gear ratio choices are specified to match the intended operating drive cycle in light of the engine characteristics, transmission, wheel, and tyre sizes. In effect, a significant portion of the heavy truck industry produces custom-built vehicles. Viewed externally, the trucks from a given manufacturer may appear to be identical, but the systems contained within the skin of the vehicle can be substantially different. The performance of these third party components is beyond the control of the truck manufacturer, yet they will influence the overall fuel efficiency of the vehicle.

In most cases, vehicle manufacturers do have control over the shape and aerodynamic treatments of the power unit (truck tractor or cab and chassis). However, the manufacturer does not necessarily have control over the aerodynamics of the final vehicle. Tractors are coupled to trailers and, depending on the whole vehicle configuration, the drag coefficient of the vehicle can vary by as much as 20% depending on the vehicle shape and spacing of the trailer(s).

4.8.4. Cargo mass and volume performance

Given that the task of a commercial vehicle is to transport freight, limited by either mass or volume, the value of the vehicle and the regulatory system that governs it can be initially assessed by determining the amount of freight that the vehicle can accommodate. To assess volumetric capacity, the inner dimensions of the freight compartment were used to calculate the available freight volume assuming maximum GVM condition. For mass capacity, the tare weight of the vehicle was subtracted from the allowable GVM, yielding the freight mass capacity of the vehicle. The results are shown in Figure 4.8 and 4.9.

Figure 4.8. **Cargo mass capacity of the vehicle**

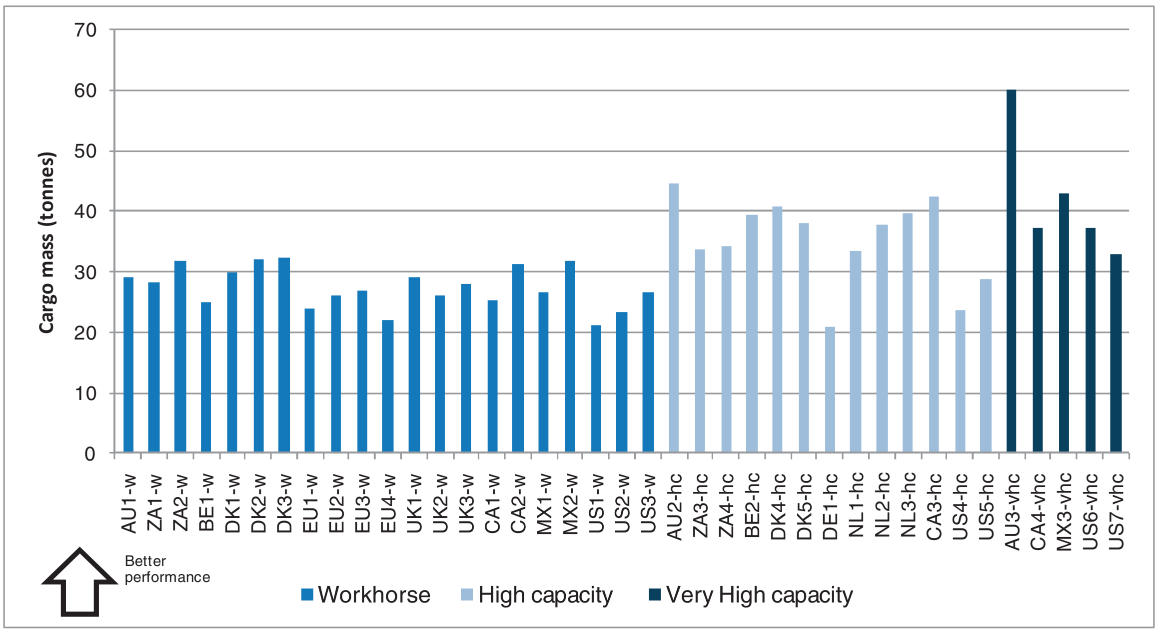
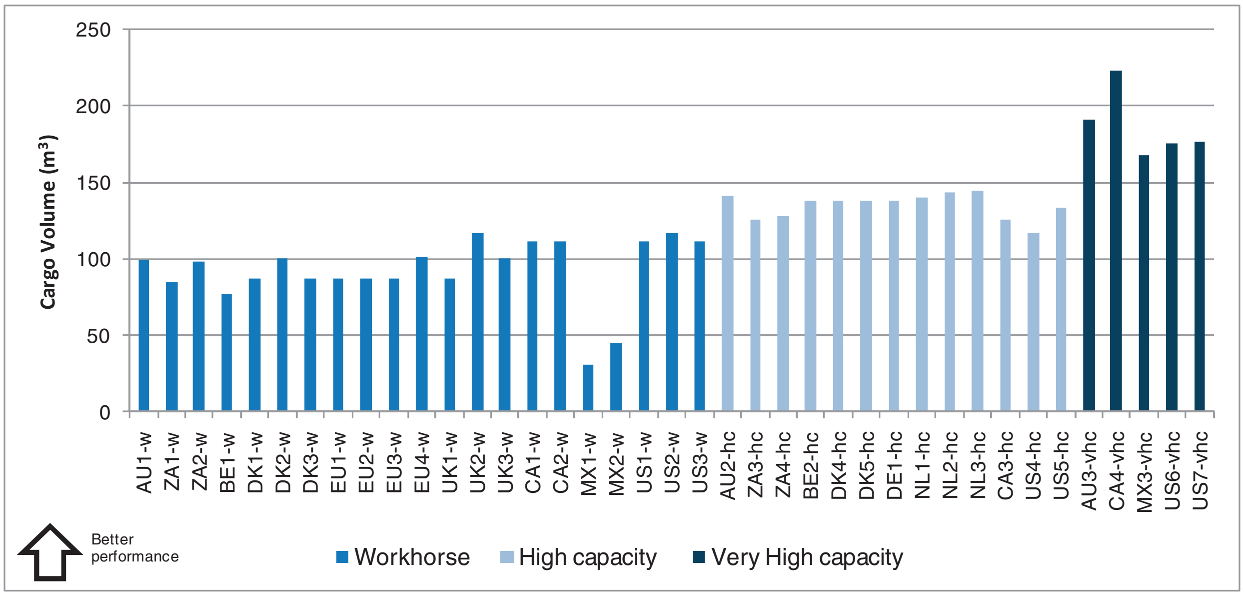


Figure 4.9. **Cargo volume capacity of the vehicle**



From Figure 4.8 it can be seen that cargo mass varies significantly within each vehicle category. In almost all cases the workhorse vehicles have less cargo mass capacity than the high, and very high, productivity vehicles. Overall, the larger vehicles show greater variation in the cargo mass capacity. It is worth noting that the poorest cargo mass capacity vehicle was found in the higher capacity category rather than the workhorse, as would be expected.

Figure 4.9 shows that the cargo volume capacity increases consistently from the workhorse to the higher capacity and to the very high capacity vehicles as would be expected. The Mexican 1 and 2 trucks are somewhat different because they are tanker vehicles, specifically designed to carry high density liquid product. The findings in Figures 4.8 and 4.9 suggest that most regulatory systems promote volumetric capacity over mass capacity so that on balance, the data suggest that cubic capacity valued more highly than improvements in cargo mass.

Payload Efficiency

Payload efficiency is a measure of the proportion of GVW that is utilised for freight transport based on either mass or volume.

Figure 4.10. **Payload mass efficiency (payload/GVW)**

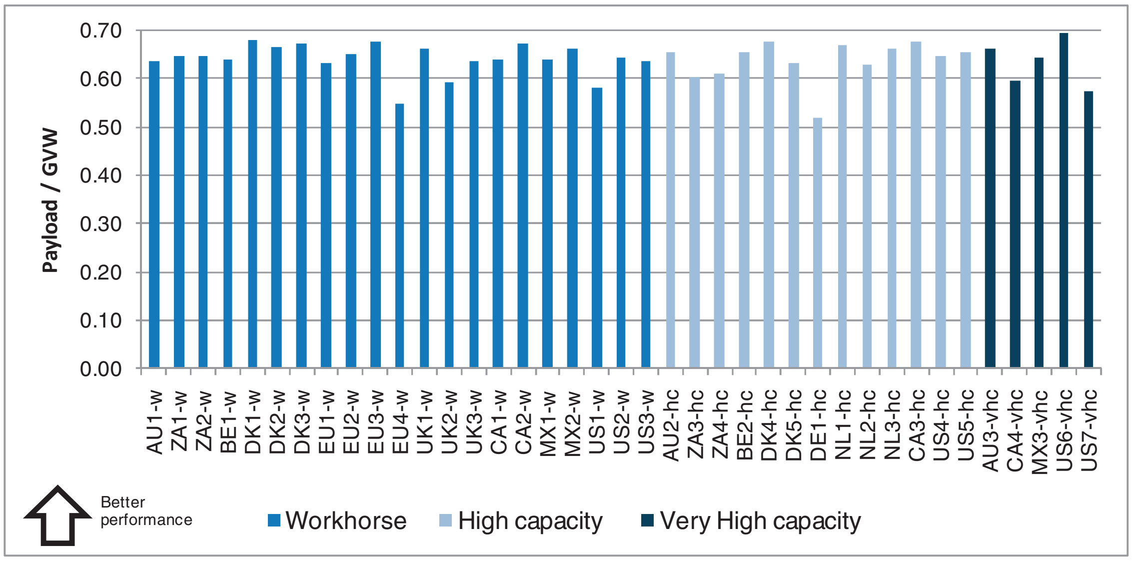


Figure 4.10 shows that payload mass efficiency is reasonably uniform for all vehicles, with a few exceptions. While variations do occur within each vehicle category, there is little difference among the three vehicle categories. Indeed, it can be concluded that the variation in payload mass efficiency are similar in magnitude for all three vehicle categories; that is, no vehicle category shows significantly superior payload mass efficiency. Given the uniformity among the vehicle classes, and the presence of outliers within the group of vehicles assessed, this measure may be a suitable candidate for a productivity performance measure for size and weight regulation. For example, it may be desirable to require that all general freight vehicles have a payload mass efficiency greater than 0.6. As with all measures, there are limitations to its use. This measure would only be suitable for freight that can be loaded such that allowable gross vehicle mass is achieved.

Figure 4.11. **Payload volume efficiency (m^3/GVW)**

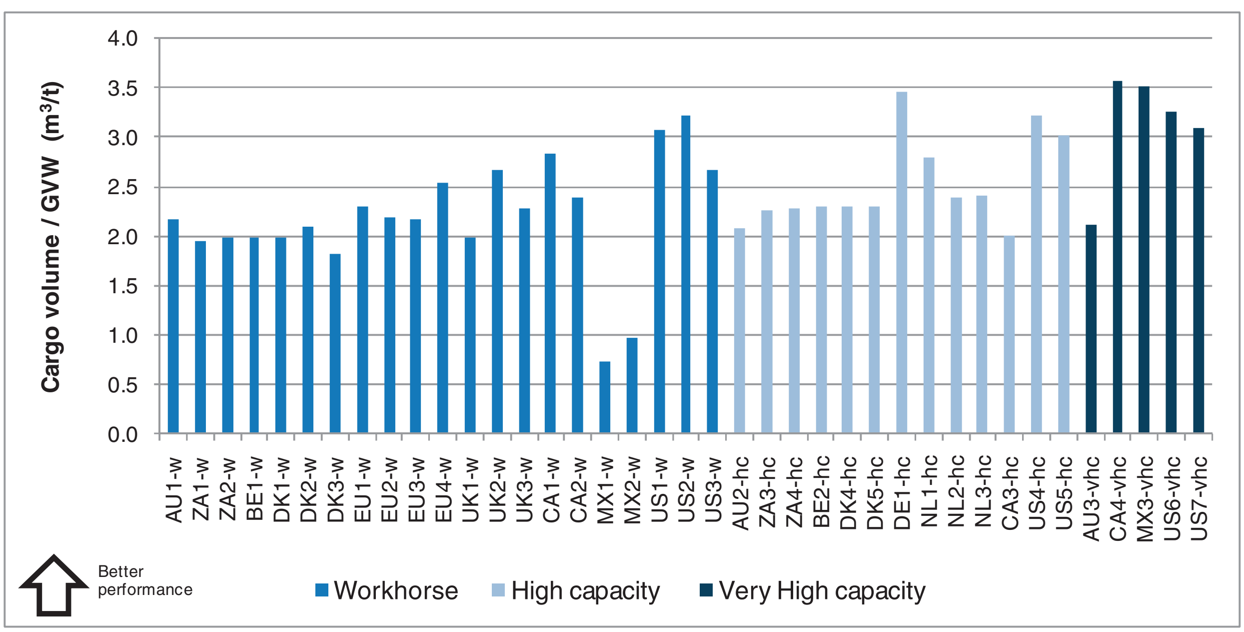
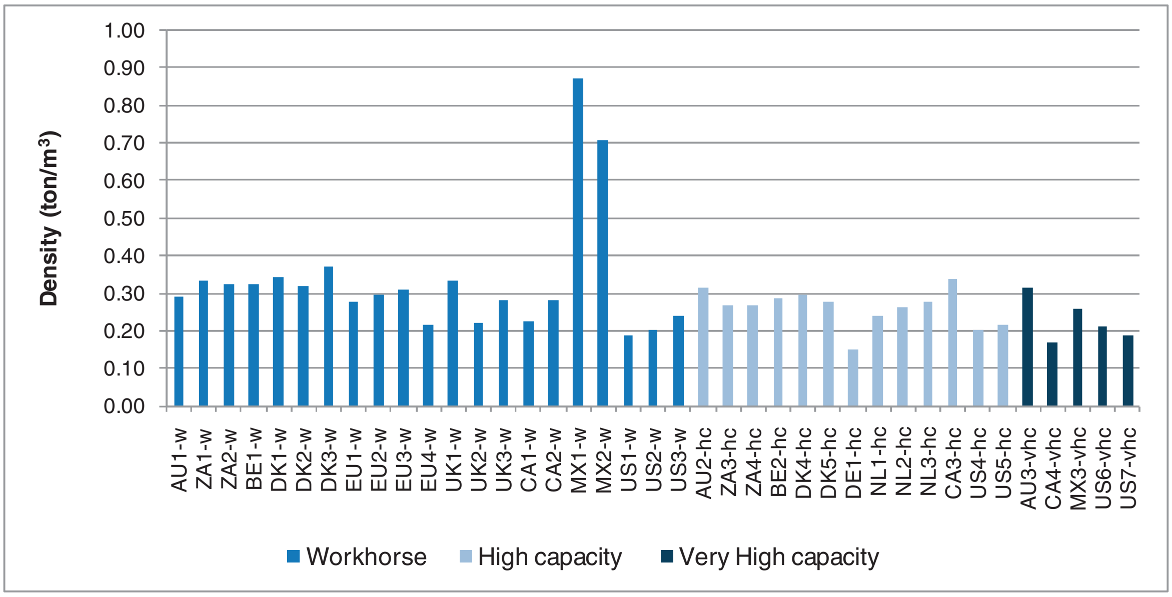


Figure 4.11 shows that there are large variations in payload volume efficiency within each vehicle class, but only the very high capacity vehicles exhibit consistently better payload volume efficiency. This supports the earlier observation that higher productivity vehicles are more likely to have increased volume efficiency than cargo mass efficiency. As mentioned earlier, the two tanker vehicles naturally have lower payload volume efficiency.

Optimum Freight Density

Figure 4.12. **Optimum cargo density**

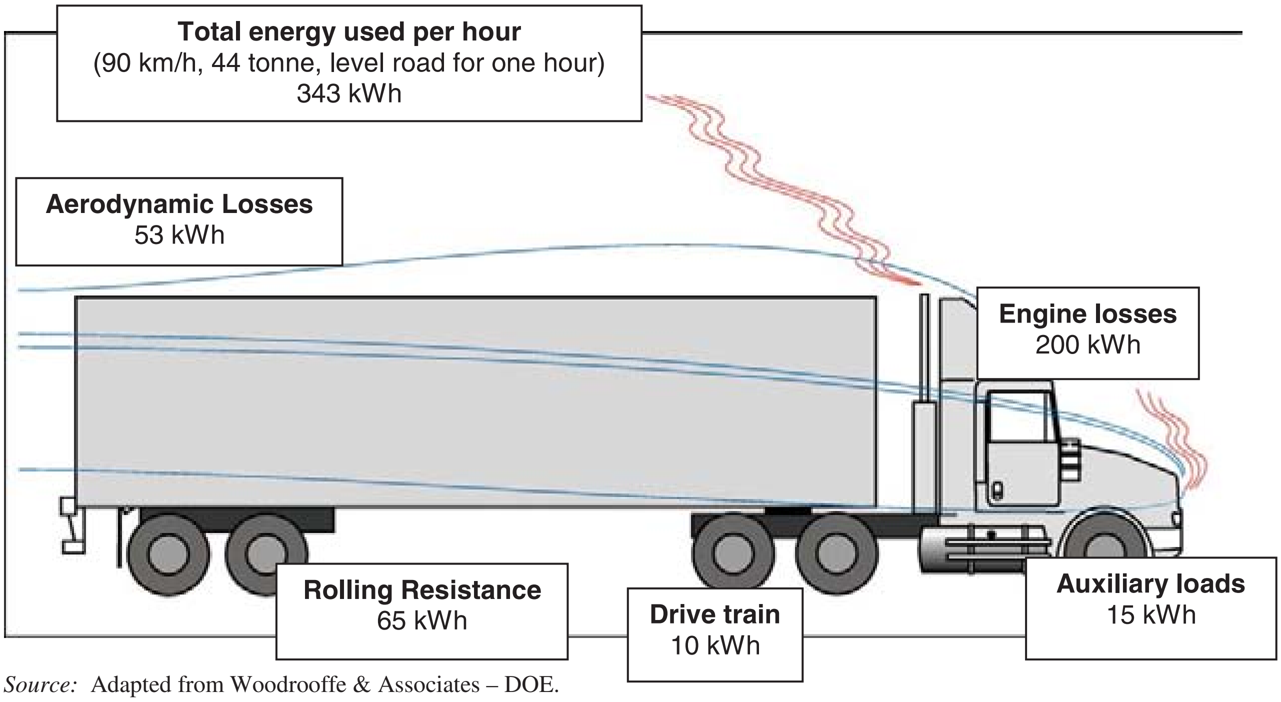


Optimum freight density is defined as the density of freight that would occupy the total available cubic capacity of a vehicle, while simultaneously reaching the maximum allowable cargo mass of the vehicle. The optimised vehicle density shown in Figure 4.12 clearly shows the specific of the tanker vehicles (MX1 and MX2) specifically designed to carry high density liquid product. It also shows that the very high capacity vehicles are better suited to lower density freight. On balance, the workhorse vehicles appear to be better suited to carry higher density freight. This finding is of particular interest to the rail *vs.* truck debate, given that rail is traditionally strong in dense bulk freight markets, while increased truck size appears better suited for freight of decreasing density.

4.9. Calculating power and energy

The primary variables influencing energy consumption for large trucks are the driving cycle, the efficiency of the engine and powertrain, vehicle mass, aerodynamic drag and tyre rolling resistance. However, many of these variables can be considered the same for all trucks or are variables that depend on the specific region. This means that they are either unnecessary or unsuitable for use in an international vehicle benchmarking study. For this reason, all energy and emission analyses for this study assume the vehicle is travelling at a constant speed of 90 km/h in calm wind conditions as shown in Figure 4.13. Only three variables are considered, vehicle mass, tyre rolling resistance and overall vehicle aerodynamic drag. While this analysis does not consider the energy required for acceleration, the study focuses on vehicles for higher speed longer haul applications where acceleration is less frequent.

Figure 4.13. **Typical Energy Distribution for a North American Tractor Semi Trailer**



Source: Adapted from Woodrooffe & Associates – DOE.

4.9.1. Energy consumption

The power required to overcome aerodynamic drag and tyre rolling resistance at constant cruising speed on a level road with no wind can be expressed as follows:

$$P = (F_R + F_A) * v = \left(C_R * m * g + \frac{1}{2} * \rho * C_D * A * v_x^2 \right) * v$$

P is the power required to overcome the resistive forces – (expressed as Watts)
F_R is the tyre rolling resistive force
F_A is the aerodynamic resistive force
C_R is the tyre rolling resistance coefficient
C_D is the aerodynamic drag coefficient
A is the frontal area of the vehicle

v is the velocity of the vehicle

ρ is the air density

This equation excludes all internal losses, such as engine losses, power train losses and power take off. These losses will be represented in the final calculations by a constant of 225 kWh applied equally to all vehicles in this analysis.

4.9.2. *Rolling resistance*

A typical C_R value for a traditional tyre dual tyre axle is approximately 0.006 (1). Super single tyres decrease rolling resistance by up to 20 %, therefore for single tyres a C_R value of 0.005 was used for the axles equipped with these tyres.

4.9.3. *Air resistance*

The projected frontal area of a heavy truck varies depending on the design of the truck tractor and the height and width of the trailer. The frontal area for each vehicle was determined from the vehicle data submitted by each member country. The drag coefficient C_D varies depending on the vehicle type and shape. For the purpose of this study all vehicles were assumed to have the same drag coefficient (C_D), that of a typical European tractor semi trailer combination: C_D of 0.55 with no side wind effects. This single value was considered representative for the vehicles assessed in this analysis. For all calculations, air density ρ was assumed to be 1.23 kg/m^3.

4.9.4. *Calculation CO_2 emissions*

The amount of CO_2 produced per kWh is estimated as follows:

The amount of diesel fuel consumed for truck applications is approximately 200 grams/ kWh (assuming 50% efficiency). The mass of diesel fuel is approximately 850 grams/litre. The amount of CO_2 emissions produced by diesel fuel is 2.668 kg/litre. Therefore the amount of CO_2 produced per kWh is 0.628 kg (2).

4.9.5. *Productivity metrics related to energy and CO_2*

Consider two vehicles of equal cargo volume capacity, but with different cargo mass capacities due to differences in regulated GVW.

Figure 4.14. **Two vehicle units of identical volume but of different mass capacities**

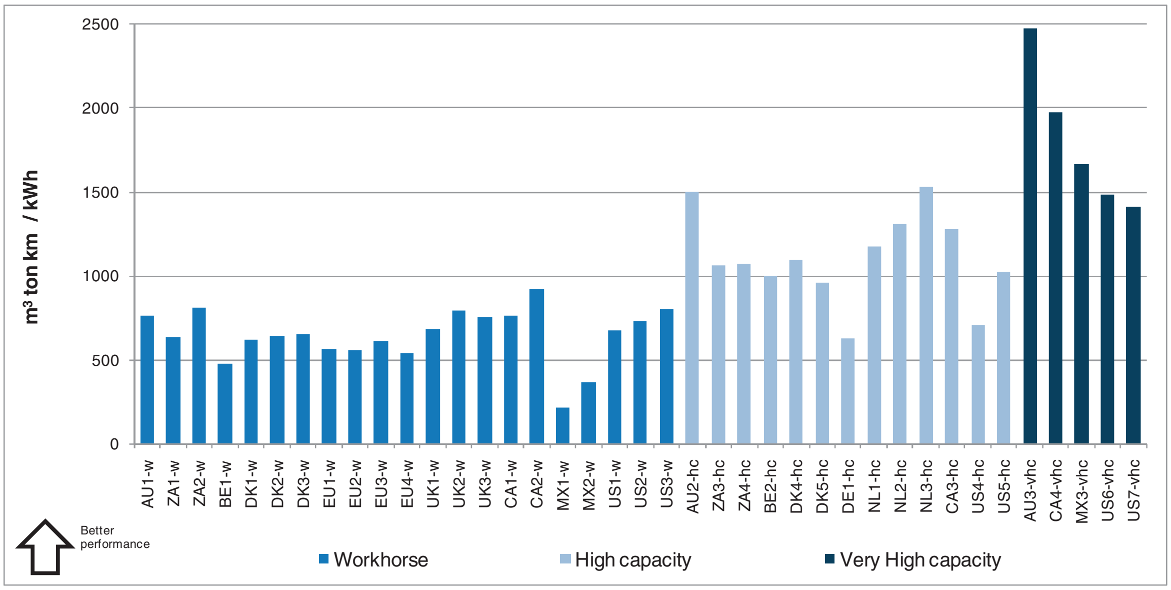
If evaluated on the basis of mass efficiency (tonne-km/kWh), vehicle A will clearly have superior performance compared with vehicle B (if both vehicles have the same engine power and fuel consumption). On the other hand, if the vehicles are evaluated on the basis of volumetric capacity (m^3 km/kWh), then vehicle B is the clear winner given that the lower vehicle mass would require less work to transport the volume and therefore less energy would be consumed. This presents a problem because in practical terms, vehicle A is considered more valuable because it can transport more product of higher density than vehicle B. In fact the value of the volume capacity of the vehicle is directly related to its mass capacity – they are inseparable. Clearly the maximum volumetric efficiency would occur when the density of the cargo is such that it reaches volumetric limit of the vehicle simultaneously with the mass limit of the vehicle. For this reason, it becomes necessary to co-relate volumetric and mass capacities. Considering these conditions the potential measures that were selected to express mass and volumetric efficiency for this study are as follows, assuming constant travel speed of 90 km/h:

$$e_{mass} = \text{(cargo mass capacity)}/ E \quad \text{cargo tonne km/kWh}$$

It is proposed that we account for volumetric efficiency by combining the cargo volumetric capacity with the cargo mass capacity as follows:

$e_{volume\text{-}mass}$= ((cargo volume capacity) x (allowable cargo mass)) / E cargo tonne-m^3 km /kWh

Figure 4.15. **Cargo mass volume by energy consumption**[2]



The cargo mass volume results shown in Figure 4.15, very effectively differentiates the productivity performance of the three vehicle classes. Within each vehicle class the variations are significant and the performance measure results show improvement with each increasing vehicle capacity category. This measure appears to be the most sensitive and revealing of all of the productivity measures examined. Since CO_2 production is directly proportional to diesel fuel use, the emissions characteristics relative to each vehicle will be the same as those shown in Figure 4.15. Both the cargo mass volume by energy consumption and cargo mass volume by CO_2 production are potential candidates for energy and emissions related productivity measures.

4.10. Impacts of trucks on pavements and bridges

The results of the impact of the 39 truck configurations on pavements and bridges are presented in the chapter on Infrastructure.

4.11. Conclusions

The benchmarking process used in this study confirmed that performance measures applied to vehicles complying with a variety of size and weight regimes can differentiate safety and productivity performance providing an objective means of measuring and ranking vehicle in terms of safety and efficiency. The measures used and data obtained from this research effort provide evidence that regulatory systems could reliably promote safer and more efficient vehicles by using performance measures to guide policy decisions. The study has also shown that significant safety and productivity improvements are possible within the existing worldwide fleet.

Operational

Trucks exist to do work and to do it efficiently. Their worth and function are tied directly to work performance in exchange for money, which is very different from the passenger car value proposition. Freight tasks vary, as do the weight and shape of cargo transported, so vehicle use and fuel consumption vary for a given cargo and duty cycle, which is also very different from passenger cars where the weight and fuel consumption vary comparatively little between empty and full load.

For all truck transport, the nature of goods movement can be volume limited or mass limited. Productivity measures based on the product of cargo mass and volume have proven to be a particularly effective means of capturing vehicle efficiency in the context of mass and volume capacity.

Energy and emissions

From the vehicles examined in this study, it is apparent that the higher productivity vehicles in use around the world are delivering greater increases in cargo volume than cargo mass.

Payload mass efficiency may be a suitable candidate for a productivity performance measure for size and weight regulation. It may be desirable to require that all general freight vehicles have a payload mass efficiency greater than 0.6. However this measure would only be suitable for conditions where freight can be loaded such that allowable gross vehicle mass is achieved.

Cargo mass volume by energy consumption and cargo mass volume by CO2 production may be potential candidates for energy and emissions related productivity measures.

A vehicle rated as having low fuel consumption on standard tests will not necessarily show good fuel or emissions efficiency in use. Fuel and emissions efficiency depend on the amount of fuel used to accomplish a specific freight task. For road transport, fuel efficiency measured with respect to the quantity of cargo transported (by mass and volume separately) are preferred performance metrics.

Vehicle design

Basic aspects of truck design, such as the length, wheelbase, width, height, axle loads, axle spacing and GVW, are influenced and limited by size and weight regulations. Since these factors directly influence fuel consumption, it can be concluded that fuel consumption and fuel efficiency are strongly related to size and weight regulation.

The benchmarking process has shown that, in many instances, higher capacity vehicles performed equally if not better than workhorse vehicles. Despite workhorse vehicles being used to transport the majority of the freight around the world, the workhorse vehicle is not necessarily any safer or better performing than the higher capacity, or very high capacity, vehicles simulated in this study.

Vehicles with ‘A’-type couplings (non-roll coupled connections, such as drawbars between vehicle units) performed well in low speed turning manoeuvres. However, they performed poorly in high speed dynamic manoeuvres in comparison to vehicles with ‘B’-type couplings (roll coupled connections between vehicle units, such as fifth-wheel connections). Such couplings provide increased stability to the vehicles and tend to perform better during the dynamic manoeuvres.

The study brought out the different focus that different regions have in the composition of their representative vehicles. The European countries tend to design their vehicle combinations in order to have a lower swept path, while sacrificing higher speed dynamic performance, whereas the Australian, South African and North American vehicles performed better at the dynamic measures, but less well on the low speed swept path measures.

Commercial vehicle size and weight regulations were initially introduced to protect roads and bridges from excessive deterioration caused by larger heavier vehicles. The regulations also mitigate other concerns, such as safety risks and compatibility with other road users. The prescriptive nature of the regulations influence key aspects of truck design, such as the length, width, height, wheelbase, number of axles, axle loads, axle spacing and GCM. These vehicle characteristics influence vehicle stability, manoeuvrability, productivity, fuel use and emission output. Therefore size and weight regulation represents a tool that can not only protect the infrastructure, but also create vehicles that provide significant societal benefits. In order to realise these benefits the regulatory community should keep the size and weight regulations under review to ensure, with the support of full cost benefit analyses, that the freight transport task can be optimised to deliver these broader societal benefits.

NOTES

1. Woodrooffe, J, M. Bereni, A. Germanchev, P. Eady, K.P. Glaeser, B. Jacob, P. Nordengen, *Safety, Productivity, Infrastructure Wear, Fuel Use and Emissions Assessment of the International Truck Fleet: a Comparative Analysis,* OECD/ITF, Paris.

2. Some dimensions were missing to perform the calculations for DK4 and NL3.

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Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability

CHAPTER 5. ENVIRONMENTAL CHALLENGES

Abstract

This chapter reviews the environmental challenges of road freight transport. It includes a review of local air pollutants and greenhouse gases emitted by trucks, and describes technologies to mitigate environmental impacts and improve fuel efficiency. It also briefly discusses the issue of noise.

5.1. Local air pollutants

Trucking represents an important source of emissions of local air pollutants. These include: carbon monoxide (CO), which is toxic in high concentrations; hydrocarbons and nitrogen oxides (NO_x), which are the main ozone precursors; particulate matter (PM); sulphur dioxide (SO_2) which, like NOx, is both a PM precursor and an acidifying gas; and a number of toxic and carcinogenic metals and chemical compounds. These emissions can damage health in a number of ways, aggravating respiratory and cardiovascular diseases and causing cancer of the lungs and other organs and general loss of lung function. PM also has a climate forcing effect by re-radiating visible light and lowering the albedo of ice and snow covered regions by dirtying the surface. Acidification also lowers crop and ecosystem productivity and damages buildings.

The focus of health concerns from truck exhaust is currently on NOx and PM emissions. Most of the PM emitted by heavy diesel engines is fine (under 2.5 micrometers) or ultrafine (under 0.1 micrometers). These particles are able to penetrate deep into the lungs. Toxic organic compounds in the exhaust are adsorbed onto their surface and carried into body tissues. NOx is more difficult to control from diesel engines than petrol engines, and emissions have not fallen entirely as expected with successive limits for emissions from new vehicles. Ozone formed from the photochemical reaction of NOx and hydrocarbons is an irritant in sufficient concentrations and contributes to causing chronic bronchitis and asthma. Exceedance of ambient air quality standards for NOx is widespread in urban areas due, in part, to emissions from heavy and light duty vehicles.

The levels of NOx and PM emissions permitted for type approval of new heavy duty vehicles in the EU, Japan and the United States have been reduced sharply over the last two decades in a series of steps (see table 5.1 and also Chapter 3). The latest round of emissions limits in Japan and the United States are summarised in Table 5.1. Well maintained vehicles of recent design emit very low levels of these pollutants.

Table 5.1a. **EU emission standards for HD diesel engines, g/kWh**

	Date	CO	HC	NOx	PM
Euro 1	1992, < 85 kW	4.5	1.1	8.0	0.612
	1992, > 85 kW	4.5	1.1	8.0	0.36
Euro 2	1996.10	4.0	1.1	7.0	0.25
	1998.10	4.0	1.1	7.0	0.15
Euro 3	*1999.10, EEVs only*	*1.5*	*0.25*	*2.0*	*0.02*
	2000.10	2.1	0.66	5.0	0.10 0.13[a]
Euro 4	2005.10	1.5	0.46	3.5	0.02
Euro 5	2008.10	1.5	0.46	2.0	0.02
Euro 6	2013.01	1.5	0.13	0.4	0.01

Source: EU Regulation 595/2009/EC.

Table 5.1b. **Latest emission standards for Heavy Duty Vehicles in Japan and the US**

	Entry into Force	NOx (g/kWh)	PM (g/kWh)	PM (#/kWh)
Japan (NLT)	2009	0.7	0.01	
USA (HD07)	2007 PM, 2010 NOx	0.27	0.013	

Source: ICCT 2007.

To meet recent regulations, most Japanese and US trucks are equipped with particulate filters. These are effective not only in controlling the mass and toxicity of particulate emissions, but also reduce the number of ultra-fine particles by 95% or more. In Europe, many Euro IV and V vehicles are instead equipped with diesel oxidation catalysts. These remove carbon monoxide and hydrocarbons as well as PM from the exhaust. This avoids the need for an additional device, reducing the load on the engine and avoiding the fuel penalty associated with burning soot off filters. Up to a certain point diesel oxidation catalysts are also less affected by sulphur than particulate filters. However, they are much less effective in removing ultra-fine particles than filters. They are also the source of the elevated levels of NO2 emissions observed recently in European and Japanese cities (Carlslaw 2005, AEA 2009). A regulatory limit on the number of particulates emitted to be set in Europe in 2010 is expected to move the European market to using particulate filters in preference to oxidation catalysts.

There are currently three routes to controlling NOx emissions. Exhaust gas recirculation (EGR), recycles exhaust into the engine cylinders to reduce the temperature of combustion; the inert exhaust gas dilutes the combusting gases. Reducing peak combustion temperature slows the rate of oxidation of nitrogen in the air taken into the engine, reducing NOx concentrations in the exhaust. EGR is a mature and relatively low cost technology. Against initial expectations that it would no longer be sufficient to meet Euro IV standards, some Euro IV and V vehicles do meet the standards with advanced EGR. It has the advantage of being a passive control system that reduces the formation of NOx at source in the engine and does not rely on downstream systems to take NOx out of the exhaust, nor does it require the injection of additives.

Selective catalytic reduction (SCR) injects a mixture of urea and water into the exhaust to reduce NOx to nitrogen and water. It can reduce NOx emissions to very low levels, even when engines are optimised to run hot to improve fuel economy with consequent very high levels of NOx formation. This is a major attraction in high fuel tax countries. SCR is less affected by the sulphur content of diesel than the other NOx control systems but may require addition of an oxidation catalyst to control emissions of ammonia. On the down side, trucks can be operated with a defective SCR system with no effect on driving performance, if for example the urea reagent (marketed as Ad-Blue) runs out. This presents a risk because engines using SCR, tuned to run at high temperature, produce much higher levels of NOx in untreated exhaust than permitted even by Euro I standards. To control this risk, trucks are required to be fitted with on-board diagnostic systems that detect failures and elevated NOx levels in the exhaust. The systems warn the driver of problems and after a certain period limit the power available from the engine until the problem is fixed. It took a year for the regulatory performance standards of these systems to be agreed, after authorisation of SCR in the European market. Some further time may be required to make the systems sufficiently tamper-proof.

NOx adsorbers are the third option. They trap and store NOx in a catalyser during normal engine operation. Once the catalyst is saturated the engine control system delivers a burst of fuel rich exhaust that produces a chemical reaction to reduce the stored NOx to nitrogen. This technology promises to achieve very low levels of NOx emissions without the use of additives. It is, however, very sensitive to sulphur, which is also adsorbed by the catalyst reducing its efficiency in trapping NOx. Periodic high temperature regeneration cycles are required to remove the sulphur, increasing fuel consumption. The performance of current catalysts used in NOx adsorbers is permanently impaired by exposure to sulphur, unlike three-way catalysts and diesel oxidation catalysts, which recover performance after short exposure to elevated sulphur levels.

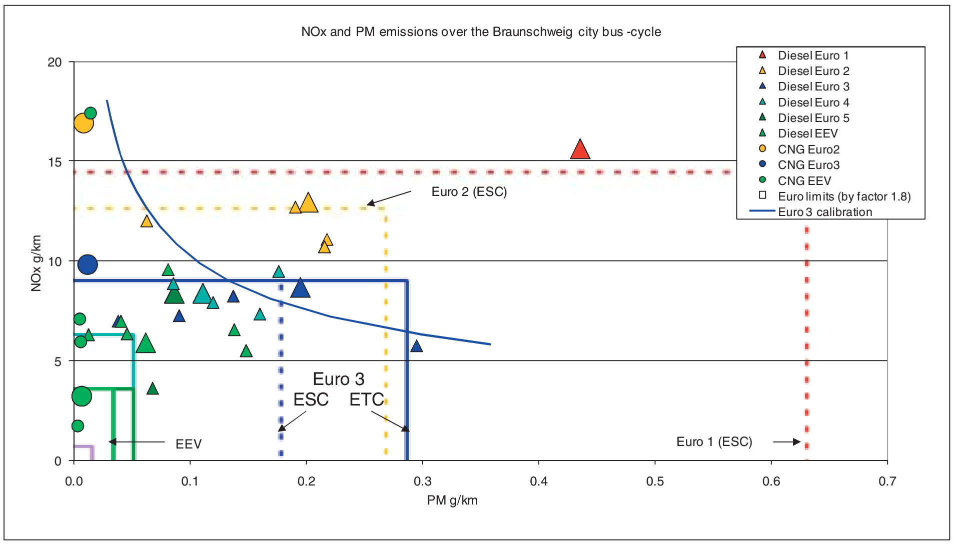
The advantages and disadvantages of these PM and NOx treatment systems illustrate the trade-offs to be made between effectiveness, durability, robustness and fuel efficiency. This is a dynamic environment and advances in catalysts, in the design of catalysers, in engine control systems and exhaust system engineering change the relative merits of each approach over time. One of the challenges of designing regulations is to enable these advances and avoid prematurely picking winners that might cut commercial interest in developing the alternative treatment systems.

Differences between test cycle and on-road conditions have led to disparities in the test and on-road emissions performance of heavy vehicles. Urban buses are particularly prone to this as their typically stop-go operation in congested traffic is not sufficiently represented in most test cycles. Earlier generations of trucks also showed large gaps between on-road and test cycle performance. The disparity in NOx emissions was such that Euro III trucks may have emitted similar levels of NOx to Euro I vehicles in many real driving environments.

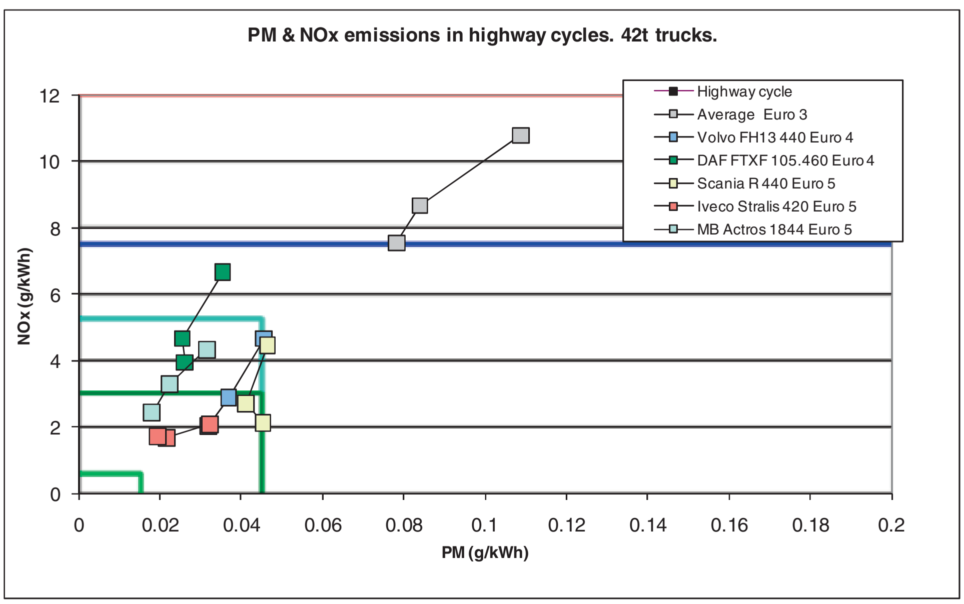
Recent testing of a reasonably large sample of trucks and buses by VTT in Finland reveals continuing large disparities in bus performance with Euro IV, V and EEV vehicles. (EEV or Enhanced Environmentally Friendly Vehicles meet standards between Euro V and Euro VI limits). The EEV buses show a particularly wide scatter in performance. In highway driving conditions, truck performance is much more predictable and coherent with emissions standards. For urban truck delivery cycles there remain gaps in performance, but these are not as pronounced as with buses. The results of the tests by VTT are summarised on the following three figures, where the boxes indicate the NOx and PM limits under successive regulations (Euro I red; Euro II yellow; Euro III blue; Euro IV cyan; Euro V dark green; EEV light green).

Figure 5.1. **Performance of tested Euro IV, V and EEV vehicles in relation to NOx and PM standards**

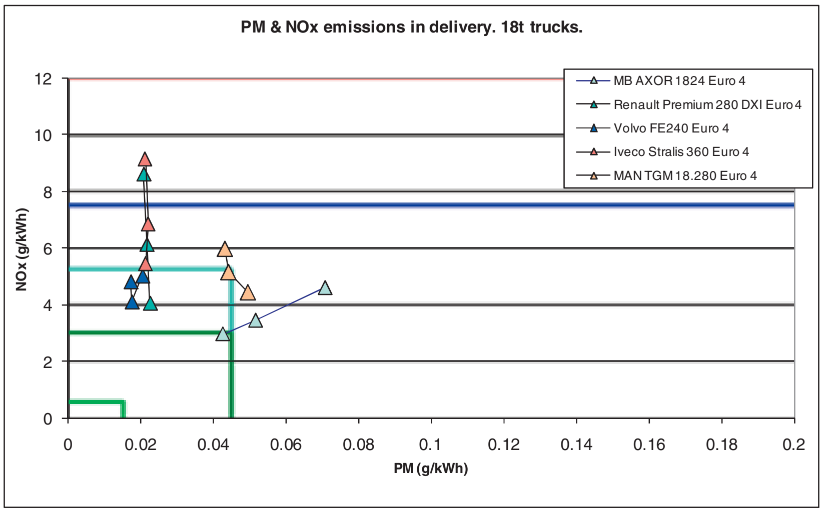
Buses



Trucks



Trucks



Source: VTT 2009.

These tests were carried out on well maintained fleet vehicles owned by large operators, taken from the road without any special preparation for testing on a transient dynamometer. It is not known whether the sample is representative of the average condition of vehicles on the road. Maintenance, and operating vehicles according to manufacturer's instructions, is critical to emissions performance, as the discussion of emissions control technologies above underlines.

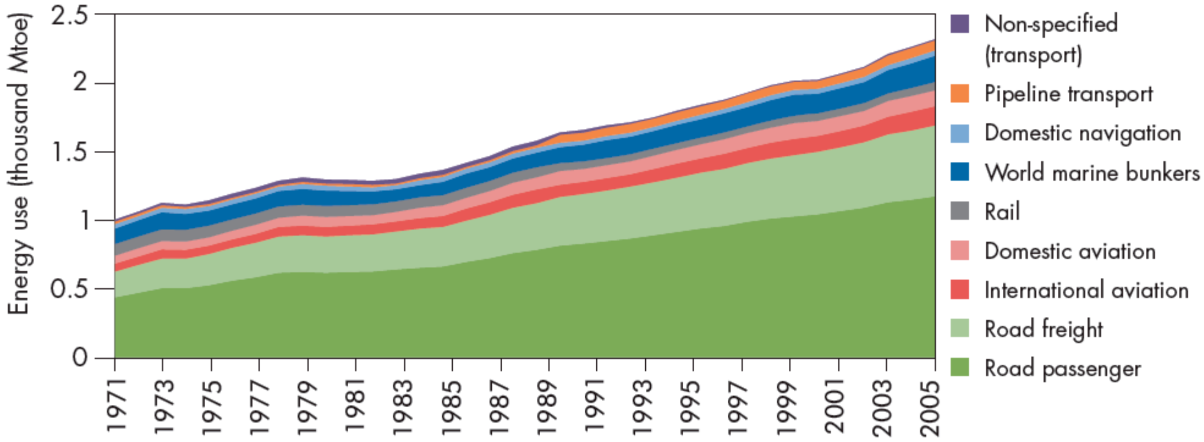
Europe's Euro VI emissions regulation introduces a number of changes that have the potential to eliminate problems of excess off-cycle emissions. The test cycle is improved to include a larger share of low speed, stop-start driving conditions. The same test cycle will be used in the United States and Japan, reducing barriers to a globalised truck market. The use of portable emissions monitoring systems (PEMS) will be introduced, making it possible to test emissions in the full range of driving conditions, and on-board diagnostics and anti-tampering provisions will be completed. Euro VI vehicles entering the market in 2013 are likely to use a combination of advanced EGR and SCR to meet the stringent requirements.

5.2. Fuel consumption and CO_2 emissions

5.2.1. Fuel consumption

Diesel engines are expected to remain the dominant power source for the long-haul trucking fleet for the medium term future. Trucks are a major consumer of oil, accounting for around 20% of world oil consumption, approximately a quarter of all transport oil demand and a third of road transport consumption (IEA/ITF 2007; IEA 2009).

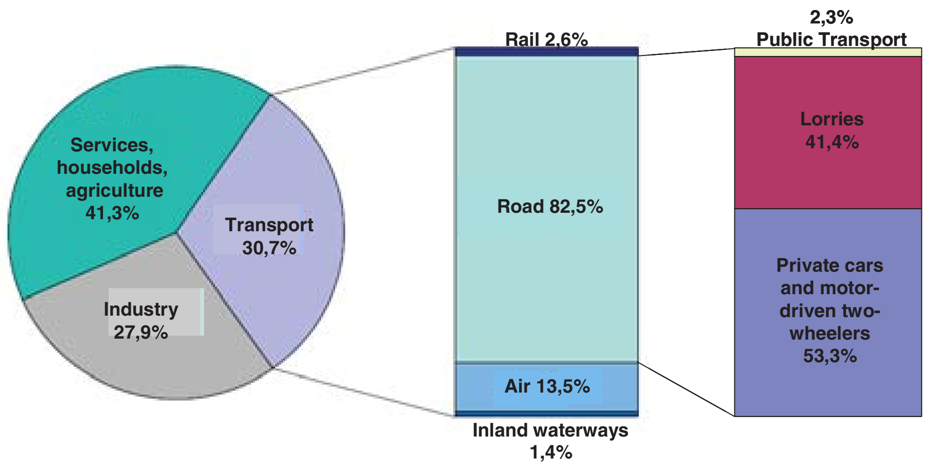
Figure 5.2. **World transport energy use by mode**



Source: IEA 2009a.

Taking Europe as an example, road freight transport accounted for 10.5% of all EU-25 energy consumption in 2004, 41% of the energy consumption by road transport as a whole, consuming 120 million tonnes of oil equivalent (Eurostat, 2007). The 352 million tonnes of oil equivalent (toe) consumed by road, rail, air and inland waterway transport in 2004 represented nearly 31% of total final energy consumption[1] (see Figure 5.3).

Figure 5.3. **Share of transport in final energy consumption in the EU-25 in 2004 (in % of toe)**



Source: Eurostat (Energy), PRIMES.

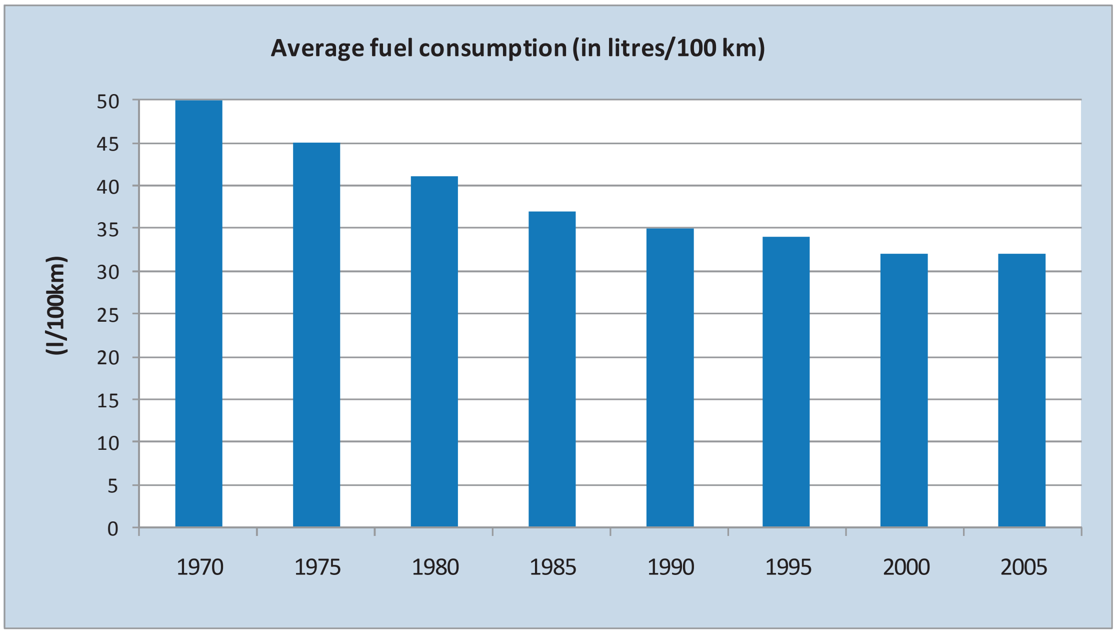
Heavy duty vehicle fuel efficiency in OECD markets has historically improved at a rate of around 1% per year (IEA/ITF 2007). This trend will likely continue, though there has been a temporary drop-off in response to mandated NOx and particulate matter emission controls which have involved technologies that increase fuel consumption. There remains a large potential for near-term energy efficiency improvements of the order of 10-20% through improvements to engines, cab and trailer aerodynamics, drivetrains, tyres and embarked auxiliary systems. The largest absolute increases in energy efficiency are likely to come from advances in engine design.

Diesel engine fuel economy has improved significantly over recent decades. Illustrative test data from Europe are presented in the figures below. These show that in 1970 a 40-tonne truck consumed around 50 litres of diesel per 100 km driven on standard test cycles. By 2000, this consumption had been reduced by 36% to 32 litres of diesel per 100 km (see Figure 5.4) with a levelling off in the trend since then.

The tests used to determine truck fuel economy usually involve running the engine alone on a test bed, recording the fuel consumed as the engine is subjected to a standard cycle of loads replicating representative driving conditions – with phases of acceleration, deceleration, gear changes and cruising. Some testing is performed on transient chassis dynamometers, where the whole vehicle is placed on rollers and fuel consumption measured as it is "driven" through a standard cycle of loads – applied through resistance to the rollers – replicating standard driving conditions. In real driving conditions a number of factors can result in very different fuel consumption performance. More frequent phases of acceleration and climbing hills results in much higher consumption. The fuel consumption of trucks driven by the same engine with the same design of cab varies enormously with the weight, aerodynamic properties and loading of the trailer hauled and with the configuration of axles and tyres on the trailer.

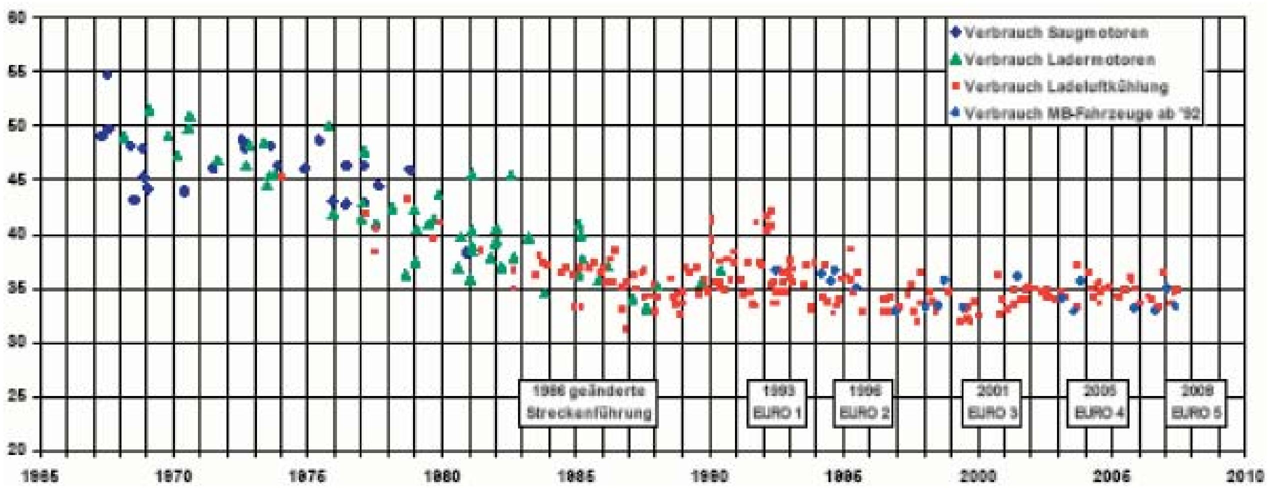
The fuel consumption of road carriers is not only determined by the technical efficiency of the vehicle, but also closely related to driving patterns, highway driving versus stop-start delivery cycles, and flow conditions on the transport network. Each stop increases the fuel consumption of heavy vehicles, and five stops on a trip of 10 km are enough to double the fuel consumption of a forty-tonne articulated combination compared to travelling the same distance at a constant speed.

Figure 5.4. **Evolution of the average fuel consumption of a forty-tonne truck over 100 km**



Source: Verband der Automobilindustrie (VDA) 2006.

Figure 5.5. **Fuel consumption for Mercedes Trucks, 1968-2008**
Complete Vehicles GWT 38/40 tonnes (litres/100km)

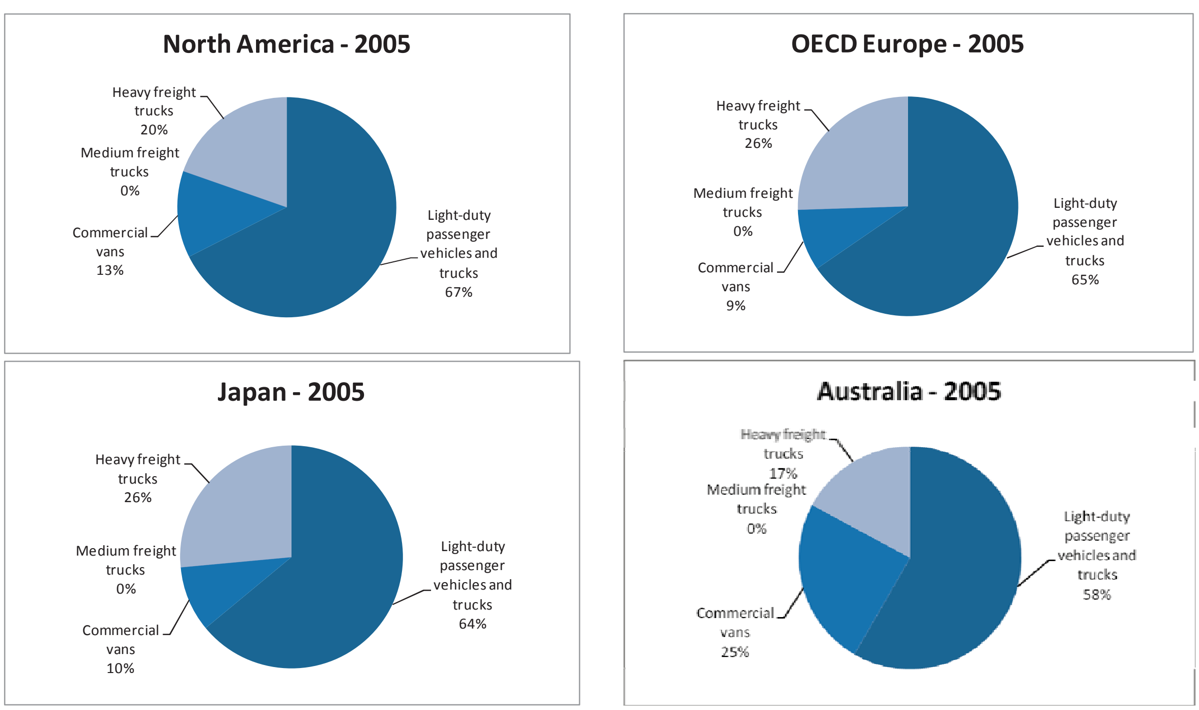


Source: Lastauto Omnibus, in presentation by Stefan Larsson, ACEA (IEA/ITF 2007). http://www.internationaltransportforum.org/statistics/ParisJan2008/indicators.html

5.2.2. Greenhouse gas emissions

Road freight transport contributes to greenhouse gas emissions, accounting for approximately 7% of the global emissions of CO_2 due to energy combustion in 2005 (IEA 2009a) on a well-to-wheels basis. On a tank-to-wheel basis, *i.e.* excluding upstream emissions from oil production and refining, the figure is 5%. Trucks are estimated to account for around 22% of total world CO2 emissions from transport (ITF 2008).

Figure 5.6. **Estimated CO2 emissions from road transport**



Source: IEA MoMo model 2009a.

Estimating emissions from trucks is not simple. The amount of CO_2 released into the atmosphere is closely related to the amount of fuel consumed, approximately 2.8 kg CO_2 per litre of diesel, so emissions track fuel consumption. However, data is not regularly collected on the split between sales of diesel to heavy trucks, buses, delivery vans and passenger cars. Emissions can be estimated from heavy vehicle activity levels but this is complicated by differences between tested fuel economy and actual fuel consumption on the road that can be large. The gap results from differences in truck-trailer configurations, driving patterns, topography and traffic conditions. This approach to estimating emissions is also made difficult as few administrations regularly collect data on truck vehicle kilometres driven. Different approaches to estimating fuel consumption and emissions can yield widely different results. This complicates policy making as data sets are often incompatible and both historical data and projections tend to be revised substantially from time to time because of methodological changes.

McKinnon and Piecyk (2009) examined emissions estimates for the UK in detail and found that, among the official estimates for road freight transport in 2006, the highest figure was 37% larger than the lowest estimate. A 19% difference remained even after correcting for emissions from foreign registered vehicles (not reported in the methodologies adopted by the UN FCCC), correcting for omission of own-account transport in some studies, and correcting for differences in geographical coverage (UK versus Great Britain). This 19% divergence is attributable to the gap between tested average fuel efficiency and real fuel consumption on the road. This is not unique to the situation in the UK.

The fuel efficiency gap is biggest for vehicles used predominantly in urban areas in heavy traffic and on delivery cycles with multiple stops. This is supported by the data on rigid and articulated HGV's (table 5.2). Rigid trucks are typical of urban deliveries and articulated vehicles are used more for long-distance trucking on motorways, where they tend to achieve steadier running at more fuel efficient speeds. Test cycles more closely replicate highway driving than driving in urban traffic. The figures indicate that the larger vehicles are associated with a smaller gap.

Care must be taken in interpreting data on CO_2 emissions from heavy vehicles because of the data issues highlighted here. McKinnon reports that, as a result of adjusting UK government figures to correct for the factors identified above, estimates for the growth of greenhouse gas emissions from road freight over the period 1990-2002 dropped from +59% in early 2004 to only +11% in 2009.

Table 5.2. **Comparison of test cycle and surveyed estimates of fuel efficiency (miles per gallon)**

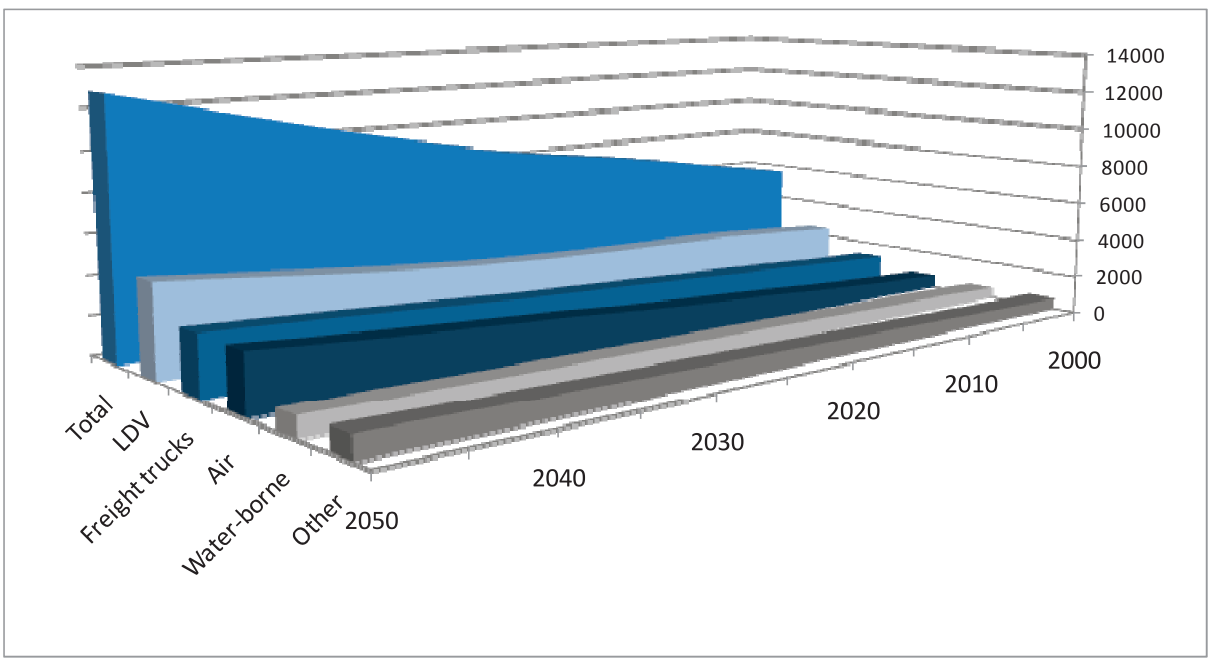
	Rigid HGVs			Articulated HGVs		
Axles	2	3	4+	3-4	5	6+
Survey	11.4	10.0	6.7	9.0	8.0	8.0
Test Cycle	16.3	11.7	9.3	11.3	9.0	8.2
Gap	30%	14%	28%	21%	11%	3%

Source: McKinnon and Piecyk 2009.

For projecting emissions, the most transparent and widely used model was developed by the IEA, originally for the World Business Council on Sustainable Development, and this is used for examining future trends by the ITF Transport Outlooks. The IEA's "MoMo" model uses tested fuel efficiency figures for new vehicles and vehicle registrations data together with estimates of transport activity to project CO2 emissions, reconciling historical data with information on fuel sales. It splits road sector CO2 emissions between passenger and freight vehicles, as shown in figure 5.6. The split assumed is subject to the uncertainties discussed above and regularly revised as data improves. The current business as usual case sees heavy truck and delivery van CO2 emissions combined remaining more or less at the current 22% share of global transport sector emissions through 2050, and doubling overall (see figures 5.7 to 5.9). The model projects little or no increase in emissions in OECD countries, but strong growth rates in Asian and Latin American countries.

The model assumes average rates of fuel efficiency improvement in new trucks in OECD countries that for the coming 20 years exceed the historical 1% pa trend. This implies policies are developed to encourage uptake of many of the innovations discussed in the next section. The model assumes rapidly declining rates of improvement in later years, with an average over the 45 years to 2050 of around 0.5% p.a. for new truck fuel efficiency improvement in OECD countries. It assumes very little growth in vehicle kilometres driven in the OECD countries, which is likely to result in a significant underestimation of actual emissions. The gap between on-road and test cycle fuel efficiency may also imply a tendency to underestimate growth in emissions, as the improvement in test-cycle performance foreseen will not fully translate into real emissions reductions. These factors are to be examined in more detail in future work on the ITF Transport Outlook.

Figure 5.7. **World tank to wheel CO2 emissions, BAU, 2000 – 2050**
Mt of CO2-equivalent



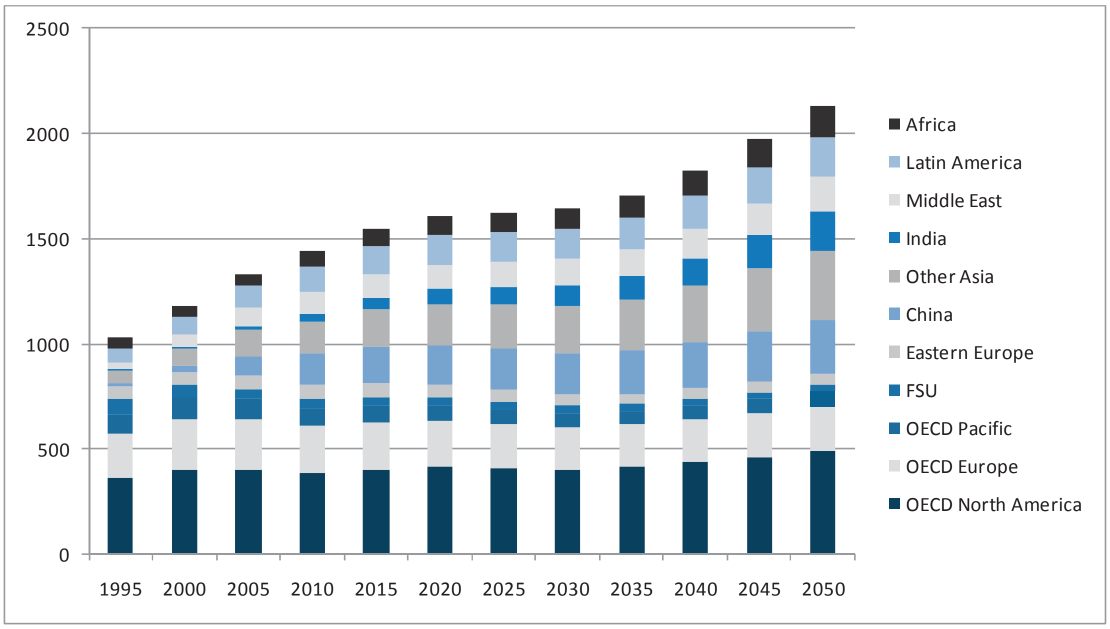
Source: ITF calculations using the IEA MoMo Model Version 2008 (ITF 2008).

Table 5.3. **Modal shares in world vehicle CO2-emissions, BAU, 2000 – 2050, %**

BAU	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Freight + Passenger rai	2.1	2.2	2.3	2.5	2.7	2.8	2.9	2.9	2.9	2.9	3.0
Buses	6.8	6.3	5.7	5.4	5.2	4.9	4.6	4.3	4.1	3.8	3.6
Air	12.9	13.5	14.8	16.8	18.1	19.5	21.1	21.5	21.8	22.3	23.0
Freight trucks	22.4	22.2	22.8	23.4	23.9	24.0	23.7	24.1	24.1	23.8	23.4
LDVs	43.8	43.3	41.9	39.5	37.6	36.4	35.6	35.6	35.9	36.4	36.5
2-3 wheelers	1.6	1.8	2.0	2.2	2.5	2.6	2.6	2.6	2.6	2.5	2.4
Water-borne	10.4	10.8	10.3	10.2	10.0	9.8	9.5	9.0	8.6	8.3	8.0
Total	100	100	100	100	100	100	100	100	100	100	100

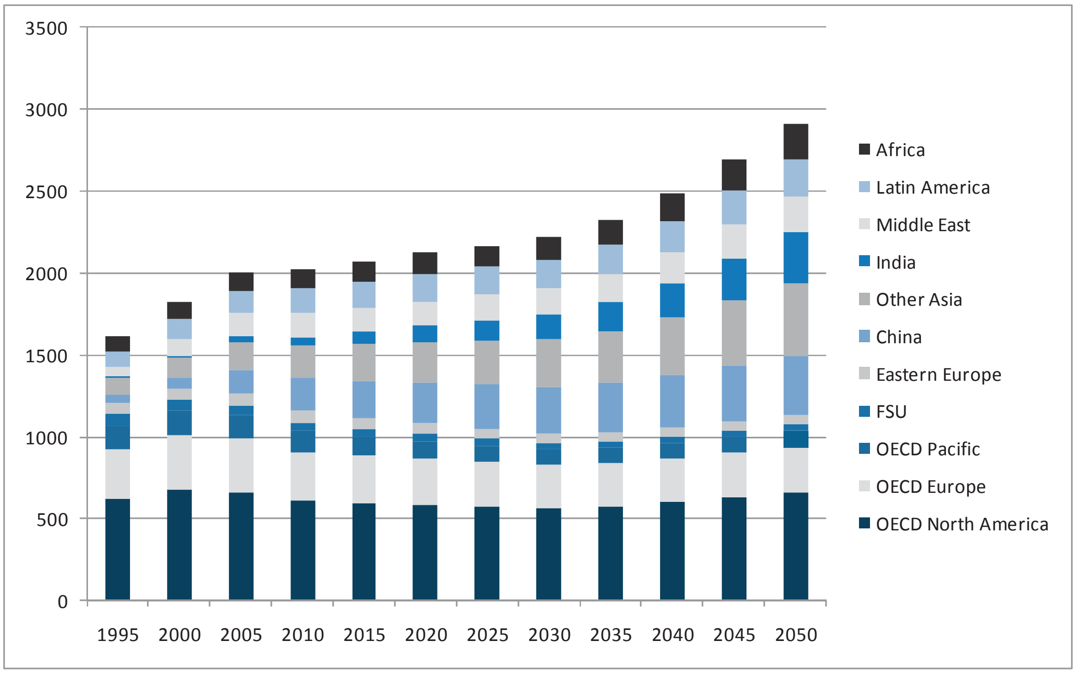
Source: ITF calculations using the IEA MoMo Model Version 2008 (ITF 2008).

Figure 5.8. **Projection for worldwide evolution of CO_2 emissions by heavy trucks Business as usual case Well to Wheel (in millions of tonnes of CO_2)**



Source: IEA MoMo Model 2009.

Figure 5.9. **Projection for worldwide evolution of CO_2 emissions by all trucks and delivery vans Business as usual case Well to Wheel (in millions of tonnes of CO_2)**



Source: IEA MoMo Model 2009.

A number of countries have set overall targets for CO2 reduction, as shown in Table 5.4. As yet none have set targets specific to transport but it is clear that transport, including road freight transport, will have to reduce emissions if such ambitious targets are to be met.

Table 5.4. **CO_2 target in different countries/continent**

	CO_2 reduction Target for 2020	CO_2 reduction Target for 2050
Australia	5% compared with 2000 level (15% if convention is passed in Copenhagen in December 2009)	/
Canada	20% compared with 2006 level	60% to 70% compared with 2006 level
EU	20% compared with 1990 level	60 to 80% compared with 1990 level
Germany	40% compared with 1990 level	/
Great Britain[2]	34% compared with 1990 level	80% compared with 1990 level
Russia	/	/
United States	Return to the same as 1990 level	80% reduction compared with 1990 level

5.2.3. Mitigation potential

Engines

The automotive industry is preparing the passenger car and small van market for a diversification of its energy sources as part of a transition from fossil fuel powered engines to hybrid, battery electric or fuel cell electric technology. Changing the energy sources for heavy freight transport is more challenging, but progress is being made and the first examples of Mild Hybrid Propulsion for heavy trucks can now be seen (*e.g.* in the United States). The technical challenges mean that, for heavy trucks (*e.g.* >12 tonnes) used in long distance transport, diesel engines will dominate the market in the short- to medium-term future. Compressed natural gas may also gain a role for freight transport in environmentally highly sensitive areas and electric traction may be introduced for special purposes, such as drayage operations in port areas with low air pollution limits[3].

Today's long haul trucks carrying 40-44t have engine powers between 260 kW and 360 kW, corresponding to 7-8 kW/tonne, depending on the intended use of the vehicle. A 40-tonne truck and trailer unit only needs about 120 kW, at constant drive at 85 km/h on a flat highway, to overcome tractive resistances. The additional power is only required for accelerating and climbing hills (modern vehicles can climb a gradient of 3% to 4% in the highest gear without losing speed).

While in the past displacements between 12 and 17 litres were necessary for the 400 HP class (294 kW), new generation engines reach 300-380 HP using an 8 litre engine and 450 HP with only 10 litres displacement (ATZ, 2008). The reason for this is the installation of exhaust turbochargers and better ignition as a result of higher fuel injection pressures. This engine downsizing reduces engine mass and increases the available payload.

Fuel consumption for a truck has decreased over the past 30 years from about 50 litres/100 km to 30-35 litres/100 km, while the engine power has doubled from about 180 kW to 360 kW. The engines of today's trucks have high thermodynamic efficiency, but it is possible to decrease the fuel consumption further to about 25 litres/100 km, for example, by downsizing the engine, reducing aerodynamic drag, reducing rolling resistance and improving the efficiency of auxiliary systems. These potential improvements are described in more detail in the following sections.

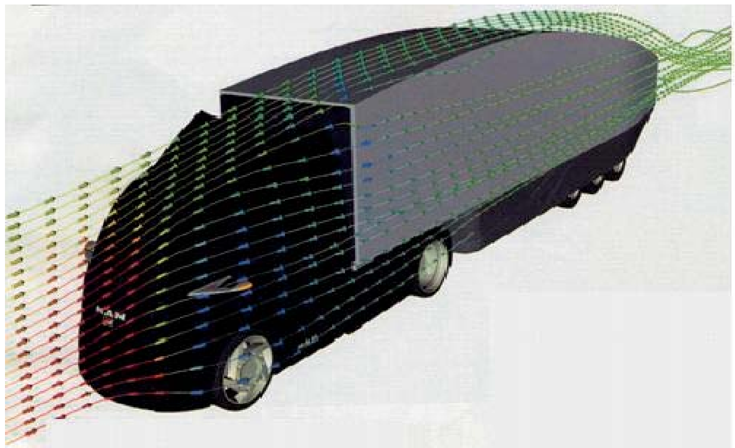
Tractive resistances

When driving a truck at constant speed on a flat level road, about 40% of the fuel consumed is used to overpower the air resistance (drag) and 45% is needed to overpower the rolling resistance. The rest is consumed by powertrain losses and auxiliaries.

Aerodynamics

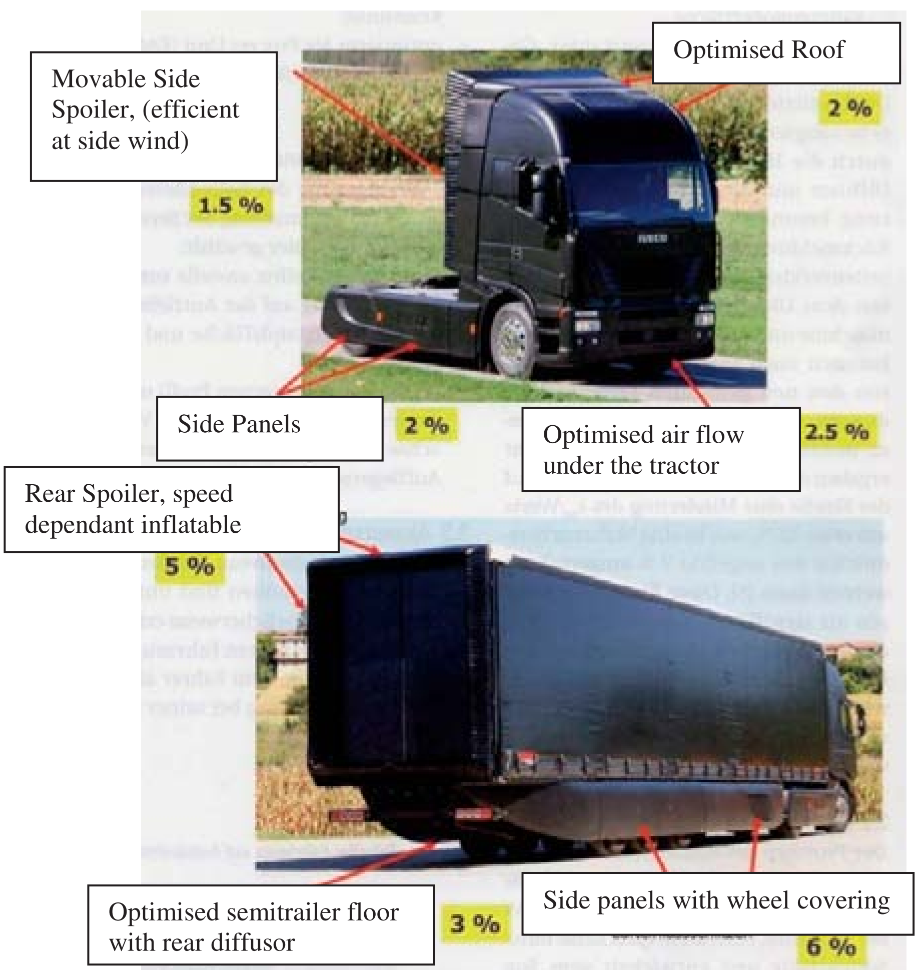
In simple terms, the air resistance depends on the drag coefficient, the cross-sectional area of the front of the truck, and the square of the velocity with which air passes over the truck. If the speed and dimensions of a truck are assumed to be fixed, the only parameter which can be improved is the drag coefficient (cw).

Figure 5.10. **Aerodynamic model of a tractor semitrailer combination with extreme low air drag**



Source: Wirtschaftswoche Nr 36 9/2008.

Figure 5.11. **Example of aerodynamic optimisation and share of cw decrease [%] (total 22%)**

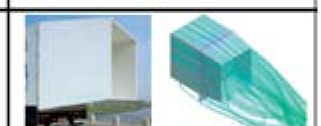
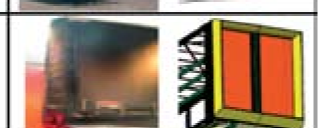
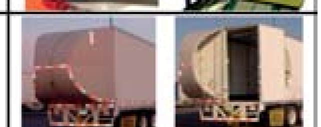


Source: Optimiertes Transportkonzept für Sattelzüge ATZ 2/2008 S.154ff.

Aerodynamically, most of the current trucks and articulated vehicles can still be described as "wheeled bricks" [*CEO of MAN in Wirtschaftswoche Nr 36 Sept.2008*]. The drag coefficient (cw) of today's trucks and tractor-semitrailer combinations vary from 0.5 up to 0.9, but could (theoretically at least) be improved to about 0.3, using changes such as those shown in figure 5.11. In this case, 1.50m has been added to the length of the semitrailer and 0.70m to the tractor in order to keep the same cargo volume capacity as a standard vehicle. Such an increase in the length of the tractor unit could potentially also be used to improve the truck's safety through improvements to pedestrian protection, field of view, improved underrun protection, and truck occupant protection (Aprosys, 2008).

T&E has researched devices available on the European market to reduce aerodynamic drag at the rear of trucks, finding a potential to cut CO2 emissions in the range 5-8% (T&E 2010). It recommends amending European type approval regulations of truck dimensions to exempt such devices from length measurement up to a maximum of 0.6 m. It similarly recommends modifying underrun protection legislation so that it is not a barrier to the use of aerodynamic devices certified to be safe.

Figure 5.12. **Devices to reduce aerodynamic drag at the rear of trucks**

Device	approx. additional dimension required	best suiting trailer type	approximate CO2 reduction long haul	Image / working principle
Open cavity tails	1.0 - 1.5 m	box, curtain, refridgerated box (reefer)	6%	
Inset open cavity tails	0.6 m - 0.8m	box, curtain, refridgerated box (reefer)	5-8%	
Inflatable open cavity tails	0.4 - 0.6 m	box, curtain, refridgerated box (reefer)	3-4%	
Inflatable closed cavity tails	1.0 - 1.5 m	box, curtain, refridgerated box (reefer), chassis	5%	
Active Flow Control / Difusors	0.3 m	box, curtain, refridgerated box (reefer)	7%	

Source: T&E 2010.

In the United States, the 21st Century Truck Partnership aims for an aggressive target of 20% reduction in aerodynamic drag by designing and deploying boat tailings, collapsible roof lines, side and underbody skirts, tractor-trailer interfaces, and deflectors. Reducing the aerodynamic drag by 20 to 25% is predicted to result in theoretical fuel savings of 7 to 12%. The measures shown in Figure 5.11 lead to an experimentally confirmed fuel consumption decrease of 7%.

Since 2007, the US Environmental Protection Agency's "SmartWay" programme has supported the marketing of fuel efficient trucks by offering manufacturers the license to use a mark that identifies tractors or trailers which meet fuel efficiency and emissions standards established by the Agency. These include engine standards, aerodynamic fairings, low rolling resistance tyres and power supplies for the extended use of auxiliaries without engine idling. Owners of such vehicles who are committed to the continued use of their fuel saving features are granted the right to display an *exterior* SmartWay mark on their vehicles to communicate this commitment to the public.

The Canadian EnviroTruck shown in figure 5.13 has a modern heavy truck engine, a speed limiter set at no more than 105 km/h, and a combination of other devices designed to improve fuel efficiency. The types of add-on devices that make up the EnviroTruck programme include: auxiliary power units to run truck heating and cooling systems without the engine idling; tractor and trailer aerodynamics (roof and side fairings, cab extenders), low rolling resistance tyres, and double trailer configurations. Estimates suggest that if the entire Canadian fleet of 294 000 Class-8 trucks (33 000 lbs and up) were to adopt a full package of energy-efficiency technologies, the Canadian trucking industry could save annually 4.1 billion litres of fuel and reduce emissions by 11.5 million tonnes of GHG while maintaining current distribution of vehicle weights across the fleet (Ogburn and Ramroth, 2007). This is equivalent to taking 2.6 million cars or 64 500 trucks off the road. A limited package of measures applied to 50 % of all Class-8 trucks would save 3.4 million tonnes of GHG, corresponding to taking 750 000 cars or 19 200 trucks off the road.

Figure 5.13. **The Canadian "EnviroTruck" concept (2007) with fuel-reducing improvements**

Source: Canadian Trucking Alliance.

Tyre rolling resistance

Nearly half of the drive resistance at constant speed comes from the rolling resistance of the tyres. In reality (mixed traffic), every 3rd fuel filling is related to rolling resistance. The tyre rolling resistance coefficient is the ratio of the rolling resistance force to the wheel load in percent. The rolling resistance coefficients of truck tyres are lower than those of passenger car tyres. Rolling resistance changes with load and inflation pressure, and marginally with speed.[4] The smaller the tyre diameter the higher the rolling resistance coefficient and drive axle tyres have higher rolling resistance coefficients than steering axle tyres (see Table 5.5).

The total rolling resistance is dependent on the number of tyres on the vehicle and the wheel loads. A decrease of 20 to 25% in rolling resistance would save about 10% of the fuel. Theoretically, a 2.2 % average rolling resistance reduction for all tyres on a truck translates into a 1% fuel saving (0.022 x 0.45=0.01).

Table 5.5. **Mean rolling resistance coefficient values of 5 truck tyres in each tyre size**

	Normal (steering axle tyres)	M&S (drive axle tyres)
215/75 R 17.5 Class C3	0.7% +/- 0.1%	0.8% +/- 0.1%
275/70 R 22.5 Class C3	0.6% +/- 0,1%	0.65% +/- 0.05 %
315/80 R 22.5 Class C3	0.5% +/- 0,05%	0.6% +/- 0.1%

Source: Stenschke R. *et al.:* Umwelteigenschaften von Reifen, UBA 2004.

Today's trailer tyres (towed axle tyres, 385 mm size) have a rolling resistance of about 0.6%.

Wide-base single tyres (495 mm size) have been in some cases replaced the twin tyre assemblies on the drive axles of a trucks in Europe and the USA. They have 20% less rolling resistance than the twins, leading to a 2-2.5% fuel saving and a weight reduction of 80-100 kg per truck *[COST 334*]. In the US where two drive axles are common, the use of four times one 445/50 R 22.5 tyres instead of four times two 275/80 R 22.5 tyres leads to a weight saving of 330 kg which can be used as additional payload. Light weight rims can give some additional payload benefits.

The US Environmental Protection Agency's SmartWay Transport Program encourages use of wide-base single tyres to replace twins, and aluminium wheels to replace steel rims. The 21st Century Truck Partnership in the United States aims for a target of 40% reduction in rolling resistance. It has identified that major breakthroughs in material dissipation properties, tyre construction, and wear and traction optimisation are needed to improve rolling resistance. The tyre manufacturer Michelin expects to reduce the rolling resistance (and the wear) of truck tyres by 50% in the 25 years to 2030 by continuous improvement, with a potential 20% fuel saving per vehicle.[5]

Finally, rolling resistance is not generated by the tyre in isolation, but by the tyre rolling over the road surface. Thus, the texture and evenness of the road surface also contribute to rolling resistance. If pavements can be conceived with durable texture and low rolling resistance without critically reducing friction then additional fuel saving would be possible. Up till now, little research has been done in this area.

Vehicle components: Power train and auxiliaries

The powertrain (gearbox and transmission) and the additional auxiliary equipment (*e.g.* cab heaters) take about 15% of the total available power.

The driveline consists of transmission, drive shaft, differential, and wheel bearings, and is a reasonably mature system that typically achieves better than 95% efficiency at high-torque applications, and approaching 98% efficiency at highway speeds. However, in the United States, the 21st Century Truck Partnership aims for an aggressive target of a 30% reduction in the remaining driveline losses, which would yield 1.5% fuel savings. Automated manual transmissions with 12 (or 16 for the heavy sector) gears are standard on today's trucks. These transmissions have replaced the former un-synchronised transmissions.

Automated gearboxes are weight optimised, and non-synchronised, mechanical gearboxes with two countershafts. All gear changing processes are computer aided and are controlled by sensors with algorithms that have been refined over a number of years. This means that the correct gear is always chosen such that the engine always operates at the engine speed of lowest specific fuel consumption (typically 1 400 rpm -1 600 rpm). However, a manual intervention by the truck driver at any time can override the automatic shifting strategy (ATZ, 2008). A sensor controlled topography dependent gear shifting programme is the latest development.

The “Euro VI” emissions standard will be introduced by 2012, and will require very low limits for NO_x and particulate matters. This is likely to be achieved at the expense of slightly increased fuel consumption. These losses can be offset by turbo-compound systems, utilising the thermal energies found in the exhaust fumes, which may help to save 3% fuel. Hydrodynamic couplings for such turbo-compound systems are available.

Auxiliaries include the engine alternator, air compressor, air conditioning compressor, hydraulic fluid pump, engine oil pump, fuel pump, and “accessory loads”. In the United States, the 21st Century Truck Partnership aims at fuel savings of 1-2% through an aggressive target of a 50% reduction in the energy required by auxiliaries. Electrification of all of the above components (except of course, the alternator) might help to achieve this. It would, at a minimum, eliminate the energy losses from the use of belts to draw mechanical power, and could be powered from energy recovery systems, solar cells or other zero emission sources.

Alternative fuels

Biodiesel, which can be used as a replacement for petroleum diesel fuel, is currently manufactured from vegetable oils, recycled cooking greases, or animal fats. Biodiesel in blends of up to 20% can reduce CO_2 emissions by more than 15% compared with 100% petroleum diesel, but they can result in higher well-to-wheels GHG emissions than diesel, depending on how they are produced (ITF 2008). Biodiesel blends can typically be used in conventional combustion engines without engine modifications and do not require substantial changes to the fuelling infrastructure.

The net CO_2 reduction from using biodiesel can differ significantly from the theoretical potential, depending strongly on the manufacturing process, and the indirect effects on land use. The energy used to transport the feedstock and final products are also important factors to consider. Recent studies (Searchinger *et al.,* 2008 and Gallagher, 2008) recommend a carefully controlled introduction of all biofuels to prevent effects on land use that may offset the GHG savings goals, limit any contribution to rising food prices and prevent the introduction of measures that are unsustainable in the longer term.

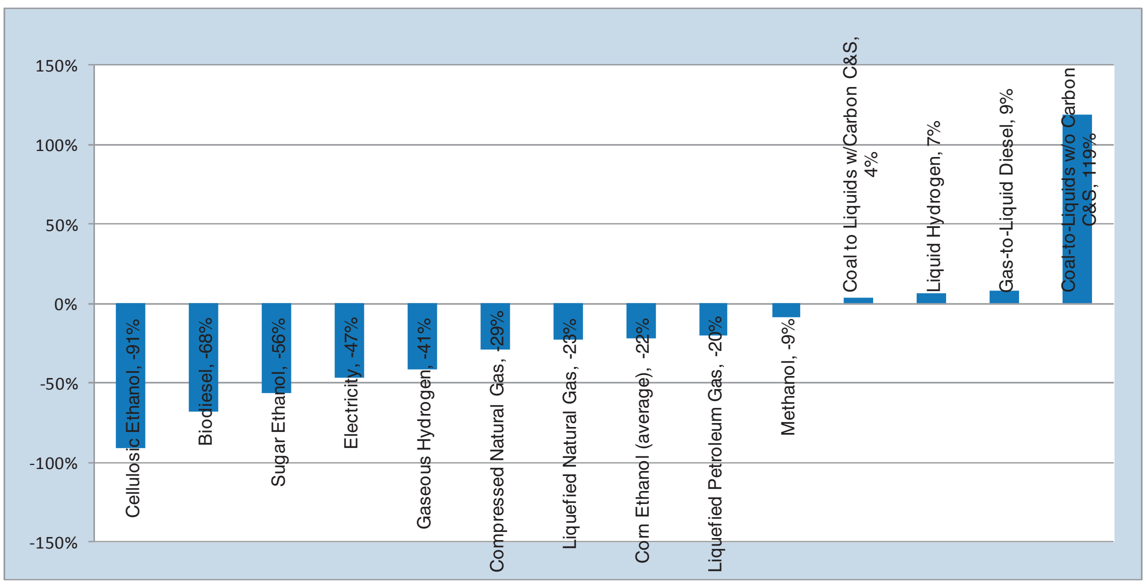
The EU has agreed on a directive[6] which requires from all Member States that 10% of land transport energy needs are met by renewable sources by the year 2020. In a different approach, the US Environmental Protection Agency (EPA) has proposed new regulations for renewable fuels[7], mandating the volume requirements year-by-year until 2023. Both specify minimum GHG reduction targets for the various biofuels including quantification of the GHG effects of land-use change.

In the United States, a biodiesel blenders’ tax credit is a key driver of the biodiesel market. It provides biodiesel and petroleum handlers with a credit for each gallon of biodiesel blended with diesel fuel. In Europe, volumetric production and blending targets have driven development of the biodiesel market. The emergence of ultra low sulphur diesel (ULSD) regulations also drives biodiesel demand, as it is naturally sulphur-free. Technology will play a major role in lowering the cost of biodiesel production and finding alternative higher value uses for the primary by-product, which is glycerine.

Fischer-Tropsch fuel is another alternative for heavy duty vehicles. It is synthesised from coal gas, natural gas, biomass, or any other carbonaceous material and can replace petroleum diesel fuel without any modification to a conventional diesel engine. It biodegrades more easily than conventional diesel fuel, and can be used to run conventional diesel engines at cold temperatures as shown in demonstrations conducted by the US Federal Transit Administration in 2007[8]. It reduces exhaust emissions compared to conventional diesel, although production and supply line emissions must not be neglected. However, currently the costs of producing the Fischer-Tropsch fuel are still too high to allow a general introduction of this diesel 'mimic' on the free market.

The reduction in total green-house-gas (GHG) emissions achievable with alternate fuels is highly dependent on the GHG emission of the processes by which these fuels are produced, as well as the GHG emissions associated with the production of feedstock/raw materials and their transportation to the point of production. Figure 5.14 illustrates the range of GHG emission reductions achievable from alternate fuels, using current or projected production practices, in the United States in 2007 when compared with the emissions from the petroleum fuel that was replaced.

Figure 5.14. **Percent change in GHG emissions**



Source: US Environmental Protection Agency EPA420-F-07-035, April 2007.

Potential of eco-driving

The automatic transmission in modern trucks does not give the driver much opportunity to select incorrect and inefficient gears. Nevertheless, eco-driving behaviours and techniques can be used by drivers to optimise the fuel economy of their vehicle and has significant potential to deliver fuel savings and CO2 reductions quickly and cost effectively. Based on recent assessment of eco-driving initiatives, eco-driving can bring an immediate 10% reduction in fuel consumption and CO2 emissions.

Training is an essential success factor for eco-driving. Immediately after eco-driving training, average fuel economy improvements of 5 to 15 percent were recorded for cars, busses and trucks. The best results for individual drivers showed 20-50 percent improvements in fuel economy under test conditions (ITF/IEA, 2007). Over the mid-term (<3 years), average fuel savings of around 5% have been shown in cases where there is no support beyond the initial training, and with continuous feedback this can be improved to about 10%. There is little evidence available regarding the long-term impacts (>3 years) of eco-driving training, but a few studies have been conducted on companies with truck and bus fleets that provided one-off training with no follow-up incentive programmes, recording a 2-3% residual improvement in fuel consumption.

The Workshop organised by the International Transport Forum and the International Energy Agency in November 2007 (ITF/IEA, 2007b) confirmed eco-driving as a highly cost-effective measure to reduce CO2 emissions. The Dutch presentation provided a figure of cost effectiveness for all eco-driving projects of an average of less than 10 € per tonne of CO2 avoided. These relatively low costs (compared to most technical measures) mean that eco-driving can be considered as a first order "no regrets" measure for administrations.

Many eco-driving initiatives are undertaken without the help of government measures. Fleet operators often take action themselves because there is significant cost-saving potential and eco-driving initiatives fit perfectly into responsible/green entrepreneurship. However, there is the potential for many more fleet operators to introduce eco-driving with government support because the upfront costs of eco-driving are still more visible than the long term savings.

5.3. Noise emissions

Noise level is a major concern for the population living in urban areas or along major roads. Traffic noise can disturb sleep patterns, affect cognitive functioning and aggravate some cardiovascular problems (Den Boaer and Schroten, 2007).

Different road transportation vehicles have different scales of noise emissions. Main sources of noise come from the engine and the friction of the wheels over the road surface. Travel speed and the intensity of traffic are directly linked with noise emission from road transportation. One truck moving at 90 km/hr makes as much noise as 28 cars moving at the same speed (Rodrigue, 2009). Also, noise level grows arithmetically with speed.

The serious effects of transport noise have been recognised since the 1970s. For a long time however, they received relatively little attention with the public focusing instead on transport's air pollution impact. The situation has been changing in Europe since the Environmental Noise Directive of 2002 and, for example, the EEA 2008 report on "Transport at a crossroads" is the first to contain an assessment of EU-wide noise data. Hooghwerff *et al*. (2000) estimated the spread of exposure to noise in the EU15 shown in Table 5.6.

Table 5.6. **Estimated exposure of the EU population to road traffic noise**

LdndB(A)	<55	55-65	65-75	>75
% exposed	68	19	11	2
Population (M)	251	71	41	8

An EU Directive 92/97 entered into force in 1996 to fix the noise limits at 80 dB(A) for commercial vehicles. In August 2001, a tyre / road noise directive (2001/43/EC) was published. Requirements on tyres where tyre/road noise is concerned entered into force on 4 February 2004. Similar standards exist in other OECD regions.

The traditional potential measures to mitigate traffic noise, including truck noise, include:

- Technological improvements to vehicles, aerodynamics and components, including low noise tyres.
- Improvements to infrastructure, such as low noise road surfaces.
- Urban planning that limits encroachment close to busy roads, and rules on the location, layout and acoustic quality of buildings.
- Traffic management techniques, such as traffic calming, controlling the speed of road vehicles.
- Restricting access for the noisiest vehicles (*e.g.* at night in urban areas).
- Noise barriers and improved soundproofing of dwellings (although only as a last resort, because these measures are rarely cost-effective).

The level of rolling noise generated by tyres on road pavements, which increases with vehicle speed, is the field where the most significant progress is expected in the coming years.

If improvements have been achieved by limiting noise from individual sources – such as individual vehicles – it is doubtful whether any significant improvement has been observed in the overall exposure of the population to noise from road vehicles, mainly because of the increase in road traffic. According to ITF statistics, ton-kilometres performed by heavy vehicles have been multiplied by at least a factor of 4 since 1970.

Managing growth in traffic as a strategy to reduce noise volumes has limitations. Reducing car traffic on roads with a high proportion of trucks and buses, for instance, has little impact on the overall traffic noise since car noise is masked by the heaviest vehicles. To be effective, the noisiest vehicles have to be targeted first, but some of these – trucks – have a higher social value in performing transport operations than cars. Even on roads mostly used by cars, a traffic reduction of at least 40% would be needed to start perceiving reduced noise due to the logarithmic pattern of the phenomenon of noise. An integrated policy package is indicated, using both market-based and regulatory measures to give transport manufacturers, planners, consumers and service providers the right incentives to adopt new technologies and practices. The optimal package of measures is an area that requires more research.

5.4. Conclusions

Trucks impose significant impacts on the environment in terms of local pollutants, greenhouse gas emissions and noise, as well as consuming non-renewable energy resources.

Significant progress has been made in reducing emissions of local pollutants. Air pollution from truck diesel engines has been reduced through the adoption of stringent emissions standards and the associated efforts of truck manufacturers. Test limits for the certification of new trucks have been reduced for emissions of NOx, hydrocarbons and particulate matter by 60%, 30% and 80% respectively since 2000 in Europe, with similar scale reductions in other OECD countries. Further, albeit smaller scale, reductions are expected in the future.

Emission treatment systems illustrate the importance of technology-neutral standards. The advantages and disadvantages of currently available PM and NOx treatment systems illustrate the trade-offs to be made between effectiveness, durability, robustness and fuel efficiency. Advances in catalysers, in engine control systems, and exhaust systems, change the relative merits of each approach over time. A challenge in designing regulations is to enable such new approaches and avoid prematurely picking winners that might cut commercial interest in developing the alternative treatment systems.

Estimating CO_s emission from trucks is not simple. Few administrations regularly collect data on truck vehicle kilometres driven; and data on the split of sales of diesel to heavy trucks, buses, delivery vans and passenger cars is not regularly collected. Estimating emissions from truck activity levels is further complicated by the gap between tested fuel economy and fuel consumption on the road. Alternative approaches to estimating fuel consumption and emissions can yield results with large differences, which can be seriously misleading if not analysed with care.

For the class of vehicles considered in this report the diesel engine will remain the dominant source of propulsive power for the foreseeable future. Thus, the reliance on diesel fuel will persist, although the increasing use of biodiesel will limit the consumption of fossil fuel. Truck fuel economy has improved in the past 30 years from about 50 litres/100 km to 30-35 litres/100 km; while engine power has doubled from 180 kW to 360 kW. As the fuel saving potentials from reduced drag and rolling resistance are realised, along with more efficient auxiliary systems and engine downsizing, future overall fuel economy is expected to improve to about 25 litres/100 km. These savings from technical measures may be complemented by the use of speed limiters, storing and reuse of braking energy (mild hybridisation), and eco-driving.

The influence of driving patterns and traffic conditions on truck fuel consumption is very large. The fuel consumption of road carriers is not only determined by the technical efficiency of the vehicle, but also closely related to driving patterns, highway driving versus stop-start delivery cycles, and flow conditions on the transport network. Each stop increases the fuel consumption of heavy vehicles, and five stops on a trip of 10 km are enough to double the fuel consumption of a 40-tonne articulated combination compared to travelling the same distance at a constant speed.

Some regulatory or fiscal incentives may be required to deliver all of the improvement to fuel use and relatively small modifications to the regulation of truck dimensions could facilitate the aerodynamic changes and accelerate the rate of improvement.

NOTES

1. Final energy consumption is the amount of energy supplied to the final consumer for all energy uses. Sea and pipeline transport have not been included in the transport data used here.
2. Some countries in EU have decided to go beyond the EU target.
3. The United Parcel Service runs a fleet of liquefied natural gas trucks hauling parcels from its hub on the east Coast of the U.S. through the Mojave Desert to Las Vegas, Nevada. Propane and compressed natural gas buses are being deployed in the Bryce, Zion, and Grand Canyon National Parks in the U.S. to help preserve environmental quality.
4. What might be surprising is that rolling resistance changes with tyre wear. In general, tyre fuel economy is worst when tyres are new, gets better as they wear, and is best right before removing them.
5. Michelin Press Release 2006.
6. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

7. EPA Proposes New Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond, 26 May 2009.

8. Much of the work that has been done in the US to demonstrate the use of biodiesel, Fischer-Tropsch fuel, and other alternative fuels in heavy duty vehicles has been done with transit buses. The Federal Transit Administration of the U.S. Department of Transportation published "Biodiesel Fuel Management Best Practices for Transit" in 2007. This best practices guidebook is directly applicable to trucking industry. The guidebook addresses the common problems of low-temperatures, biodegradation, and lubricity.

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Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability

CHAPTER 6. HEAVY TRUCK SAFETY

Abstract

The chapter compares truck safety in countries with accessible and comparable safety data. The analysis highlights the crash patterns of heavy vehicles and discusses the evidence of the main contributing factors (speed, fatigue, and infrastructure).

6.1. Introduction

The regulation of heavy vehicles in relation to road safety focuses on managing the kinetic energy of vehicles and driver vigilance. This implies particular attention and to the respect of weight limits and secure loading of trucks and to speed management. Vigilance covers the regulation of working time and driving hours for commercial vehicles, as well as driver distraction and impairment related to alcohol, drugs and fitness to operate heavy vehicles. The most significant regulatory innovations currently in the process of development or deployment involve driver alert systems for the condition and operation of the vehicle, monitoring of driving hours and performance and automation of compliance with weight and other regulations and the opportunities for more flexible regulatory systems automation provides. As with other vehicles, maintenance of braking systems, tyres and other safety related equipment is critical.

This chapter compares truck safety in Member countries, examines trends in crash patterns, accident causation patterns, measures to improve the safety of trucks and new driver-support vehicle technologies.

This first part of the chapter compares truck safety in countries with accessible and comparable safety data. It seeks to remedy the current lack of international benchmarks of heavy truck safety. There have been a number of recent regional studies on aspects of heavy truck safety, but while these reports provide valuable insights into the issues and safety performance within the region studied, their applicability in other regions is uncertain. The *Large Truck Crash Causation Study* (LTCCS, FMCSA 2007) in the United States and the *European Truck Accident Causation Study* (ETAC, International Road Transport Union 2007) have been used as sources of valuable information for this project. Recent reports on the assessment of the safety benefits of improving interaction between heavy vehicles and the road system have also been consulted (Styles *et al*., 2007), together with reports on the impact of heavy vehicles after they have been admitted to the road system (Vierth *et al*., 2008) and forecasts in anticipation of their admission (Knight *et al.,* 2008). For the purposes of this chapter, a truck has been defined as a heavy commercial vehicle other than a bus with gross vehicle mass rating in excess of 4.5 tonnes or 3.5 tonnes (depending on the national definitions used).

Where it was possible to distinguish between rigid trucks (having motive power and load carrying capacity in the one unit) and articulated trucks (having the motive power in a separate unit from the load carrying capacity – also known as tractor-trailers), the articulated trucks have been analysed separately.

Articulated trucks are predominately employed for higher mass loads, and longer distance freight transport tasks than rigid trucks, making their comparative safety performance of particular interest for considering impacts of forecast growth in long distance freight activities.

Comparison has been limited to fatality rates because it is known that injury reporting criteria and completeness of reporting vary significantly between countries. Data was obtained for this study from Working Group participants, member countries of IRTAD (International Road Traffic Accident Database) and through the CARE database (Community database on Accidents on the Roads in Europe). Detailed data on truck crashes can be found in Annex B.

6.2. Recent trends in fatal truck crashes

Table 6.1 below shows the evolution in the number of fatalities from accidents involving a heavy vehicle between 1985 and 2005, and compares it with the evolution in the total number of road fatalities during the same period. With the exception of Canada, where there has been a 7% increase in the number of persons killed in a collision involving at least one heavy vehicle, there has been a remarkable decrease in these types of fatalities. This reduction is of the same order of magnitude as the overall decrease in road fatalities in general.

Table 6.1. **Number of fatalities in accidents involving heavy good vehicles**

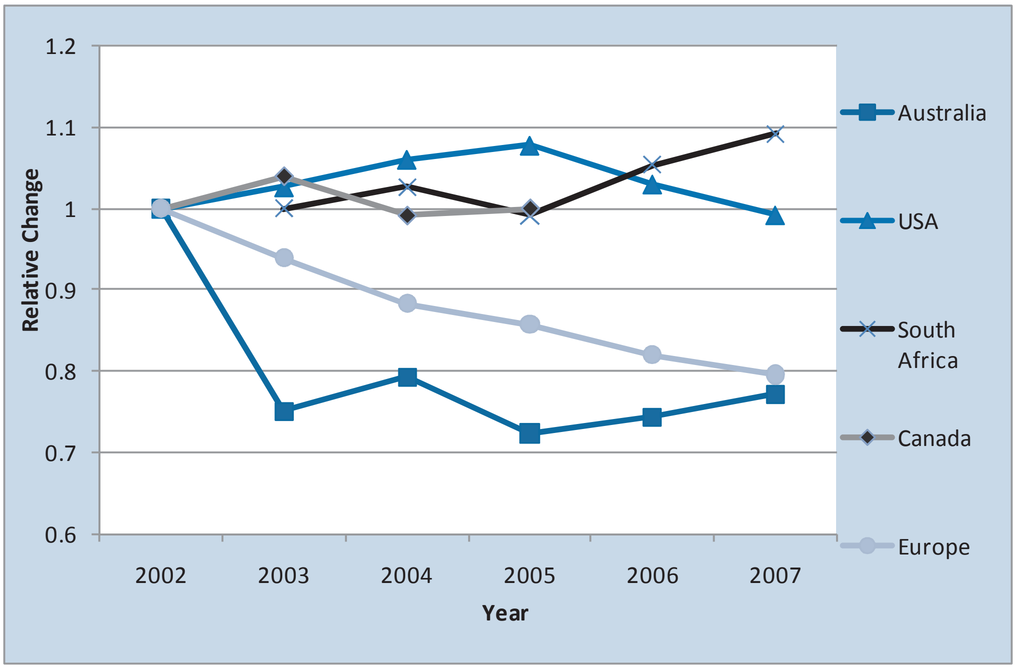
	Number of persons killed in accidents involving at least one heavy good vehicles						Total number of road crash fatalities		
	1985	1990	1995	2000	2005	Evolution 1985-2005	1985	2005	Evolution 1985-2005
Austria	218	233	186	148	129	-41%	1524	768	-50%
Canada	519	679	571	558	553	7%	4364	2 925	-33%
France	1 724	1 681	1 349	1 055	727	-58%	1 1387	5 318	-53%
Great Britain	811	883	597	560	486	-40%	5 165	3 201	-38%
Spain	1 084	1 565	952	921	473	-56%	6 374	4 442	-30%
Switzerland	101	90	88	78	45	-55%	881	409	-54%

Source: IRTAD.

The recent trend (2001-2007) in the number of fatal truck crashes is generally downward in Europe and Australia, but there has been little change in crash numbers for South Africa, the United States and Canada. Kilometres travelled by heavy trucks has increased significantly in all these regions, and for most countries examined the trend in fatal truck crashes per vkm is downward (Figure 6.1).

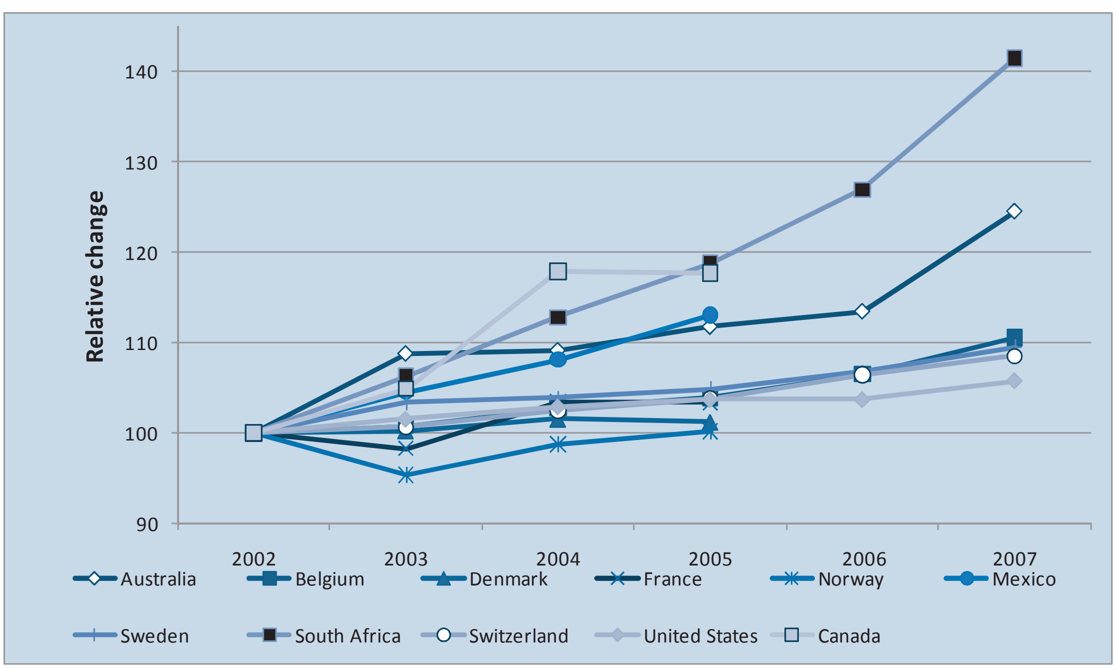
Various factors can influence the total number of fatal crashes, including total distance travelled, changes to vehicle safety standards, improvements to the road infrastructure, advanced IT systems and regulations relating to truck operations. Most fatalities in fatal truck crashes are not truck occupants, so these factors are relevant not only for truck operations, but also for all road users.

Figure 6.1. **Trends in fatal crashes in which a truck was involved**
2002 = Index 100 (except for South Africa, relative to 2003)



Source: Data provided by Working Group members from national datasets. Europe in this graph includes France, the Netherlands, Great Britain, Germany, Denmark, Switzerland, Sweden, Belgium and Austria.

Figure 6.2. **Recent trends in vehicle kilometres travelled by trucks, relative to 2002**
Index 100 = 2002



Source: Data provided by Working Group members from national datasets.

Impact of truck crashes on overall safety

The impact of truck crashes on the overall toll of road fatalities varies substantially between countries, from a low 9.1% in Poland to 24.9% in New Zealand. The extent to which the occupant of the truck is among the survivors of the fatal crash also varies, with only 4.1% of truck occupants killed in Denmark, and 4.2% in Switzerland, while 25.1% of deaths in South African fatal truck crashes are occupants of the truck. The low seatbelt use in South Africa (under 2% of fatally injured truck occupants wore a seat belt) undoubtedly contributes to this disparity. The higher rates for occupant fatalities in the United States, Australia, Canada and South Africa can be accounted for in part by the higher incidence of single vehicle fatal truck crashes than in other countries. The variable incidence of truck occupant fatalities is expressed as a fatality rate in Table 6.2 below.

Table 6.2. **Truck occupant fatalities per 100 million kilometres travelled (travel data from 2005)**

	Australia	Canada	Denmark	France	Great Britain	South Africa	Switzerland	United States
Truck occupant Fatalities per 10^8 km travelled	0.5	0.32	0.09	0.26	0.19	3.13	0.04	0.22

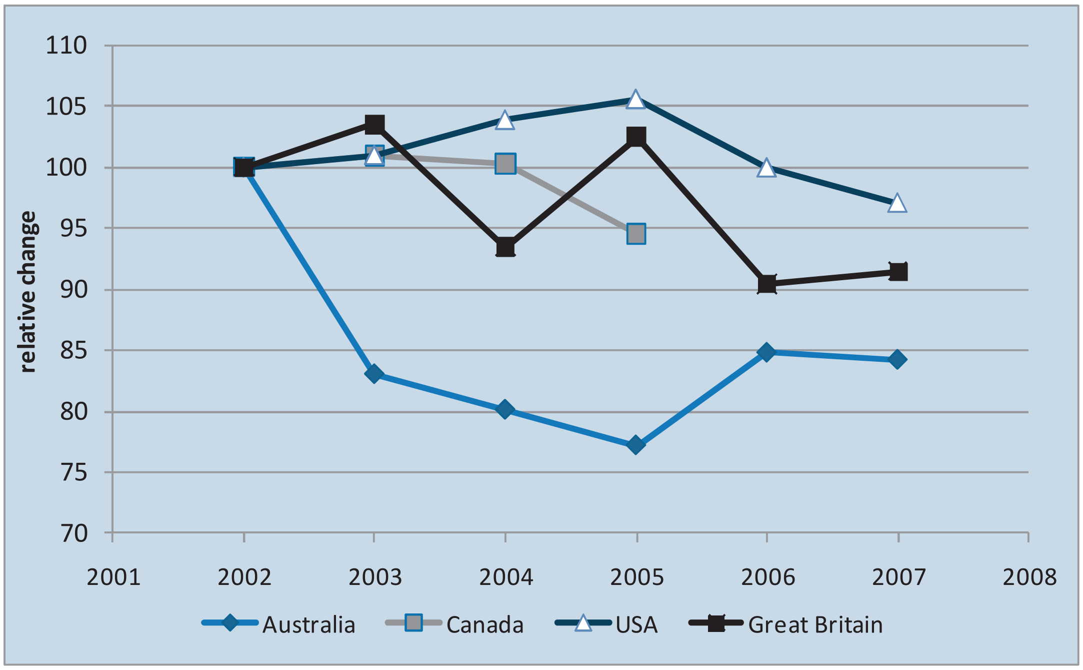
Source: Data provided by Working Group members from national datasets.

For all countries, the largest group of fatalities in fatal truck crashes are occupants of cars or other light vehicles, although unprotected road users (pedestrians, cyclists, motorcyclists) represent more than 20% of victims in Great Britain, South Africa, Israel and Switzerland, with 18.9% of Danish truck crash fatalities being cyclists and the same proportion of British truck fatalities being pedestrians.

Crashes by vehicle category

Few countries collect national crash information that can separate crashes involving articulated vehicles and those involving single unit (rigid bodied) trucks. Where such separation is available, there is considerable variation in the proportion of serious road crashes involving each type. Articulated vehicles are involved in the majority of fatal truck crashes in the United States (67%), Canada (67%) and Australia (63%), but in only a quarter to a third of fatal crashes in other countries such as Switzerland, Denmark, Israel and Japan. This may reflect a lower proportion of articulated trucks in use in these countries. France (49%) and Great Britain (46%) fell between the other two groups.

Figure 6.3. **Recent trends in fatal crashes in which an articulated truck was involved, relative to 2002 (2002 = Index 100)**



Source: Data provided by Working Group members from national datasets.

These data may reflect the different configuration of heavy trucks employed for the freight task in these regions, with rigid truck plus trailer being more widely used in Europe for heavy loads that would be carried by tractor-trailer combinations in North America and Australia. In Denmark, for example, between 2002 and 2006, 32% of vehicles in fatal crashes were tractor and tractor plus trailer combinations, but a further 28% were rigid truck plus trailer combinations. In the Netherlands, however, only 16% of vehicles in fatal crashes had an unladen mass of 12 tonnes or more, indicating a much lower involvement of the largest heavy trucks in fatal crashes compared with North America and Australia. The distribution of total road freight tonne-kilometres between long distance inter-urban trips (in large trucks or truck-trailer combinations) and urban distribution in smaller trucks will also affect the type of trucks involved in crashes.

For all countries for which data is available, articulated heavy vehicle registrations and vehicle kilometres travelled have risen over the course of the 21st century, and for all countries other than the United States and Canada (vehicle registrations) they have risen at a greater rate than for the heavy vehicle fleet as a whole.

Comparison of fatal crash rates for trucks

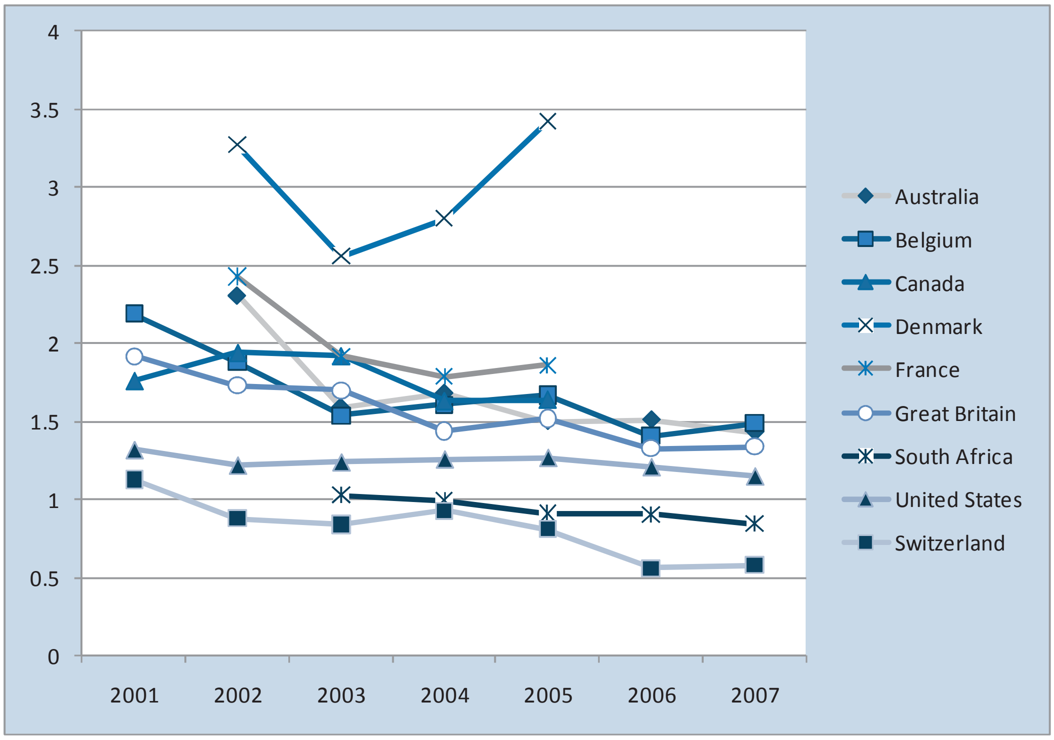
In general, fatalities from accidents involving trucks have not increased to match the growth in heavy truck travel. Table 6.3 shows that except in the case of Denmark, the rate of fatal crashes involving a truck per 100 million kilometres travelled has fallen or remained static in all of the countries for which data is available.

Table 6.3. **Fatal truck crashes per 100 million kilometres travelled**

Year	2001	2002	2003	2004	2005	2006	2007
Australia	-	2.31	1.59	1.68	1.5	1.51	1.43
Belgium	2.19	1.88	1.54	1.61	1.67	1.41	1.49
Canada	1.76	1.94	1.92	1.63	1.64	-	
Denmark	-	3.27	2.56	2.8	3.42	-	
France	-	2.43	1.92	1.79	1.86	-	
Great Britain	1.92	1.73	1.7	1.44	1.52	1.33	1.34
South Africa	-	-	10.29	9.95	9.12	9.08	8.44
United States	1.32	1.22	1.24	1.26	1.27	1.21	1.15
Switzerland	1.13	0.88	0.84	0.93	0.81	0.56	0.58

Source: Data provided by Working Group members from national datasets.

Figure 6.4. **Fatal truck crashes per 100 million kilometres travelled 2001-2007**



Note: Figures for South Africa divided by 10 (see table 6.3 for true data).
Source: Data provided by Working Group members from national datasets.

Similarly, Table 6.4 shows a consistent decline in fatal crashes involving an articulated truck per 100 million kilometres travelled.

Table 6.4. **Fatal articulated truck crashes per 100 million kilometres travelled**

Year	2001	2002	2003	2004	2005	2006	2007
Australia	2.74	3.15	2.43	2.28	2.09	2.36	2.08
Canada	1.85	1.96	2	1.78	1.6		
Great Britain	1.59	1.47	1.54	1.32	1.47	1.27	1.26
United States	1.5	1.44	1.44	1.45	1.46	1.4	1.33

Source: Data provided by Working Group members from national datasets.

Comparison of fatality rates for trucks and all vehicles

Despite the substantial growth in the number of kilometres travelled by heavy vehicles in recent years, most countries have also experienced declining or static numbers of people killed in heavy vehicle crashes.

Table 6.5 shows that the number of persons killed in truck crashes per 10 000 vehicles varies considerably. These differences in rate will be strongly influenced not only by local safety conditions, but also by the amount of truck travel undertaken by vehicles not registered in the country where the crash takes place. For example, in Australia practically all truck traffic, and thus truck accidents, involves vehicles registered in Australia. However, Germany has a lot of transit traffic where vehicles registered in different countries travel through Germany on their way to other destinations and have accidents in Germany. This would tend to increase the crash rate per 10 000 vehicles in Germany compared with Australia.

An indicator of the extent to which the truck fatality risk is greater than the overall road fatality risk can be obtained from considering the ratio of the truck fatality rate to the total road fatality rate. The ratio varies from a low of 1.9 in Switzerland to a high of 18.9 in Belgium (see table 6.5). The differences between the fatality rate for trucks are much more pronounced than those for all vehicles. Australia, for example, has a similar all-vehicle fatality rate to Denmark, but a substantially lower truck fatality rate. This may reflect a number of factors. Notably, the three countries with the lowest per vehicle fatality rates (Switzerland, Australia and the United States) are also those with the lowest average kilometres travelled per vehicle. Likewise, the European country with the highest per vehicle fatality rate (Belgium) also has one of the highest average kilometres travelled per vehicle. Increased exposure cannot be the entire explanation however, as South Africa is among the lower average kilometres travelled per vehicle, despite having the highest per vehicle fatality rate and Sweden one of the higher average kilometres travelled, despite a comparatively low fatality rate.

Table 6.5. **Ratio of fatality rates: persons killed in truck crashes per 10 000 vehicles registered vs. persons killed in any crash per 10 000 vehicles registered**

Country	Trucks		All vehicles		Ratio of fatality rates for fatal crashes involving trucks: all fatal crashes
	Fatalities per 10 000 registered vehicles	Year	Fatalities per 10 000 registered vehicles	Year	
Switzerland	1.5	2005	0.8	2005	1.9
South Africa	52.4	2005	21.0	2005	2.5
Germany	3.1	2005	1.0	2005	3.1
United States	6.2	2005	1.8	2005	3.4
Australia	5.6	2005	1.2	2005	4.6
Canada	8.8	2005	1.5	2005	5.9
Netherlands	7.1	2005	0.9	2005	7.9
France	12.1	2005	1.4	2005	8.7
Sweden	8.1	2005	0.9	2005	9.0
Great Britain	11.2	2005	1.0	2005	11.5
Denmark	18.1	2005	1.3	2005	13.9
Belgium	34.0	2005	1.8	2005	18.9

Table 6.6 shows that the number of persons killed in truck crashes per 100 million kilometres of truck travel is lowest in Switzerland (0.8), while the United States (1.5), Sweden (1.6), Australia (1.7), Great Britain (1.7) and Belgium (1.9) have somewhat higher, but similar, rates. The rate for South Africa (12.5) is considerably higher.

Table 6.6. **Ratio of fatality rates: persons killed in truck crashes per 100 million km travelled vs. persons killed in any crash per 100 million km travelled**

Country	Trucks		All vehicles		Ratio of fatality rates for fatal crashes involving trucks: all fatal crashes
	Fatalities per 100 million vehicle kilometres travelled	Year	Fatalities per 100 million vehicle kilometres travelled	Year	
South Africa	12.5	2005	11.3	2005	1.1
Switzerland	0.8	2005	0.7	2005	1.2
Belgium	1.9	2005	1.2	2005	1.5
United States	1.5	2005	0.9	2005	1.6
France	2.0	2005	1.0	2005	2.0
Germany	1.5	2006	0.7	2006	2.1
Australia	1.7	2005	0.8	2005	2.2
Canada	2.0	2005	0.9	2005	2.2
Sweden	1.6	2005	0.6	2005	2.7
Great Britain	1.7	2005	0.6	2005	2.8
Denmark	3.0	2004	0.8	2004	3.8

Source: Truck data provided by Working Group members from national datasets All vehicles data derived from IRTAD 2005 values (except South Africa and Great Britain. Great Britain was derived from National Accident and Registration statistics.).USA data from FHWA Highway statistics 2005.

The ratio of truck fatality rate to the total road fatality rate is an indicator of the extent to which the truck fatality risk is greater than the overall road fatality risk. The ratio varies from a low of 1.1 in South Africa and 1.2 in Switzerland to a high of 3.8 in Denmark (see table 6.6). The number of countries for which comparable data is available is small, but a consistent picture emerges of higher numbers of persons killed per km travelled by trucks than is the case for all vehicle travel. Compared to the per registered vehicle rates, the small amount of variation between individual countries is notable. This is perhaps a reflection of the amount of truck travel (and crashes) involving vehicles registered in countries other than to which the crash data pertains.

Table 6.7. **Ratio of fatality rates: persons killed in truck crashes per 100 million km travelled vs. persons killed in any crash per 100 million km travelled 2005 vs. 1998.**

Country	Trucks: Fatalities per 100 million vehicle kilometres travelled		All vehicles: Fatalities per 100 million vehicle kilometres travelled		Ratio of fatality rates for fatal crashes involving trucks: all fatal crashes	
	2005	1998	2005	1998	2005	1998
Australia	1.7	2.5 (1996)	0.8	1.2 (1995)	2.1	2.1
Canada	2.1	2.1	0.9	0.94	2.3	2.2
France	2.0	4.4 (1995)	1.0	2.9 (1995)	2.0	1.5 (1995)
United States	1.5	1.7	0.9	0.98	1.6	1.7
Germany	1.5 (2006)	2.2	0.8	1.24	1.9	1.8
Great Britain	1.7	2.1	0.6	0.7	2.6	2.8
Sweden	1.6	3.1	0.6	0.8	2.7	3.9

Source: Truck data provided by Working Group members from national datasets 1998 data from Vulcan *et al.* (2002) except Great Britain derived from National Accident and Registration statistics.

A similar analysis conducted in 2002, using data from 1996-1998 (Haworth *et al.,* 2002.) shows there have been significant improvements in both heavy vehicle and general road safety in this period. Sweden, France, Australia and Germany have substantially reduced the number of truck crash fatalities per vehicle kilometres travelled over this period. However, only Sweden has substantially improved the relative rate of truck fatalities. It would appear that for most countries, the measures which have led to the differences in overall crash rates over this period have been similarly effective for both heavy and light vehicles.

It is worthy of note that the above analysis, being based on fatal crashes, is not necessarily indicative of the much more numerous non-fatal crashes in which trucks are involved. Data on non-fatal crashes is not as readily obtainable as fatal crash data, but consideration of the data available from the United States suggests that the relative risk of crash involvement may be significantly different for non-fatal crashes, with trucks showing a lower relative crash risk in these less-severe crashes (Figure 6.5a and 6.5b). This suggests that trucks are less likely to become involved in a crash compared with other vehicle types but, once involved in a crash, it is more likely to be fatal.

On the evidence available, it is difficult to be certain of the causes of the relative improvements in Sweden and France. A plausible explanation for the changes can, however, be found in major road safety initiatives in each country during the past decade.

In the case of France, the deployment of a programme of automated speed enforcement from 2003 resulted in substantial reductions in over-speeding, both by heavy trucks and lighter vehicles (Carnis *et al*., 2008). This programme was concentrated on autoroutes and main roads, with 76% of fixed speed cameras being located on these road classes (ONISR, 2006). The subsequent improved speed compliance coincided with a reduction of the number and proportion of fatal truck crashes on these routes (from over 49% of all fatal crashes and over 45% of injury crashes in the 2 years prior to the programme commencing, to under 40% of fatal and injury crashes in 2006).

In the case of Sweden, the progressive upgrade of sections of the high-speed, high-volume road network to the standard of 'collision-free roads' within the Swedish Vision Zero framework has resulted in a reduction in fatal crashes on these roads of over 75% (Carlsson, 2009). The installation of flexible barriers on these roads eliminates head-on collisions – a major component of fatal heavy truck crashes.

Both these examples are of road safety measures of proven effectiveness that were implemented in places where heavy truck traffic volumes, and hence heavy truck crashes, were high, rather than through specific actions targeting heavy trucks.

Figure 6.5a. **US comparative fatal crash rates 2000-2007**

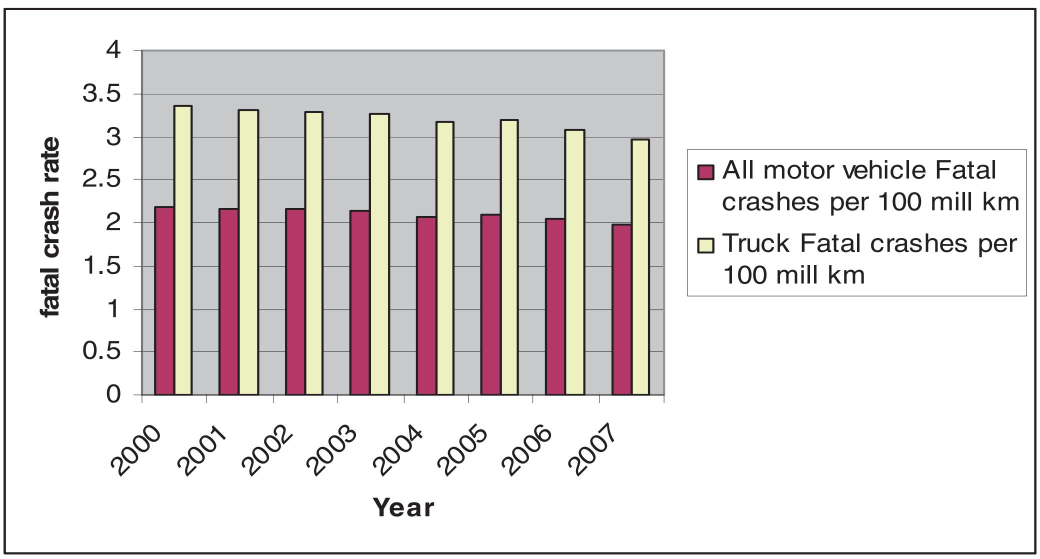
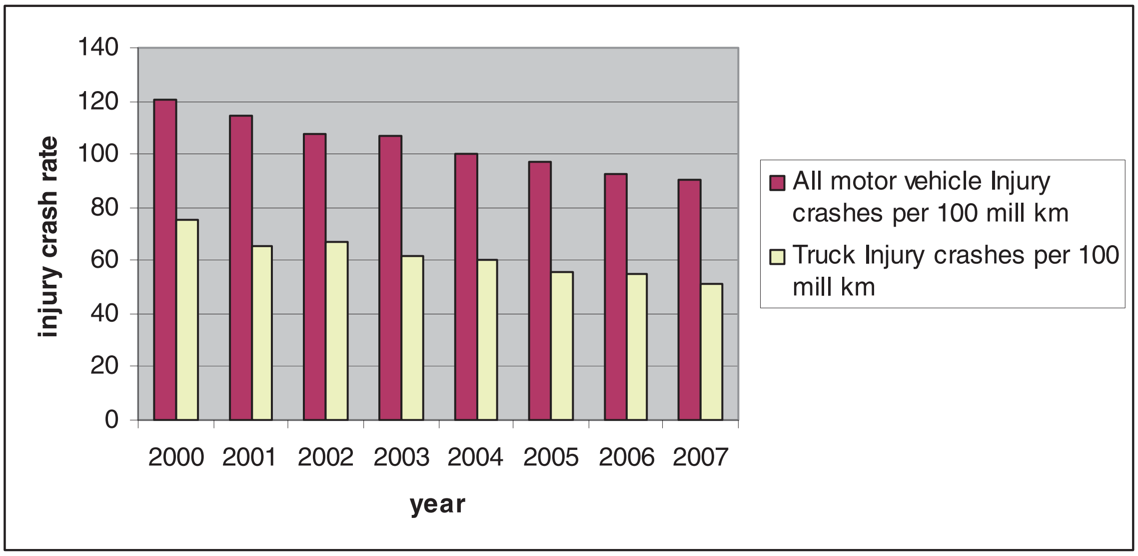


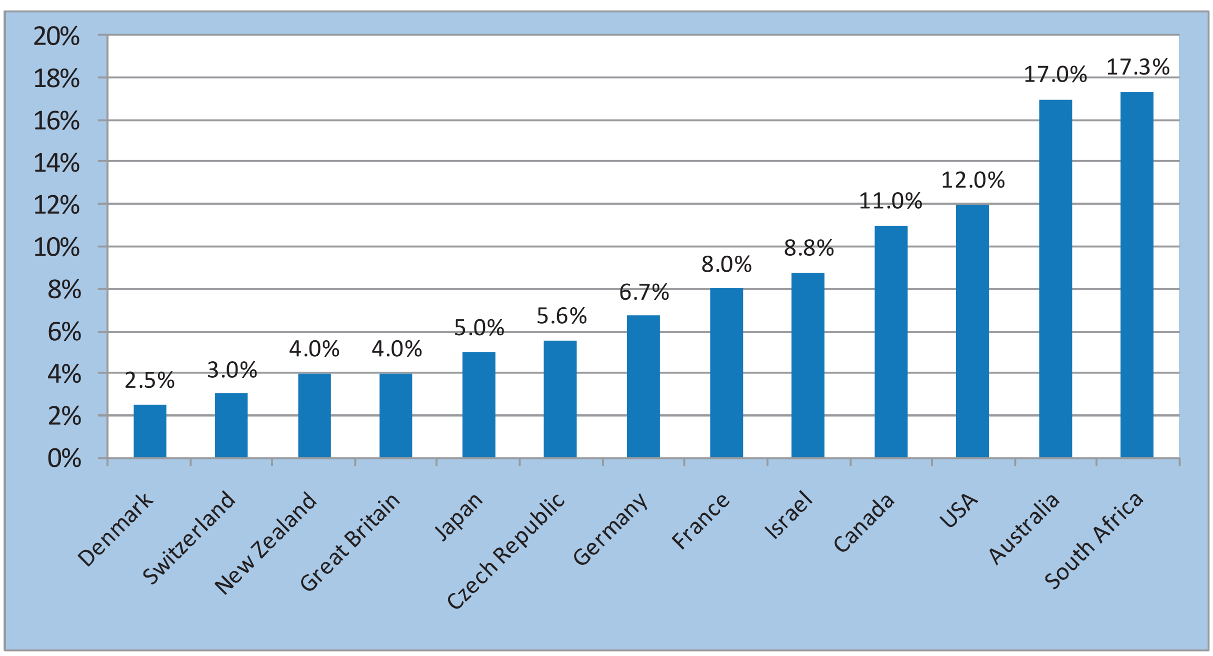
Figure 6.5b. **US injury crash rates 2000-2007**



6.3. Truck crash patterns

Single vehicle crashes account for between 2 and 17% of fatal truck crashes. The highest rates are mainly found in countries such as Australia, the United States, and Canada where very long distances are covered. These are mainly run-off road accidents typical of roads in sparsely populated areas.

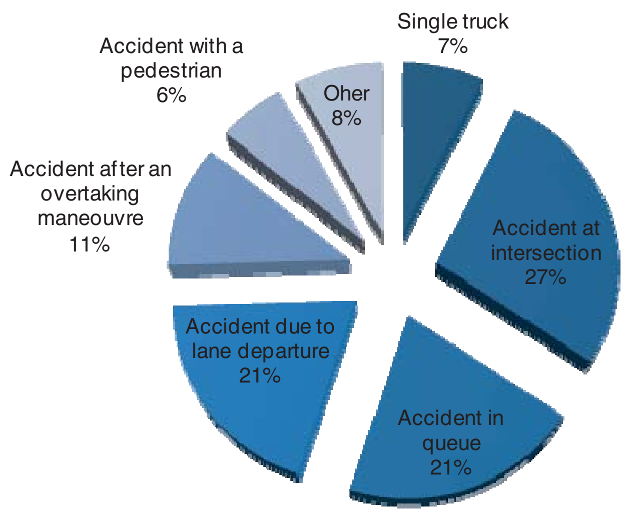
Figure 6.6. **Single vehicle fatal truck crashes (excluding pedestrian fatal crashes) as a percentage of fatal truck crashes**



Source: Data provided by Working Group members from national datasets.

IRU (2007) suggested that 7.4% of European accidents involving heavy vehicles were single truck accidents, while 92.6% involved another road user (passenger car, pedestrian, etc.). In this latter case the most common crash types are: Accident at intersection, accident in queue, accident due to lane departure, accident following an overtaking manoeuvre, accident with a pedestrian (figure 6.7).

Figure 6.7. **Crash types**



Source: IRU.

The LCSS study made estimates of the type of crashes involving trucks at national level. Table 6.8 shows the number and percentage of crashes by type, with slightly different results than in the IRU study.

Table 6.8. **Estimated number of trucks in crashes by crash type in the United States for the year 2005**

Type of crashes	Number	Percentage
Rear end	33 000	23%
Ran off road	25 000	18%
Side Swipe, same direction	15 000	10%
Rollover	13 000	9%
Turning across path/into part	11 000	8.0%
Intersecting vehicles, straight paths,	8 000	5.8%
Side Swipe, opposite direction	6 000	4.6%
Head on collisions	4 000	3.0%
Hit object in road	3 000	1.8%
No impact (fire, jack-knife, other)	1 000	0.9%
Backing into other vehicles		0.3%
Other crash type	22 000	15.5%

Rear-end collisions are a major crash scenario in high traffic environments. They are estimated to represent around 30% of all crashes with heavy trucks on central European roads, with no, or inadequate, driver reaction in around 60% of the cases (ETSC, 2001). US research identified rear-end collision as one of the major risks identified by heavy vehicle operators (FMCSA, 2007), and almost 21% of crashes investigated in the ETAC study occurred between vehicles in a queue.

British data shows that rear end collisions are generally a lower severity collision type, representing a greater proportion of slight accidents than fatal accidents (TRL, 2009). The importance also varies by accident type, with about 36% of truck occupant fatalities resulting from the front of the occupant's truck colliding with the rear of another truck. This compares with approximately 13% of car occupant deaths in truck-car collisions resulting from the car colliding with the rear of the truck, and approximately 9% resulting from the truck colliding with the rear of the car. However, truck occupants represent just 13% of all those killed in accidents involving trucks and car occupants represent approximately 45% (the remainder being vulnerable road users and the occupants of other vehicles such as vans and buses). In total, the three groups of front to rear crashes quoted above represent approximately 15% of all those killed in accidents involving trucks; a considerably lower proportion than found by other studies of all truck crash severities.

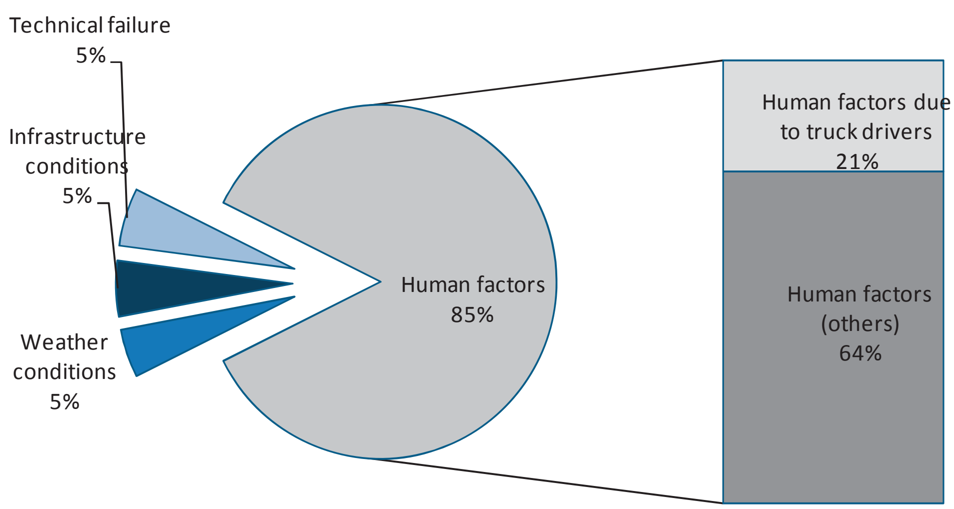
6.4. Accident causation factors

Human factors

It has been clear for more than 30 years that driver errors are implicated in the vast majority of road crashes. The importance of human factors in the context of crashes involving commercial vehicles (CMV) was also confirmed by the results of the *Large Truck Crash Causation Study* (LTCCS) (FMCSA, 2007) in the United States and the *European Truck Accident Causation Study* (ETAC) (International Road Transport Union, 2007).

The ETAC study found that human factors are involved in 85.2% of crashes (25% of which were classified as being caused by the HV drivers), with the remaining 15% split between vehicle (5.3%), infrastructure (5.1%) and weather conditions (4.4%). The authors identified *non-adapted speed*, *failure to observe intersection rules* and *improper manoeuvre when changing lanes* as high-risk behaviours that should be targeted for interventions.

Figure.6.8. **Main causes of accidents involving heavy duty vehicles**



Source: IRU.

The percentage of fatal truck crashes which occur at night varies from 48% for South Africa and 43% in Japan, to 10% for Switzerland and 14% in the Netherlands[1]. In this analysis, and in the absence of information on daylight vs. darkness, night is arbitrarily designated as 6 pm to 6 am. This is clearly a less valid assumption as one moves further from the equator, but may still be indicative of potential fatigue/circadian rhythm induced crashes that may be relevantly compared in the light of differences in driving hours/fatigue management regulations. It is, for example, likely that a contributor to Switzerland's low night time crash rate is its prohibition on driving of heavy trucks between 22:00 and 05:00 on Sundays.

Fatigue and drug use by drivers are of widespread concern – particularly for long-haul operations – with regulations in Europe, North America, Australia and elsewhere being developed to address these two safety issues. In the absence of routine post-crash drug testing, or any objective measure of post-crash fatigue, gathering evidence for the involvement of either factor in a crash is problematic. In-depth studies have found that driving impaired by drugs or fatigue are relatively unlikely to be identified as factors for crashes, however this cannot be interpreted as indicating that they are not major safety concerns. Both the effects of drug use and the effects of fatigue on cognition are undeniably contributing factors in cases where other errors are involved, such as hazard-recognition errors, inattention or decision-making error.

The US Violations Severity Assessments Study (FMCSA, 2008) provides an estimate of the relative risk of both truck crash involvement and truck crash severity for specific roadside and compliance review offences by truck drivers or operators. It found the riskiest traffic enforcement regulations to be failure to exercise caution in hazardous road conditions; reckless driving; ill or fatigued driver; improper turns; failure to yield right of way (FMCSA 2008). These results are consistent with the LTCCS study, which found illness/fatigue, illegal manoeuvre, and travelling too fast for conditions to have statistically significant associations with the assignment of the critical reason for the crash. These factors were also identified as significant crash contributors in the ETAC study.

The LTCCS study

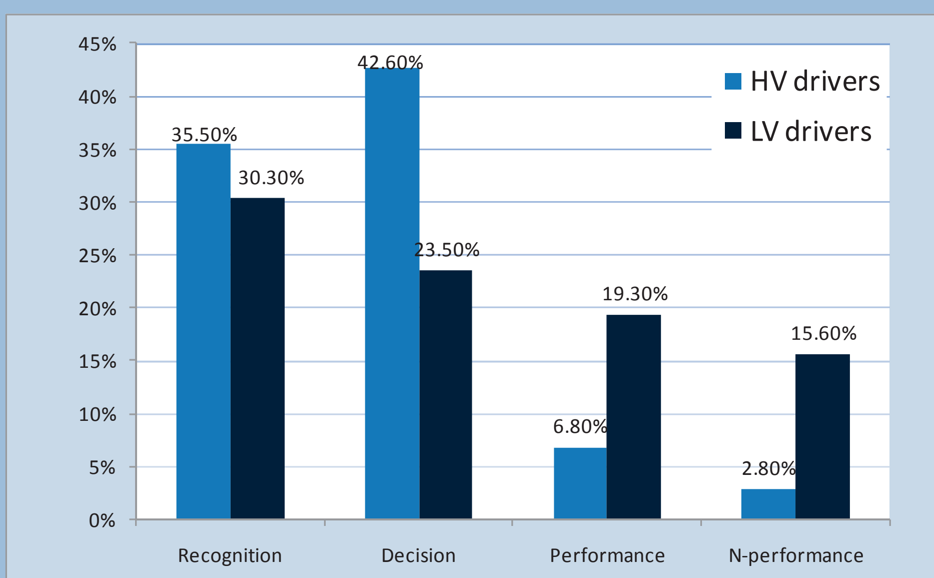
The LTCCS investigated 967 crashes between 2001 and 2003, involving 1 127 large trucks and 959 non-truck motor vehicles, resulting in 251 fatalities and 1 408 injuries. More than 1 000 factors were collected for each crash. In brief, the results show that driver factors are identified as the critical reason in 87% of the cases, with the remaining 13% split between vehicle, weather and roadway problems. Recognition (perception and attention) and decision errors (mainly risky and aggressive driving) were the most prominent problems, representing 66.4% of the critical reasons for *all crashes* (single and multiple-vehicle crashes). When only multiple-vehicle crashes involving a truck and a car are considered, these two factors represent 78% of heavy vehicle (HV) drivers' critical reasons and 54% of light vehicle (LV) drivers' critical reasons.

Furthermore, as can be seen in figure 6.9:

- Decision errors are a greater factor for HV drivers' critical reasons than for LV drivers;
- Recognition errors explain more of HV drivers' errors than LV driver errors;
- LV drivers produce more performance errors than HV drivers, as well as more non-performance errors (associated with substance-impaired driving or by fatigue).

The low prevalence of non-performance errors for HV drivers in multiple-vehicle crashes in the LTCCS study does not imply that fatigue is not a significant problem. It is in fact an associated factor in 7.5% of *all crashes* for HV drivers (14.7% for LV drivers). Moreover, the contribution of fatigue to other errors – mainly inattention – is hard to quantify but is certainly significant.

Figure 6.9. **Driver errors in the LTCCS**



Source: prepared from data in FMCSA (2007).

These results are important for developing a risk-based strategy for intervention. They suggest that decision errors represent a primary behavioural target for HV drivers, followed by recognition errors.

Decision and recognition errors

An important result to consider from the research literature is that reckless, risky or aggressive driving behaviours are the main decision errors committed by HV drivers. This was clearly shown in the ATRI CMV crash prediction study (Murray *et al.,* 2005), where the presence of a reckless driving violation is the stronger predictor, increasing subsequent crash risk by 325%. In the Sullman *et al.* (2002) study, the self-reported commission by HV drivers of deliberate unsafe or risky driving behaviours is statically associated with crashes, whereas the *errors* and *lapses* factors are not. In the Craft (2008) analyses of LTCCS data, *following too closely* and *illegal manoeuvres* are the errors with the highest risk ratio for HV drivers. In the Hanowski *et al.* (2000) and the Dingus *et al*. (2002) truck naturalistic studies, speeding/aggressive-driving behaviours represented respectively 32% and 47.6% of the critical reasons for the occurrence of critical events for which HV drivers were responsible.

The contribution of recognition errors to the production of crashes is well documented in general road safety, with the Tri-level Indiana study (Treat *et al*.,1979) and the UDA study (Hendricks *et al.*, 1999) rating them as first causes for crashes. With regards to large truck safety, significant findings come from the LTCCS, where recognition errors rank second to decision errors for HV drivers and first critical reason for LV drivers involved in large truck crashes.

Implications for interventions

If one's objective is to use crash causation data to steer the development of strategies for intervention, there is a need to go further than simply classify driver errors. The real questions that should be asked are the following: Why do drivers commit these errors? Why do they fail to perceive, recognise and understand the driving situation? Why do they deliberately deviate from safe driving practices and adopt risky behaviours? Why do they fail to perform the driving manoeuvre that they intended to do? Human error is, of course, an inherent characteristic of any human controlled system, and it is unrealistic to expect that safety can be improved solely by exhorting road users to not make errors or misjudgements (Reason, 1990). Nonetheless, instrumented vehicle studies of commercial driving have found wide variations in the incidence of driver error within groups of subject drivers, with 12% of drivers responsible for 36% of safety incidents (Knipling *et al*., 2004). Surveys of fleet safety managers and other experts revealed similar results (Knipling *et al*., 2004).

The key is to identify the processes at the root of recognition, decision, performance and non-performance errors, as well as the mediating factors that impact on these processes. Once this is done, it becomes possible to identify the best interventions that should be used to counteract the effects of these factors.

Potential interventions for recognition and decision errors include human factors engineering of the driving task (road, vehicle), ITS driver support, ITS monitoring of high-risk behaviours, management/detection of fatigue and hypovigilance, comprehensive driver training (including use of simulators), testing/evaluation of driver profile, focused clinical/educative interventions aimed at high-risk drivers, motivational interventions targeting attitudinal and behavioural changes at the carrier level, enforcement, substance abuse screening, etc. It is also worth noting that errors of the types described above are an inevitable feature of any human controlled activity. While the frequency of errors can be reduced, and systems can be developed to detect and recover from errors, the most effective approach to preventing fatalities is one that recognises that errors will occur, and ensures that the consequences of such errors are minimised.

Road factors

A number of road factors that contribute to truck crashes have been identified in earlier research. These include lane width, which must be sufficient to provide trucks with adequate turning space, thus decreasing the probability of 'same direction side swipe' crashes in particular.

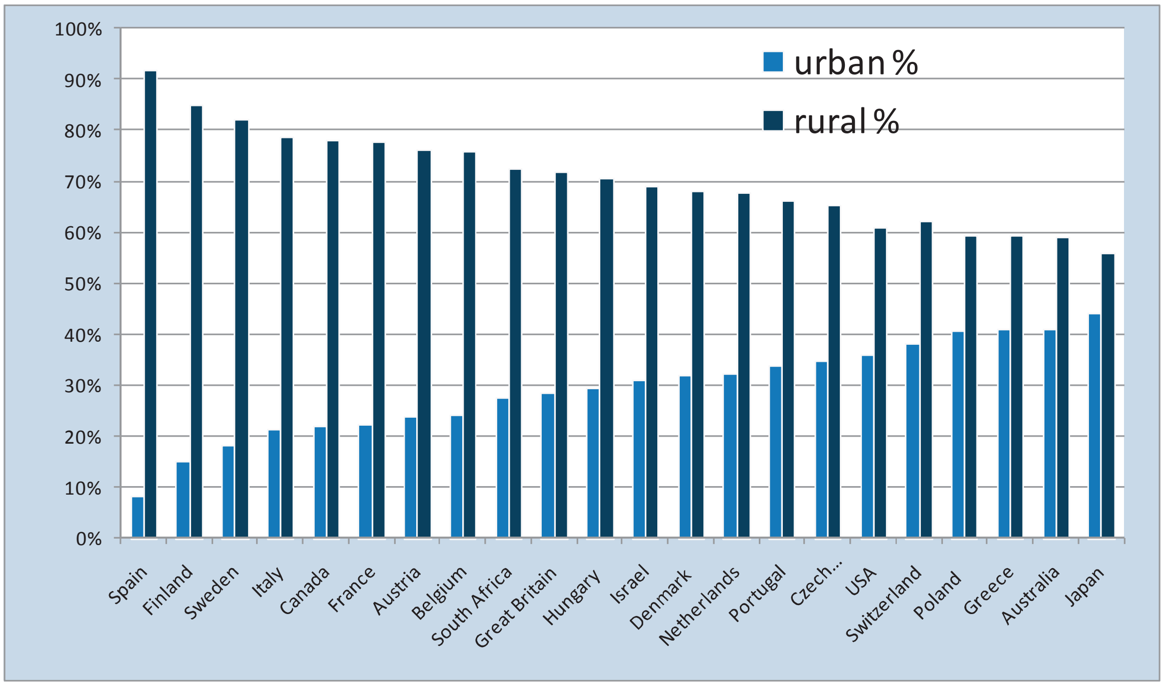
Horizontal and vertical alignment (road geometry) is a particular problem when combined with wet or other slippery conditions and low light, especially for articulated vehicles (Styles *et al*., 2007). It also appears from some individual country research that a significant proportion of the heavy vehicle run-off-road crashes that occur on bends may be fatigue related.

In both urban and rural areas, uncontrolled access onto roads with high traffic volume can be problematic, particularly where light vehicle drivers fail to allow for heavy vehicles' comparatively longer stopping distances. Related to this is the problem which can be caused by lack of adequate warning of signalised intersections to allow heavy vehicles to avoid rear-end collisions with preceding vehicles.

McLean (2001) reviewed a range of sources giving crash risk estimates for different road types in rural areas. He found that for all casualty crashes, the crash risk on freeways (expressways) was typically between quarter and half the crash risk of two-lane roads, while non-freeway multi-lane divided roads had a crash risk that was typically forty five to eighty percent of that for two-lane roads. Greater detail of crash location and travel volumes by road type will be required to determine the extent to which these issues account for the differences between the countries compared.

The road environment can significantly affect the likelihood and consequences of a serious crash. Assessing the location of truck crashes can identify clustering of crashes at higher risk locations. Intersections are a particularly high risk situation. Taylor *et al.* (2003) identified a relationship between casualty crashes on rural high speed roads and the density of sharp bends and the density of minor crossroad junctions. These increased crashes by 13% and 33% respectively per additional bend/crossroad per kilometre.

Figure 6.10. **Fatal truck crashes by rural or urban location**



Source: CARE database 2002-2006, plus data supplied by participating nations from national data bases 2002-2006.

The location of fatal truck crashes varies to a surprisingly large extent between countries. Both Denmark and the Netherlands record over 40% of fatal crashes as occurring at intersections, while France, Portugal, Spain, Poland and Austria have less than half that proportion, with Greece recording fewer than one in ten fatal truck crashes at an intersection.

The high proportion (over 40%) of crashes in urban areas shown for Australia and Japan is considerably higher than the lower (under 30%) for France, Great Britain, South Africa and Canada. In the case of Australia, this may reflect the higher urban speed limit there – particularly the number of 100 km/h limited motorways within urban areas which carry significant volumes of freight vehicles and urban commuter traffic. The juxtaposition of the high proportion of urban crashes (41%) and the low proportion of crashes on roads with speed limits below 80 km/h (17%) encourages this view.

Truck configuration

The configuration of a heavy freight vehicle – rigid vs. articulated, number of trailers, type of trailer coupling, type of axle assembly – can have a strong impact on its stability and hence its propensity to be involved in a crash. This is particularly significant for crashes on high speed and rural roads. Crashes in urban areas, with lower speed limits and higher volumes of pedestrians, cyclists, motorcyclists and cars, are not so strongly related to high-speed stability.

A full discussion of the impact of vehicle configuration on stability and safety related performance is beyond the scope of this chapter. The topic has, however, been extensively investigated elsewhere.

The US Transportation Research Board (TRB, 1990) undertook an extensive investigation of issues associated with heavy truck configuration on safety performance as part of a report on truck weight regulation. This report highlighted a range of safety relevant dynamic and static vehicle design parameters, a number of which are adversely affected by gross vehicle mass if compensatory design changes are not made. Australia's National Road Transport Commission undertook a series of investigations of critical factors for safe performance of heavy trucks as part of the development of performance-based standards to guide, *inter alia*, the making of such changes (NRTC 1999a, 1999b, 2000a, 2000b). These standards are further described in Chapter 9, where they are applied for the comparative evaluation of heavy truck safety.

The two major recent studies of heavy truck crash causation, the US LTCCS (FMCSA 2007) and the European ETAC (IRU 2007), both identified specific vehicle features as being of major concern. The LTCCS found braking problems (failure or mis-adjustment) to be factors in 29% of heavy truck crashes, and load shifting, although less common, to be associated with a 56-fold relative crash risk. The ETAC study identified visibility of blind spots for the truck driver as a major issue, with almost half of the crashes involving pedestrians or two-wheelers having poor visibility from the truck driver's driving position as a factor. A study of the circumstances of blind spot crashes in the Netherlands identified solutions and measures that can reduce the number of blind spot crashes.

This study found that the most dangerous black spot is not at the side of the truck, but in front of the truck at the right side. The use of a front view mirror (Class VI 'front mirror' in Directive 2003/97/EC) or a front camera allows this area to be "seen".

Both the performance of the driver and the condition of the road infrastructure are significant factors in determining crash rates. Trucks with basically good handling and stability properties may have poor safety records if they are operated by inexperienced or unsafe drivers, or used on lower standard roads (TRB 1990).

Of particular interest in the current report is the comparative safety performance of articulated single trailer, and articulated multi-trailer, heavy freight vehicles. Limitations in data collection make this comparison difficult in the majority of countries investigated, although individual research studies have shed some light on the subject.

Delaney (2007), using data collected from truck vs. passenger car crashes in Australia, modelled the impact on urban passenger vehicle occupants of replacing the current Australian fleet of articulated trucks with rigid trucks, without changing the amount of freight carried. The modelling estimated an 18% increase in crashes over six years if articulated trucks were replaced by rigid trucks on metropolitan roads, assuming a continued linear improvement in the prevailing trend in crash rates for the different heavy vehicle classes (or a 2% increase if heavy vehicle crash rates remained constant). A similar analysis by Vierth *et al*. (2008) considered the impact on road safety in Sweden if all trucks and trailer combinations over 40 tonnes were to be replaced with smaller EU-authorised vehicle combinations of 30-40 tonnes. This study estimated an annual increase of 12 extra fatalities per year if the entire freight task performed by the larger vehicles was to be undertaken by a greater number of smaller ones.

Woodrooffe (2004), in studying crash rates of multi-combination vehicles in Alberta, Canada, concluded that multi-trailer articulated heavy trucks operating under a special permit programme had superior safety performance, as measured by crash rate, than the common tractor semi-trailer operating under normal policy on the same roads. The study results tend to support the argument that imposing restrictions on LCV movements during adverse conditions is an important part in managing safety risk. The work of Regehr *et al.* (2009) in examining comparative safety performance of combination vehicles with one, two, or three trailers operating on the Canadian section of the CANAMEX trade corridor, reached similar conclusions. Regehr *et al.* found that turnpike doubles have the lowest collision rate of all articulated truck types (16 collisions per 100 million vehicle-kilometres of travel or VKT) followed by Rocky Mountain doubles (32 collisions per 100 million VKT) compared to the collision rates for tractor semitrailers (42 collisions per 100 million VKT) and shorter tractor double trailers (44 collisions per 100 million VKT).

Knight *et al*. (2008) describe substantially higher fatal crash risks for drawbar linked truck trailer combinations than for rigid single units or B-coupled truck-trailer combinations. Their data was restricted to UK crashes, and they note the caution needed when interpreting their results due to the small numbers for both crashes and exposure data of these vehicles. They also observed a weak relationship between non-fatal crash rate and GVM for articulated heavy vehicles.

Safety of higher capacity vehicles

This is addressed in Chapter 8.

Speed

Another factor which will influence the truck fatality rate, and specifically the ratio of the truck fatality rate to the overall fatality rate, is speed. Insufficient adaptation of speeds to driving conditions or habitual speeding are frequently crash causation factors in truck crashes. In addition, speed is a severity factor in all crashes.

Research over several decades has established that when travel speed is lowered, crashes, injuries and fatalities are reduced (OECD/ECMT, 2006). A fourth power relationship was found between the fatal crash rate and the mean speed reduction, but this was for all traffic rather than for truck speeds (Nilsson, 1984). Thus a drop in the mean speed of traffic from 100 km/h to 95 km/h could be expected to result in an 18.5% drop in fatalities. Evaluations of speed limit changes applying to all types of vehicle in both Australia (Long *et al*., 2006) and the United States (Paterson *et al*., 2002) have confirmed the achievability of crash reductions.

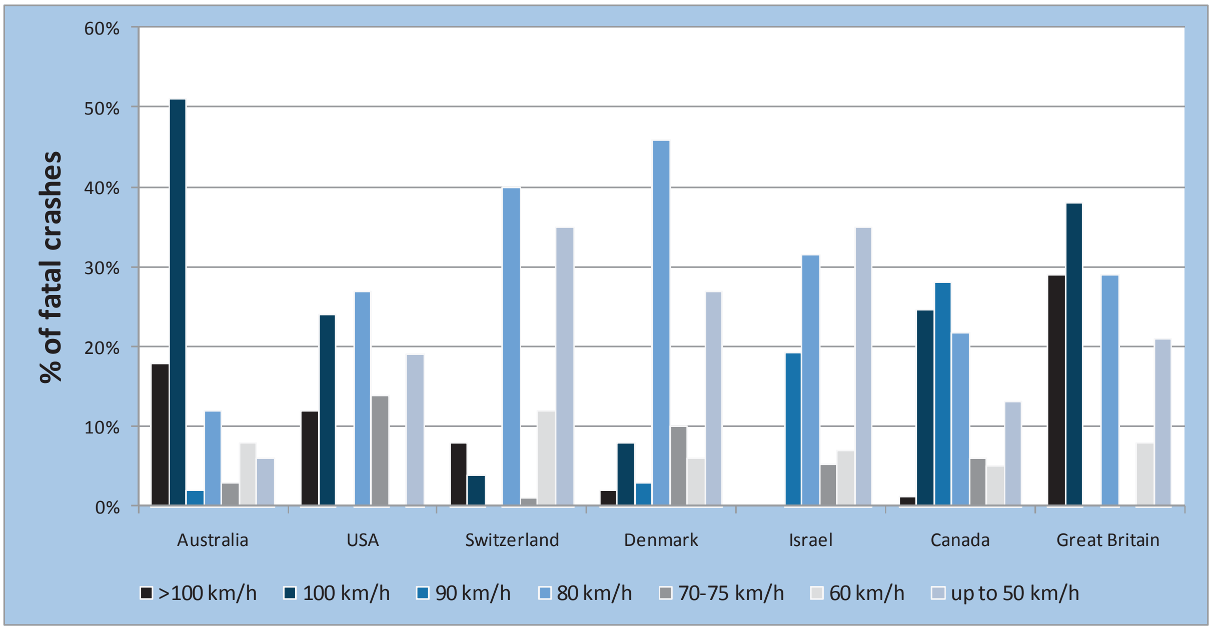
While the same laws of physics still apply to trucks, both in relation to stopping distance and energy dissipation on impact being dependent on impact speed, the fourth power relationship may not apply when the issue is one of reducing the maximum speed limit of trucks. A recent evaluation of the benefits of differential speed limits for trucks and other traffic found that there was no compelling safety evidence to support introducing differential speed limits on roads to which they did not currently apply, nor to remove them from roads to which they did apply (Turner-Fairbank Highway Research Centre, 2004). Nonetheless, individual companies have reported improved safety outcomes for their own operations as the result of reducing operational speeds on their own vehicle fleet.

Results of the Federal Motor Carrier Safety Administration’s Large Truck Crash Causation Study[2] indicate that “travelling too fast for conditions” was cited as an associated factor in 23 percent of large truck crashes involving a fatality or injury. Over the 33-month study period, it is estimated that 32 000 large trucks were travelling too fast for conditions at the time of their crashes, which involved approximately 1 000 fatalities and 42 000 injures. An analysis conducted by the Insurance Institute for Highway Safety[3] shows 15% more fatalities per vehicle kilometre travelled for States that have higher speed limits.

Figure 6.11 shows that, in Australia, 69% of fatal truck crashes occur in speed zones of 100 km/h or greater, compared with 36% in the United States, while in Canada the figure is only 26%. Great Britain also has 29% of fatal truck crashes (and 42% of fatal articulated truck crashes) occurring on roads with a speed limit above 110 km/h (70 mph= 112 km/h) It should be noted that in Australia, Great Britain, several States of the United States and in some other countries, the maximum speed limit of trucks is lower than that for cars. (See also tables B.4 and B.5 of the Annex B)

Nevertheless, it could be expected that, as is the case with other vehicles, lower truck speed limits on lower standard roads are likely to result in lower truck fatality rates, but only if the lower speed limit results in some reduction in travel speeds.

Figure 6.11. **Distribution of fatal crashes involving a truck by speed zone**



Source: Data provided by Working Group members from national datasets.

An implication of this difference in crash distribution is the nature of measures which could be anticipated to improve heavy vehicle safety in each country. Measures which target high speed stability when cornering or maintaining the in-lane tracking of vehicle trailers will deliver fewer benefits where the bulk of heavy vehicle travel, and hence most crashes, are in a relatively low speed environment.

Seatbelts

While the estimates vary, it is clear that seatbelts prevent death and serious injuries. Notwithstanding this, seatbelt rates for truck drivers can be very low. For example, the British Heavy Vehicle Crash Injury study found only 5 of the 97 fatally injured truck drivers for which seatbelt information was available were wearing a seatbelt at the time of their fatal crash (Knight *et al*., 2008). A Swedish survey (Cedrson & Karlsson, 2008) found only 38-44% of truck drivers used their seatbelt, compared to 96% of car drivers. Similarly, a 2008 German survey found that, for trucks exceeding 12 tonnes, only 26% of drivers wore seatbelts in urban areas, increasing to 46% on motorways (DEKRA, 2008). Differences also exist in terms of wearing rates between local and foreign drivers. For example, in Germany in 2005, the wearing rates for occupants of locally registered vehicles and vehicles registered abroad were 39% and 53% respectively (Vis & Van Gent, 2007).

A number of field studies have quantified the safety value of seat belts for truck drivers. Campbell and Sullivan (1991) estimated that between 27% and 77% of truck driver fatalities could be prevented by seat belt use. A review of a range of studies by Gibson *et al*. (2001), together with information from the Crashed Vehicles Study, produced an estimate that 40% to 50% of Australian truck driver fatalities could be prevented by seatbelt use at similar levels to that observed in light vehicles. Knight (2000) predicted that not only would up to 36% of truck occupant fatalities be prevented by use of 3-point seatbelts, but also that this could be increased to a 50% reduction if combined with improved cab crashworthiness.

Table 6.9. **Seatbelt wearing rates**

Year(s)	Country	Number of truck occupants killed			Number of truck occupants injured		
		Wearing seatbelt	Not wearing seatbelt	Belt use unknown	Wearing seatbelt	Not wearing seatbelt	Belt use unknown
2002 and 2004	**Australia**	11%	47%	43%	43%	11%	46%
2002-2006	**Austria**	29%	71%	0%	28%	72%	0%
2003-mid 2007	**Israel**	51%	39%	10%	61%	24%	15%
2002-2005	**Japan**	44%	49%	7%	88%	15%	2%
2003-2007	**South Africa**	2%	49%	50%			
2002-2006	**Great Britain**	4%	51%	45%			

Source: Data provided by Working Group members from national datasets.

6.5. Measures to improve the safety of trucks

Road safety models such as Vision Zero (Sweden), Sustainable Safety (Netherlands) and Safe System (Australia) accept that vehicle operators will make errors, and consequently interventions to improve safety must recognise and accommodate this fact. Understanding the nature of the errors made by drivers, and the reasons for those errors, allows interventions that:

- Reduce the frequency of errors.
- Identify errors and rectify them before a crash occurs.
- Mitigate the effects of any crash which does occur.

These interventions may be through modifying driver alertness or behaviour, making changes to the road environment, or by vehicle safety features.

Some strategic approaches to road safety have at their core the notion that death and serious injury are not an acceptable consequence of inevitable human error. Implementing such a strategy will require the evolution of road networks and usage to the point where no road user is exposed to forces which cannot be survived. Among these approaches are Vision Zero (Sweden), Sustainable Safety (The Netherlands) (Wegman & Aarts (2005) and Safe Systems (Australia) (Australian Transport Council, 2008). These approaches have been comprehensively reviewed (OECD/ITF 2008).

Truck design

In regard to unprotected road users, *i.e.* pedestrians, cyclists and motorcyclists, the design of the truck exterior is important. Rear-end collisions are a significant crash scenario in high traffic environments and are identified as one of the major risks by heavy vehicle operators. The use of a rigid front under-run protection system (now a regulatory requirement of UN ECE vehicle standards) allows the energy of the crash to be absorbed by the deformation of the vehicle, rather than by the occupants, hence reducing the severity of injury incurred. Rear under-run systems provide similar protection in the event of rear-end collisions.

Axle steering on semitrailers

Long semitrailers present load distribution issues and low speed maneuverability problems with direct safety consequences which can often be solved by axle steering systems. These can be broadly categorised as follows:

- Self steer.
- Command steer.
- Pivotal bogie.
- Active steer.

The basic principle governing the use of steered rear axles is that they reduce the effective wheelbase, thus reducing the "cut in" or swept path of the vehicle, but increasing the tail swing at the rear of the trailer. However, the exact effects of any individual implementation will depend on the position of the steered bogies and axles and the relationship between steer angle at the front axle and steer angles at the trailer axles.

The impact on the stability of the combination vehicle at high speed will depend on the type of steering system. Research does not offer a complete answer to the question, but recent results with advanced systems indicates that they may offer improved stability also at higher speeds. (See Box 6.1.)

Jujnovich and Cebon (2002) state that self-steering axles are the most widely used form of trailer steering and that the main advantages are their relative simplicity and low cost. The basic principle of self-steer axles is that the centre line of the steered tyre is offset from the centre line of the king pin which is free to pivot, which means that the tyre forces cause the wheel to align with the direction of travel.

When truck combinations increase in length and complication, simple self-steer systems cannot keep up with demands for maneuverability and more advanced systems are required at additional costs both for acquisition and maintenance. Though well researched, the more promising of these systems are not yet on the market (see box).

Box 6.1. **Development of advanced steer systems**

Command steer systems steer the trailer in proportion with the articulation angle between tractor and semi-trailer. This can be achieved in a number of ways. The simplest systems are mechanical and involve fitting a moveable plate to the semi-trailer king pin. This turns with the relative movement of the fifth wheel and uses pushrods to translate that rotation into a steering action at the trailer axles. Typically where installation is difficult (*e.g.* space or geometric restrictions), the mechanical pushrods can be replaced by hydraulic systems. One significant variation on the command steer principle is to steer not only individual axles but the whole bogie set.

All of these steering systems involve trade-offs between axle loads/load distribution, cut-in and rear outswing. A small number of researchers (*e.g.* Hata *et al*., 1989; Notsu *et al.*, 1991; Cheng & Cebon, 2007; Kharrazzi *et al.,* 2008) have been investigating the potential of active steering systems to offer further improvements in cut-in, without adverse effects on outswing, while also improving high speed stability. In this context, active steering means a command steer system where the linear relationship between articulation angle and semi-trailer steer angle, typically provided mechanically or hydraulically, is replaced by a more sophisticated non-linear control function provided electronically.

All of the research agrees that adopting such an approach can provide substantial improvements in low-speed manoeuvrability (cut-in and outswing) while also improving stability at higher speed. Jujnovich & Cebon (2008) describe the development of control algorithms for active steering systems for articulated vehicles. They found that systems could be developed that allowed the rear of the vehicle to track the path of the front of the vehicle at any speed and on any path. These could also be applied to multiple trailer vehicles.

Infrastructure and traffic management

As the foregoing analysis and prior research has demonstrated, large and heavy vehicles do not mix well with other road users, even at low speeds. An effective way to deal with this incompatibility is the separation of lighter, more vulnerable, road users from larger, heavier ones. This approach has been effectively employed to segregate, for example, pedal cyclists from motorised traffic in several countries. Whilst the development of a physically segregated freight-only road network is not feasible in most circumstances, measures to separate road freight movements from other road users by operating late at night and in the early hours of the morning are not uncommon.

A 2007 assessment of the safety benefits of improving interaction between heavy vehicles and the road system (Styles *et al.,* 2007) identified a range of activities which could comprise part of a strategy for addressing heavy vehicle safety on major freight routes, both in the short term and the longer term. The importance of some previously identified solutions, such as clearance of roadside hazards, shoulder sealing, passing lanes, and programmes to minimise the risk posed by utility poles was supported. Further investigation of some other promising solutions – such as the use of barriers to reduce the risk posed by roadside hazards, audible edge lining for heavy vehicles and delineation – appeared warranted. Other appropriate long term measures pertained to skid resistance treatments, junction layout and sighting distances, lane widths and applying a safe system approach for heavy vehicles. Styles (2007) provides a more extensive review of the application of road design features to improve heavy truck safety.

Wegman (2005) has suggested one model is the restriction of large heavy truck operations to identified freight logistics routes. This would allow infrastructure investment to be directed at upgrading economically important routes to accommodate the performance characteristics of these freight operations. A similar model is an explicit element of the Australian Performance Based Standards approach to heavy truck regulation, which not only classifies vehicles by their performance requirements, but also provides criteria for assessing routes through the road network to ensure that both the performance of the vehicles and the physical constraints of the road network are compatible for safe travel. The creation of dedicated truck roads or lanes to separate heavy freight from other road users is a related concept that may be considered for major freight routes or bottlenecks.

Driver training and licensing

In addition to measures to maximise vehicle and road network safety performance and compatibility, the skill and training of the driver of heavy trucks is an important consideration for providing safe transport of freight through the road network. Although most countries have some form of graduated licensing system for drivers of heavy trucks, requiring some experience in driving lighter vehicles before moving up to a longer, heavier vehicle, many make no distinction between a licence to drive rigid (single unit) trucks and articulated or truck plus trailer combinations.

Wegman (2005) has written of the benefits of applying a graduated licence system specifically for professional truck drivers, suggesting a first phase of general truck training, followed by a second phase requiring experience either with an articulated heavy goods vehicle on the main road network, or with a non-articulated truck on regional and local logistics routes. This would then lead to a full driving licence for the vehicle type concerned. Similar systems are already in place in some countries, and offer both a structured career path for professional drivers, as well as a greater level of assurance that drivers are properly equipped to control the largest vehicles on the road network.

6.6. Vehicle technology - Driver support and communication systems

Overview

The following subchapter gives brief descriptions of in-vehicle driver support and communications systems that have demonstrated the potential to increase safety and/or efficiency of the vehicle. The market for intelligent transport systems (ITS) is prolific and systems with comparable properties appear under various names. The aim of the chapter is therefore to identify a selection of representative systems (see Table 6.10).

Table 6.10. **Categories of driver support and communication systems**

Imminent risk detection, alert and avoidance systems	Vehicle component condition warning system
1. Lane Departure Warning	8. Onboard Brake Stroke Monitoring
2. Forward Collision Warning	9. Tyre Pressure Monitoring
3. Electronic Stability Control	**Driver condition warning system**
4. Side Collision Warning	10. Vehicle-based Driver Fatigue Detection and Warning
	11. Onboard Monitoring and Reporting Systems
Anticipating risk detection and prevention systems	**Vehicle tracking and communication systems**
5. Adaptive Cruise Control	12. Mobile Communication
6. Curve Speed Warning	13. Untethered Trailer Tracking
7. Intelligent Speed Adaptation	14 Automatic Crash Notification

Most of these systems have either entered production recently, or are expected to be implemented in production vehicles within the next few years. Common to all of them is the need for concerted efforts by many actors in order to achieve full market penetration. These include hauliers and drivers, technology and original equipment manufacturers and vendors, governments and their agencies. Enforcement officers and inspectors, insurance companies, academia and researchers could also have substantial roles to play, depending on the system.

6.6.1. Imminent risk detection, alert and avoidance systems

Electronic Stability Control Systems

Electronic stability control (ESC) systems is a generic name used to refer to a wide range of proprietary systems such as Electronic Stability Programme (ESP), dynamic stability control (DSC), and Trailer electronic braking and stability (TEBS). In Europe, the proposed General Safety Regulation will require some form of ESC to be fitted to all cars, trucks and buses, in a staged implementation, from 2011. There are two main stability functions of ESC and individual systems can offer either function or both:

- Yaw stability control.
- Roll stability control.

Yaw stability controls are intended to help the driver maintain directional stability in turns and sudden swerves. The system uses sensors to determine the angle of steering applied by the driver, the lateral acceleration, and the speed of the vehicle, to determine the path that the driver intends the vehicle to follow. It then typically uses a yaw rate sensor to determine the path that the vehicle is actually following. Where the intended and actual paths diverge, the system applies brakes at individual wheels in an attempt to correct the path. For example, if an oversteer instability is detected the wheels on the *outside* of the turn might be braked, whereas with an understeer instability the wheels on the *inside* of the turn might be braked. Yaw stability controls are available for cars, buses, rigid trucks and tractor units for articulated vehicles, and are available for some, but not all, trailers.

Roll stability control uses similar sensors and algorithms to detect when there is a risk that the vehicle could rollover and will reduce engine torque and/or apply the brakes to reduce the speed and hence lateral acceleration experienced by the vehicle. However, the way in which roll stability control is implemented and its effectiveness can vary depending on whether it is fitted to a rigid vehicle, a tractor unit or a trailer. Roll stability systems for trailers typically do not require a yaw rate sensor. The lateral acceleration is monitored and when it exceeds a certain pre-set threshold one of the wheels on the inside of the turn is braked slightly. If this brake application is sufficient to slow the rotational speed of the wheel (as measured by the ABS wheel speed sensor) then the system knows that there can only be a very low mass on that wheel and that rollover is imminent. At this point the system will go to full intervention to prevent rollover. If the test pulse on the brakes does not affect rotational wheel speed, then the system knows that considerable mass still rests on the wheel. In this case, the system takes no further action and increases the pre-set lateral acceleration threshold slightly. In this way, the system "learns" what the load conditions and centre of gravity height are as the vehicle travels along, thus avoiding "false interventions". Similar systems can be fitted to tractor units. However, the mechanics of articulated vehicle rollover are such that, when the drive axle of the tractor has lifted from the ground, it can already be too late to prevent trailer rollover. In these cases, the intervention thresholds are often set very low, which can still be effective at preventing rollover but can result in false interventions and more intrusion on "normal" driving.

ESC systems can prevent a significant proportion of loss of control and/or rollover accidents, but the effects depend strongly on vehicle class and road condition. For example, for light vehicles in all conditions a loss of directional control is more likely to be a cause of severe accidents and, even where rollover does occur, it is often preceded by a loss of directional control. For these vehicles, yaw stability control is the most important function. However, for the largest goods vehicles, rollover is the more frequent accident problem in most weather/road conditions so the roll stability control is the most important function.

Lane Departure Warning Systems

Lane Departure Warning Systems (LDWS) address crash scenarios associated with unintentional drifting from the intended travel lane. Crashes that can be prevented by LDWS include:

- Single-vehicle ***roadway*** departures to the left or the right.
- Same-direction ***lane*** departures to the left or the right.
- Opposite-direction ***lane*** departures where a truck entered into an oncoming lane.

These systems use an optical sensor system coupled to image processing software to determine vehicle state (lateral position, lateral velocity, heading, etc.) and roadway alignment (lane width, road curvature, etc.). They audio-alert the driver to which side of the lane the vehicle is drifting, and may also indicate on a display how well the vehicle is centred in the lane on a time-averaged basis.

In Europe, the General Safety Regulation[4] will require LDW systems to be fitted to new trucks and buses, though the exact implementation date is still to be determined.

LDWS can help prevent lane and roadway departure crashes. These systems can provide an advanced warning to allow additional time for a driver to react and avoid a collision. (See box 6.2.)

Forward Collision Warning Systems (including Adaptive Cruise Control and Automatic Emergency Braking System

Adaptive Cruise Control (ACC) is an in-vehicle electronic system that monitors the roadway in front of the vehicle, and either maintains the vehicle at a constant speed or maintains a certain headway distance from the vehicle in front. While ACC does autonomously activate the brakes in order to maintain headway, the deceleration is limited to relatively low levels, typically $3m/s^2$. Forward Collision Warning Systems (FCWS) build on the technology and function employed by ACC to warn a driver when the vehicle ahead is closing at a deceleration greater than the ACC can adapt to, thus meaning that a potential collision risk exists if the driver of the truck does not respond by braking harder than the ACC can or by steering to avoid the vehicle. In-cab visual displays, audible alarms and for some systems haptic warnings (*e.g.* a "tug" on the seatbelt or a hard brake pulse) are used to notify drivers to take corrective action. A further development of this type of system is the Automatic Emergency Braking System (AEBS). If the driver fails to respond to the warning issues by FCWS then the system will automatically apply emergency braking (*i.e.* $>3m/s^2$) to either avoid a collision or reduce the collision speed so as to mitigate its consequences, depending on the circumstances and the system. The General Safety Regulation will mandate certain categories of AEBS for trucks and buses sold in the EU, although the exact technical requirements, vehicle categories and implementation dates are still under discussion.

ACC can reduce the risk of rear-end crashes by maintaining a fixed headway with the vehicle in front, although some research has suggested that some of the benefits are eroded by causing a reduction in the attentiveness of the driver. FCWS further reduce the risk of front to rear crashes by identifying fast-closing situations, issuing progressive alerts to warn an inattentive driver of the danger and the need for avoiding action. AEBS further reduces the risk by taking control from drivers that fail to respond to the warnings and automatically applying emergency braking in order to avoid the collision or to mitigate its consequences. See box 6.2.

Box 6.2. **FMCSA assessment of the cost benefits of Roll Stability Control, Lane Departure Warning System and Forward Collision Warning Systems**

Roll Stability Control, Lane Departure Warning, and Forward Collision Warning Systems have recently been subjected to thorough benefit-cost analyses by the US Federal Motor Carrier Safety Administration (FMCSA). The potential benefits, in terms of crash cost avoidance, were measured against the purchase, installation, and operational costs of the technology. Data from 2001 through 2005 were used to estimate the average annual numbers and costs of crashes preventable by each of the three systems. The primary data for benefits and crash costs paid by the industry came from insurance companies, motor carriers, legal experts, and others. Crash avoidance costs were calculated for annual VMT values between 80 000 and 160 000 miles.

The U.S. FMCSA estimated that use of the RSCS could prevent annually between 1 422 and 2 037 combination vehicle rollover crashes in curves (Murray *et al.*, 2009A). The overall annual average cost of avoided crashes for a vehicle travelling 100 000 miles per year was estimated at USD 380–544. The technology and deployment cost estimates ranged from approximately USD 440–866 per vehicle. Calculations of net present values of 5 years' benefits and costs with discount rates of 3 and 7 percent showed that for every dollar spent, carriers get a benefit payback ranging from USD 1.66–9.36, dependent on VMTs, system efficacies, technology purchase prices and discount rates. The payback periods ranged from 6 to 30 months, dependent on same range of parameter values.

Similarly, the U.S. FMCSA estimated the number of the various types of accidents potentially prevented annually by LDWS (Murray *et al.*, 2009B). The overall annual average costs of avoided crashes were estimated at USD 314-667 for a vehicle travelling 100 000 miles per year. Following the same CBA procedure as described above for RSCS it was found that for every dollar spent on a LDWS, carriers get a payback ranging from USD 1.37-6.55, dependent on VMTs, system efficacies, technology purchase prices and discount rates. The payback periods ranged from 9 to 37 months, dependent on the values of the same range of parameters.

Finally, it was estimated that use of FCWS could prevent annually between 8 597 and 18 013 rear-end crashes (Murray *et al.,* 2009C). The annual average costs of avoided crashes were estimated at USD 652–1 367 for a vehicle travelling 100 000 miles per year. The same CBA procedure as was used on the two previous cases showed that, for every dollar spent on a FCWS, carriers get a payback ranging from USD 1.33–7.22, dependent on VMTs, system efficacies, technology purchase prices and discount rates. The payback periods ranged from 8 to 37 months, dependent on the same range of parameters values.

Side Collision Warning Systems

Side Collision Warning Systems monitor blind spot areas along the sides of a commercial motor vehicle, detect stationary and moving objects in these areas, and provide warnings to drivers of possible collisions with vehicles travelling in an adjacent lane. They may be integrated with other systems, such as forward collision warning systems and/or video systems for advanced side and rearward visibility beyond what can be obtained by conventional mirrors.

Side collision warning systems are aimed primarily at vulnerable road users and provide an added measure of safety for turning, merging, and lane changing manoeuvres when a driver cannot see objects in the blind spots along the sides of his vehicle. These systems can provide an advanced warning to allow additional time for a driver to react and avoid a collision. When augmented by video systems they provide added collision avoidance during reversing and low-speed manoeuvres.

6.6.2. Anticipating risk detection and prevention systems

The first two systems are on the market, but with a very low adoption in the current vehicle fleet. The third system must still be classified as in need of additional development and testing before it can gain market acceptance.

Adaptive Cruise Control Systems

The function and safety effects of Adaptive Cruise Control (ACC) were discussed in the preceding section because it is one of the building blocks of more advanced FCWS and AEBS. However, in addition to these safety effects, ACC can also influence traffic flow and hence fuel consumption and emissions.

ACC can reduce the occurrence of events which lead to rear-end collision. By maintaining safe time and/or distance interval to a lead vehicle, the system enables the truck to reduce the amount of stop-and-go events in heavy traffic, which is a significant benefit for the fuel consumption and the emission of greenhouse gases (GHG) and other pollutants of the truck, and contributes to maintaining the flow of the traffic in general.

Curve Speed Warning Systems

A Curve Speed Warning Systems (CSWS) calculates safe speeds in upcoming curves, and alerts drivers if the current vehicle condition will require a substantial amount of braking in order to stay under control in the curve ahead. Like ISA (next), it combines vehicle position data with accurate map data on road geometry stored by the vehicle. CSWS pre-empts the two functions of Electronic Stability Control Systems (see 6.1.3.3) by reducing the number of situations in which these will be activated.

Reduction of the occurrences of loss-of-control situations, in which excessive speed in a curve causes vehicles to depart from their intended path and run off the roadway to the right or left, collide with road side obstacles, crash barriers, or other vehicles in adjacent lanes, with or without roll-over.

Intelligent Speed Adaptation System

Intelligent Speed Adaptation (ISA) is a combination of technological systems that support drivers in their choice of speeds. This support may take several forms, from simply alerting drivers ("advisory" systems) to vehicle initiated speed limitation ("limiting systems") that cannot be overridden. It will generally combine vehicle position data with information about current speed limit on the actual road location. Such speed alert systems are widely available with current navigation systems, but are never fully up-to-date. However, an ISA system capable of interacting with the vehicle's cruise control system must access fully updated speed limit data for the roads on which it is planning to operate. Such ISA systems are currently being tested in several countries[5]. Future ISA developments are expected to be capable of adapting speeds to an increasing number of features of the traffic and infrastructure situation. The benefits of ISA include:

- Reduction of the occurrence of speeds exceeding local or general limits.
- Improved vehicle-following distances on lower speed roads, and thus a reduction in the frequency and severity of accidents.
- Reduced speeds with less abrupt braking and speed variation and thus less emission of GHGs and other pollutants, fuel consumption and noise.

6.6.3. Vehicle component condition warning systems

Onboard Brake Stroke Monitoring Systems

Onboard brake stroke monitoring systems utilise sensors located at each brake actuator to monitor pushrod travel and determine if a brake on an air-braked vehicle has a problem, such as over-stroking, not releasing, or not operating. These monitoring systems include driver interfaces that display the existence and location of these problems to drivers, technicians, and inspectors.

Since truck braking system design and operation are directly related to overall vehicle safety, such monitoring and warning systems can be valuable tools for carriers to avoid risks caused or aggravated by defective or underperforming brakes. The information provided by these warning systems can be used in diagnosing braking problems for carriers and so avoid unscheduled maintenance and down time on the road. Pre-trip inspection times can be substantially decreased when using onboard brake stroke monitoring systems, although they are not intended to replace regular, comprehensive brake inspections.

Tyre Pressure Monitoring Systems

Tyre pressure monitoring systems (TPMS) measure tyre air pressure with sensors attached to the tyre, wheel, or valve stem and let the driver know when tyres are under-inflated, so that corrective measures can be taken. Underinflated tyres result in excess fuel consumption due to increased rolling resistance. It also causes tyres to wear more quickly and, in extreme cases, may cause crashes by causing tyre blow outs or reduced grip or stability. Some systems may be integrated with tyre pressure equaliser or maintenance systems that monitor and automatically inflate tyres to pressure suitable for the operating conditions.

Tyres that are improperly inflated can run hot, damaging the casings and sidewalls and leading to tyre conditions that can cause crashes due to poor handling, hydroplaning, tyre blow-outs, and vehicles that are stranded on the roadway. TPMS for commercial motor vehicles can facilitate the task of drivers and fleet operators in maintaining normal tyre pressure in all tyres for optimum safety and fuel consumption and uninterrupted operation of the vehicle.

Driver condition warning systems

Vehicle-Based Driver Fatigue Detection and Warning Technology

Advances in video camera and computer processing technologies, coupled with non-invasive eye detection and tracking systems, have made it possible to characterise and monitor a driver's state of alertness. These systems can provide alerts to notify drivers when they are becoming tired and their level of alertness is dropping. Such systems may also use steering manoeuvres as additional input.

Monitoring a driver's state of drowsiness and providing feedback on his condition so that he can take appropriate action (*e.g.* stop for rest) is a way to increase alertness and reduce fatigue-related crashes.

Onboard Monitoring and Reporting Systems

Onboard Monitoring and Reporting Systems (OBMS) include hardware and software technology suites that allow for online measurement of a comprehensive set of driving characteristics that, in addition to eye movements, are indicators of unsafe driving behaviour. Using these systems, feedback can be supplied to drivers in real-time, or provided to carrier management via a report for later discussion with the driver (in jurisdictions that allow such storage of personal data).

This information about their driving behaviour can allow truck drivers to significantly improve their attentiveness and enhance their driving safety performance. Other potential benefits may be identified.

6.6.4. Vehicle tracking and communication systems

Many of the potential users (for example, 35% in the United States) have adopted some form of tracking system, and the outlook for further growth is good over the next 5 years. The most serious barrier to continued rapid adoption of this technology is the initial and ongoing high costs of the system. Thus, providing information to purchasers from tests, evaluations, and analyses is a critical need. Also, financial incentives, such as tax credits and loan programmes, may have a role for increasing deployment.

Mobile Communications System

Wireless mobile communications tracking systems use satellite-tracking Global Positioning System (GPS) technology for vehicle location information, as well as satellite and/or cellular communications technologies for two-way communication. Some systems select the lower-cost cellular network first, and switch seamlessly to the satellite network when coverage is needed in remote areas.

These systems can enhance the security and efficiency of commercial vehicle operations. By closely tracking vehicles and assets, opportunities for cargo and vehicle theft can be reduced, and dangerous goods can be given added security. Additional benefits include potential improvements in delivery service and asset utilisation through vehicle location and routing information. Human resource management can be enhanced by carriers receiving more accurate status and arrival time information on shipments. Such information can also expedite deliveries and help to ensure on-time performance to customers.

Untethered Trailer Tracking System

Untethered Trailer Tracking Systems use the same positioning and communication technology as the previous system, without the need for voice communication. Date and time-stamped position reports with the geo-coordinates of a tracked trailer can be sent to a carrier on a regular, event, or on-demand basis via a website, or they can be downloaded to carrier fleet management systems. The systems may integrate sensors that transmit other information, such as cargo status, back to fleet managers and dispatchers.

Enhanced operational efficiency and security are the major benefits of untethered trailer tracking systems. Operational benefits of untethered trailer tracking systems include improved on-time cargo deliveries, a reduction in trailer yard congestion, and better cargo theft detection and recovery.

Automatic Crash Notification

Automatic crash notification is a system for alerting the emergency services in the event of an accident. The system uses the regional emergency number and can be activated automatically when the vehicle senses a major impact, or manually by pushing a button. The system establishes voice contact with the emergency centre and at the same time transmits data about the accident, including precise position, date, time, and vehicle identification.

Known in Europe as "e-Call", the concept was introduced in 2004 by the industry, and a Memorandum of Understanding (MoU) has been signed by a majority of the European Member States with the aim of implementing it on all new cars from 2011 onwards. Development is still underway, along with extensive testing of procedures that must be capable of handling an average of 2 automatic and 26 manual calls per year, per 1 000 vehicles.

The system will reduce the consequences of accidents by providing faster medical care for crash victims. When fully deployed in Europe it could save 2 500 lives every year and reduce, by 15%, the severity of all injuries[6].

6.6.5. Implementation of driver support technologies

There are a number of barriers that can prevent, or slow, the adoption of new technologies in the road freight market. These include:

- High initial costs – for example, tracking and monitoring systems may offer positive payback over several years but still require considerable initial investment.
- Driver acceptance – many new technologies rely on the driver using them correctly, and if the driver perceives disadvantages they may not do so. Seatbelts are an example where belt wearing rates typically remain low despite the usual policy of compulsory use.
- Benefits accruing to parties other than the driver/operator – for example, many safety systems are intended to be of benefit to other road users, so operators see the costs but not the benefits.
- Productivity penalties – where new measures add mass to the vehicle, or take up space, they can have an adverse effect on the productivity of the vehicle in terms of payload capacity and fuel consumption.

The benefits that can be gained from new technologies are strongly influenced by the rate at which they penetrate the vehicle fleet. However, motor carriers are often slow to voluntarily adopt new technologies unless they can be confident of gaining tangible economic benefits from it. There are a number of ways in which increased uptake of new technology can be achieved, for example:

- Regulation
  - *Removal of regulatory barriers*. Sometimes new technology can be unintentionally prohibited by older regulation that did not foresee developments, and in other cases it can be discouraged by regulation; for example, some safety and aerodynamic improvements could only be implemented within prescriptive length regulations by sacrificing some of the available load space, which would erode or eliminate the benefits.
  - *Harmonising the technical standards of voluntarily fitted technology*. Creating a defined set of technical requirements and performance limits to be applied to certain technologies, *if fitted*, can reduce liability risks for manufacturers and provide consumers with more confidence that the system they are purchasing meets at least minimum standards of effectiveness. It can also act as a first step towards mandatory fitment.
  - *Mandating fitment to new vehicles*. This requires all new vehicles of defined categories to be fitted with the system in question, which encourages much quicker penetration of the

fleet than voluntary fitment but still takes many years to fully penetrate the market, particularly where vehicles typically have a long life (*e.g.* trailers).

- *Mandating fitment to all vehicles*. Often known as retro-fitting, this requires all registered vehicles to be fitted with the technology within a defined (short) timeframe. This offers the quickest route to full implementation, but can also create a high cost burden for industry and is often, therefore, reserved for relatively simple changes – for example, requirement to retro-fit blind spot mirrors to certain categories of heavy vehicles.

- Information and education
  - *Educating drivers* can be effective in terms of directly influencing safety and productivity, and can also help to encourage "buy in" to other technological interventions. This can range from "in-house" company schemes to mandatory requirements, such as the new European requirements for regular refresher training.
  - Identifying "best practices" amongst transport operators and promoting the wider spread of these practices can also be effective. An example of such a best practice scheme can be found at http://www.freightbestpractice.org.uk/.
- Incentives
  - *Direct subsidy*. If there is sufficient benefit the investment cost of a system can be directly subsidised, for example, the Japanese Government offered to cover part of the cost if operators fitted AEBS to their vehicles (Grover *et al.*, 2008).
  - *Tax or charging schemes*. The taxation system, or road user charging scheme, can be tailored to encourage the desired vehicles, technologies or behaviours. For example, in the UK the road fund license is cheaper for 6-axle, 44 tonne vehicles that are less damaging to the pavement than 5-axle, 40 tonne vehicles.
  - *Relaxation of other constraints*. Operators can be given an incentive to fit new technologies by offering relaxations in other regulatory constraints, for example, by granting access to parts of the road network previously prohibited or by permitting increases in GVW to compensate for increases to unladen weight.

Each of these approaches will have advantages and disadvantages. For example, mandating the fitment of a device to new vehicles provides a large step change in the rate of adoption. However, the regulatory process itself can take years and may delay implementation of proprietary systems until the detailed requirements are known. Prescribing detailed technical requirements in regulation can also reduce the incentive for vehicle manufacturers and technology suppliers to develop alternative, or superior, means of achieving the intended safety outcome. Furthermore, it can be difficult to obtain the necessary evidence to justify the making of a regulation until the device concerned has penetrated sufficiently through the fleet to generate adequate real-life data. For these reasons, an initial approach of non-regulatory encouragement of new technology can provide a valuable bridge between the current situation and a final regulatory response, and a multi-faceted approach will likely be most successful in achieving the goal of promoting the proliferation of innovation throughout the motor carrier industry.

6.7. Conclusions

Crashes involving trucks cause between 10 and 25% of all road deaths in the countries which provided data for this study. For most of these countries, the trend in the number of truck crashes has generally been downward, despite substantial increases in the number of trucks, particularly heavy trucks and the distances travelled by them. For countries which provided separate information on larger articulated trucks, four out of five had a lower articulated truck crash rate than that for all truck types. Across nations truck involvement in road fatalities per kilometre driven as compared with that of all traffic varies from being almost the same to being almost four times higher. Although the full range of relevant factors, including the contribution of the involvement of different truck types, cannot be established, such differences deserve the attention of the nations with the higher involvement of trucks in fatalities.

The majority of truck crashes involved other road users – pedestrians, bicycles, cars, motorcycles. Major improvements to heavy truck fatal crash rates within a country are almost always linked to improvements in fatal crash rates for other types of vehicle. Providing a safe system for the economically and socially essential task of transporting freight by road will not be achieved solely by actions directed at the design, use and behaviour of the heavy vehicle fleet itself.

Nonetheless, design improvements to heavy vehicles and technological support for heavy vehicle drivers can contribute to reducing the incidence or severity of major crash types arising from factors such as lane departure, frontal collisions and pedestrian collisions. Crash scenarios for long-haul trucks are often associated with unintentional drifting from the intended travel lane, causing the truck to hit vehicles in opposite or neighbouring lanes, run off the road and rollover or collide with roadside obstacles, including barriers and bridge supports. Insufficient adaptation of speeds to driving conditions or habitual speeding are frequently crash causation factors in truck crashes.

Vehicle features such as front under-run protection, improvements to driver's field of view, pedestrian friendly frontal designs and lane departure and collision avoidance systems are effective measures to deal with these scenarios. Such measures can also effectively reduce the consequences of human error (by the truck drivers or other road users) that are responsible for the large majority of crashes.

Driving impaired by drugs or fatigue are relatively unlikely to be identified as factors for crashes involving trucks under European or North American driving hour regimes, however this cannot be interpreted as indicating that they are not major safety concerns. Both the effects of drug use and the effects of fatigue on cognition are undeniably contributing factor in cases where other errors are involved, such as hazard-recognition errors, inattention or decision-making error.

Seatbelt wearing rate by truck occupants is in many countries much lower than for car occupants, and can be as low as 40% even in countries with a long safety tradition. Differences also exist in terms of wearing rates between local and foreign drivers. A large proportion of truck occupant fatalities could be avoided by increasing their usage of seatbelts.

Improvements to road construction and design, passenger vehicle safety features, improved speed compliance and reduced impairment by alcohol, drugs, medical conditions or fatigue by light vehicle drivers will contribute to reductions in crashes and fatalities involving trucks just as they do to reducing other types of multi-vehicle crashes. Pursuing a safer road network through application of Safe System principles can reduce truck crashes as it does crashes of all other types (OECD/ITF, 2008).

New technologies, including driver support and communication systems, have important potential to improve truck safety, while also contributing to a more efficient operation of the vehicles in traffic. These include systems to detect imminent risks, alert the driver appropriately and assist in the avoidance of the dangers posed by these risks; to reduce the risks of loss of control (roll or yaw); of unintended deviation from the lane; of collision with vehicles ahead of and alongside of the truck; to anticipate risk by maintaining selected speed while keeping a safe distance from vehicles in the same lane, warning of unsafe curve speeds and securing speed adaptation to proper network speeds; to alert drivers when vehicle components (such as brakes or tyre) present a failure.

Erratic driver behaviour and vehicle handling, as well as fatigue and drowsiness, are very real crash causation factors which are mitigated by driver condition warning systems to detect and alert against the onset of such conditions.

Serving the driver, the haulier and the customer – by enabling better planning and execution of the freight task – are various vehicle tracking and communication systems, including automatic crash notification.

The cost of a new safety feature imposes a significant burden on the vehicle owner, when the beneficiary of the feature is often not the operator or occupant of the vehicle. Approaches to overcome this barrier include offering various types of information, incentives or regulation of the feature. The latter may be necessary, but can result in delayed implementation and postponed development of better means of achieving the intended safety benefit and a multi-faceted approach is often most successful.

A severe limitation to the analysis undertaken has been the limited amount of comparable data, which has not been sufficient to enable some desirable analyses to be made. The inadequacy of heavy vehicle crash and traffic data in many countries is not a new observation. Previous international benchmarking studies have also been impeded by this problem.

In facing the challenge of meeting a growing freight task in a way that meets public demand to improve safety on the road network, the need for consistent, relevant data by which the safety impact of changes of the heavy vehicle fleet can be monitored is poorly served by crash statistics of many countries. In particular, it is a recommendation of this report that the IRTAD Group actively pursues the categorisation and collection of crash data that differentiates between categories of heavy vehicles.

NOTES

1. See more detail in Annex B.
2. Federal Motor Carrier Safety Administration, Analysis Division, "The Large Truck Crash Causation Study," Publication No. FMCSA-RRA-07-017, July 2007, Table 2.
3. Insurance Institute for Highway Safety (2008). *How Posted Limits Affect Speeds*. Status Report, Vol 43.
4. Regulation (EC) No 661/2009 of the European Parliament and of the Council of 13th July 2009 concerning type approval requirements for the general safety of motor vehicles, their trailers and systems, and components and separate technical units intended therefor.
5. As an example, Main Roads Western Australia is currently undertaking a state-wide demonstration trial of advisory ISA in some 50 cars, with automatic speed reference updates from beacons or relayed from other vehicles.
6. See http://www.esafety-effects-database.org/index.html with reference to several studies.

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CHAPTER 7. INFRASTRUCTURE CHALLENGES

Abstract

The chapter describes the challenges that truck operation imposes on the infrastructure and for traffic management. It describes the mechanical impacts of trucks on the infrastructure, *i.e.* mainly on road, pavements and bridges and the impact of trucks on road traffic operations and traffic and infrastructure management and briefly discusses the issues related to road tunnels. It covers the impacts of trucks on the perception that other drivers (mainly car drivers) have of the road and on the road facilities and the needs and challenges of intermodal terminals.

7.1. Introduction

To assess the mechanical impacts of trucks on the infrastructure as a whole, it is necessary to consider, in the following order:

- The actions applied to the structure, *i.e.* traffic loads, which include wheel loads, axle loads, group of axles (bogie) loads, gross vehicle weights and the sum of all vehicle loads applied simultaneously on a bridge span, or a set of bridge spans that are not independent.
- The load effects that the traffic loads induce in the structure, which are a function of the traffic loads and the mechanical behaviour of the structure (generally assumed to remain elastic). This involves knowledge of the stresses and strains induced in the structure as well as material properties such as modulus, Poisson and Young's coefficient. [Ryall *et al*., 2000].

Most bridge and pavement infrastructures are designed according to codes and standards on the basis of conventional load models [Dorton and Bakht, 1984], [CEN, 2002], [TRB-AASHTO, 2005]. These are calibrated once, when the code is designed, and are rarely re-calibrated (*e.g.* every 10 or more years) when the code is revised. Such load models are designed to be as simple as possible in order to avoid gross errors by the infrastructure designers and consultants and to remain understandable and easy to use with available tools and computer software. Load models are also general enough to cover almost all infrastructure cases. Some cases are explicitly excluded from certain codes, *e.g.* long span bridges (over 200 m for one span) in the Eurocode EN1991-2, Traffic Loads on Road Bridges [CEN, 2002]. For such exceptional structures, detailed and particular specifications must be drawn up by the owner prior to design and construction.

The conventional load models are, therefore, often conservative because they must remain simple and usable while allowing for many different existing traffic cases, potentially unknown future traffic developments, and all the potential extremes of load and load effect that could occur over the whole lifetime of the structure (*i.e.* 10 to 40 years for a pavement, and 20 to 100+ years for a bridge). As a result, they tend to be based on extrapolations of the loads and load effects that can be measured over short- (hours to months) or medium- (several years) term periods.

When exposed to repeated traffic (or other) loads of variable intensity, some structures are affected by fatigue damage – mainly cracking – which may modify their properties and strengths. In addition to traffic loads, road infrastructure is also exposed to other stresses; for example weather (temperature, wind, rain, snow and ice), natural events (ground motions, earthquakes…), and chemical actions (salt used in cold or temperate climate to prevent ice). Similarly, many structures are subject to material behaviour which induces strains and, consequently, load effects and stresses – such as concrete shrink and creep. Thus, materials and structures – as well as truck weights and dimensions – evolve over time and as a consequence standards need to be periodically reassessed.

Allowing higher capacity vehicles access to roads which were not designed for them would require an assessment of whether the infrastructure is able to accommodate them, at what cost, and which, if any, specific actions would need to be taken in order to accommodate them safely. Technical standards and guidelines are usually based on so-called standardised design vehicle concepts and on the legally permitted maximum size and load. Many higher capacity vehicles would fall outside the limits specified for these design vehicles, which could potentially have serious consequences for both the infrastructure and the vehicle.

7.2. The effect of truck traffic on pavements

In order to maintain the road in a serviceable condition truck (and other heavy vehicle) traffic needs to be suited to the pavement on which it travels. This can be achieved in a number of different ways:

- Pavement design (*e.g.* stronger, more durable).
- Pavement maintenance (*e.g.* increased frequency or higher standard).
- Truck regulation (*e.g.* limiting load, wheel and suspension configurations).
- Truck traffic management (*e.g.* limiting access).

Limiting the configuration or access of trucks can have negative effects on productivity and consequently external costs such as emissions. However, modifying an existing road asset is a very complex and expensive undertaking that can require large quantities of natural resources and involve a big decrease in road capacity for a long period. This means that in most, but not all, cases it is more cost-effective to limit the truck configuration and/or access rather than improve the pavement or accept the maintenance consequences.

7.2.1. Risks for road owners and users

Truck (and other heavy vehicle) traffic can result in severe pavement wear if the vehicles are not well suited to the pavement. When this traffic becomes more aggressive than the pavement can bear, large-scale deterioration will occur such as cracking, rutting, pot holes, peeling (or scabbing), punching or stepping. This deterioration can have an effect on the safety of road users and may even prevent the use of the road. When this occurs road owners have to carry out repairs as rapidly as possible, using expensive and often less efficient techniques. As a consequence, their resources are wasted, their pavement asset is not improved and the evenness of pavement will have deteriorated. This reduction in evenness in turn increases the impact of truck traffic and the situation thus degenerates inexorably. The DIVINE project [OECD, 1999] demonstrated and quantified this phenomenon.

Building pavements to carry very heavy traffic requires materials of high quality in thick layers. As well as being expensive, this may also involve the use of scarce resources (aggregates, binders etc.). Despite this investment, truck traffic always generates some form of pavement deterioration and the road owner must therefore undertake regular maintenance. This maintenance, under heavy traffic, has a significant price in terms of the consumption of high quality, expensive (and sometimes scarce) materials. As these road works will also disrupt traffic, all stakeholders have an interest in well-spaced and timely maintenance. Adopting less aggressive trucks can contribute to a reduced maintenance requirement.

7.2.2. The influence of truck configuration

Axle load

Since the 60s, it has been known that axle weight has a considerable influence on pavement wear. Figure 7.1 is a representation of the fourth power law, which states that adding 2 tonnes to a 10 tonne axle doubles the aggressiveness of the axle and thus reduces the service life of the road by half. Even if it is known that this law is too simple and not valid for all pavement types, it gives an indication of the relative aggressiveness of a truck for different axle loads and underlines the non linearity of the wear with the load. The fourth power is generally replaced by a power α, where α depends on the pavement type.

Figure 7.1. **Aggressiveness against a 10 t reference axle according with the fourth power law**

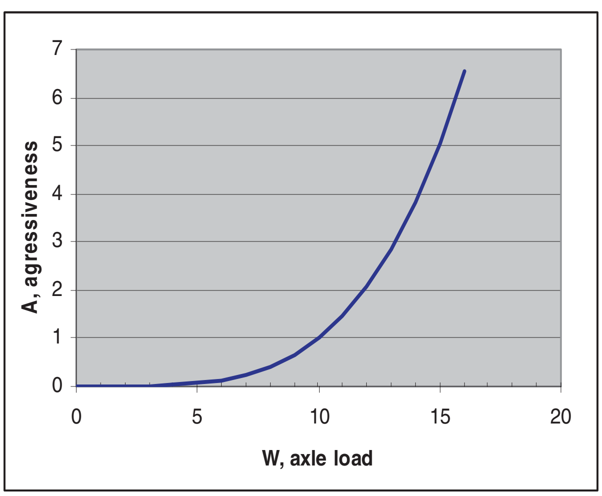
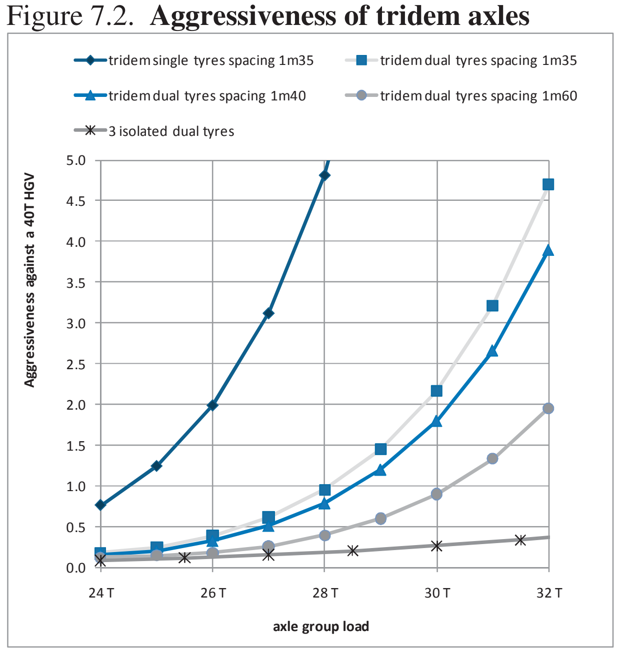


Figure 7.2. **Aggressiveness of tridem axles**



Source: SETRA, internal study.

Groups of axles

When axles are close, the effect they have on the road depends on their spacing and each of them will be more aggressive than if it was isolated. In Figure 7.2, the impact of tridem axle spacing and wheel types has been calculated using the French software *Alize* [CFTR, 2003].

Wheels and tyres

The load transmission from the wheel to the road is also very important. The parameters to consider are:

- Single or dual wheel.
- Tyre specification (*e.g.* dimension, pressure).

This question was extensively studied by the project COST 334 [COST334, 1998], which showed for example that dual wheels are substantially less aggressive than singles (see figure 7.2).

Load distribution

As seen above, for a given load the type of axle (*e.g.* spacing, wheel, tyres) has a major effect on how aggressive it is for the pavement. Typically, each truck will have several different types of axle. For example the steer axle might be a standard width single, the drive axle might be a standard width dual, a tag axle might be a reduced diameter single and the tridem trailer bogie might use wide singles. How the load is distributed between these different axles can greatly affect the aggressiveness of the vehicle.

In 2008, a study for the European Commission [De Ceuster *et al*., 2008] quantified the impact of load distribution. It was found that, even where vehicles were within the gross weight limits imposed by European directive 96/53EC, the most aggressive load distribution was four times more aggressive than the least aggressive. It is very important that weight limits are expressed for each axle type in order to limit the occurrence of poor load distributions.

Even where regulation offers strict control of axle weights, it is possible to reduce the aggressiveness of the vehicle by encouraging carriers to optimise the distribution of axle loads in favour of lower road damage. The modern instrumentation of trucks, in particular on-board axle weighing systems, is expected to improve the ability to implement such policies.

Suspensions and steerable Axles

The type and performance of suspensions have an important impact on dynamic load repetition in some cases (see section below). In the DIVINE project [OECD, 1999], it was shown that some suspension designs could cause a reduction in road service life of around 15%.

Although steerable axles are likely to be beneficial to pavement protection by reducing the lateral forces applied to the road surface during cornering, knowledge of pavement surface behaviour is not yet sufficient to quantify the extent of their impact.

7.2.3. Pavement characteristics to take into account

Materials

Different materials will have a different fatigue response to cumulative loads. Therefore, different road surfaces will behave differently with respect to a change in axle load. An exponential power, α, represents this behaviour for each type of pavement:

- Non granular pavement: α around 4.
- Bituminous pavement: α around 5.

- Hydraulic bounded or concrete pavement: α between 10 and 12.

The high exponential power applied to hydraulically bound pavement layers shows that they behave well with high levels of traffic but are highly sensitive to overload.

Design

The main objective of pavement design is to distribute loads spatially in order to reduce pressure on the subgrade. Pavements which are designed for heavy traffic have a spatial distribution, which introduces a large interaction between the axles of a truck.

Other areas of road design, such as traffic lane width and number of lanes, must also be considered, because:

- The number of lanes influences the number of trucks to take into account.
- Small width of lanes channels all of the trucks into a common position, thereby augmenting their cumulative aggressiveness.
- In the case of concrete pavements, the edge of the pavement is its weakest part; therefore if the truck is near this edge, its aggressiveness increases.

Maintenance and evenness

The DIVINE project [OECD, 1999] showed that an uneven road surface can result in a dynamic axle load that is 20% greater than the static axle load. Furthermore, poorly sealed surfaces or bad drainage will cause water to penetrate into the pavement layers. This water will have different effects, depending on the layer concerned:

- In the case of a wet surface layer, heavy traffic generates the poorly understood phenomenon of ravelling, which leads to pot-holes and peeling.
- In the case of a wet bound layer, the pavement is less efficient and fatigues quickly.
- In the case of a wet subgrade, the pavement is more stressed and fatigues quickly.

When a road is in such a condition, the axle load must be lowered to maintain the same level of aggressiveness to the pavement.

Climate

At very low temperatures the modulus of road materials increases and the strains are reduced underneath the passing truck. However, during or after the winter, in thaw periods, trucks become very aggressive on pavements because of water in the subgrade. Depending on the importance of this phenomenon, temporary measures to restrict axle loads (or axle group loads) can be taken to protect pavements.

Wet periods (rain, high humidity) have the same type of effect as thaw periods, but with lower magnitudes.

Bitumen bound materials are sensitive to hot conditions caused by the ambient temperature and solar radiation. In such conditions, they are sensitive to creep and their rigidity decreases. Creep leads to rutting under truck traffic. A decrease in stiffness, in conjunction with low bearing strength of the subgrade (if, for example, the subgrade was wet) causes a substantial increase in pavement stress.

7.2.4. Methods for evaluating truck aggressiveness on pavement structure

Equivalent Standard Axle Load (ESAL) and Vehicle Wear Factor (VWF)

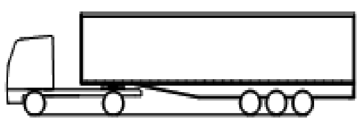
The aggressiveness of a truck on pavements may be assessed through the "equivalent standard axle load" measure (ESAL). This methodology consists of determining the number of standard axles that would have the same impact on a stretch of pavement as the passing of the group of real axles with real loads that is to be assessed. Once the aggressiveness of each group of axles has been calculated, the overall aggressiveness of a truck can obtained by adding the number of standard axles represented by each individual group of axles fitted to the vehicle under consideration.

To enable clear and easy comparisons between vehicles, the aggressiveness of any particular truck can be compared with a reference vehicle to produce a "relative wear factor". The relative wear factor of a truck is obtained by dividing the truck wear factor (VWF) by the wear factor of a reference truck (VWF_{ref}) using the following formula:

Relative Vehicle Wear Factor: $$VWF_{rel}(truck_x) = \frac{VWF(truck_x)}{VWF(truck_{ref})} \qquad (1)$$

In this study, a 40 t / 16.5 m long, 5-axle truck with a 2-axle tractor and a 3-axle semi-trailer was defined as the reference vehicle. Thus, the relative aggressiveness of the reference vehicle equals 1.

Reference truck:



The ESAL methodology only allows the wear factor to be calculated individually for each axle. The method can be improved by taking the interaction between closely spaced axles into account (see section 7.2.2). Additional improvements can be achieved by considering the type of tyre and the assembly configuration (single/dual). Data on the footprint of the tyre (contact area between tyre and pavement) are needed to calculate the stresses in the pavement structure. For the purposes of this study, COST333 and 334[1] results have been used with the assumption that the drive axle and any other axles equipped with twin tyres use 315/80 tyres while single non-driving axles use 385/65 wide tyres.

The aggressiveness of a group of axles may be assessed through the "wear factor" which is relative: it is the ratio between the damage created by the load and the damage created by the equivalent reference group of axles.

Wear factor of a group of axles: $$WF_{\text{group of axles } i} = k_i \cdot \left(\frac{W_i}{W_{ref}} \right)^{\alpha_i} \qquad (2)$$

where:

k_i and α_i are two parameters which depend, for each group of axles i, on the type of pavement and the expected traffic volume; in this case exponent α_i equals 4
W_i is the total weight carried by the group of axle i;
W_{ref} is the total weight carried by the equivalent reference group of axles.

While the exponent used in the ESAL calculation does vary among countries and for each type of pavement, the commonly used value 4 is generally accepted (the empirically developed “fourth power” law). However, more accurate results may be obtained by using a more precise formula or model of the impact of a group of axles on the pavement, such as the ALIZÉ software [CFTR, 2003].

Pavement behaviour is also highly dependent on the materials used and the traffic volume it is designed for. In according with the results of the COST333 and COST 323 actions [Jacob *et al.,* 2002], four road structures, representative of the European roads, have been selected to perform aggressiveness calculations in this study, based on the typical pavement design parameters shown in Table 7.1:

- Bituminous pavement, designed for low traffic volume (5 million 8 t standard axles).
- Bituminous pavement, designed for moderate traffic volume (10 million 8 t standard axles).
- Bituminous pavement, designed for heavy traffic (100 million 8 t standard axles).
- Cement pavement, designed for heavy traffic (100 million of 8 t standard axles).

Table 7.1. **Pavement design parameters with respect to the traffic intensity**

<table>
<tr><th>Traffic intensity</th><th>Weak</th><th>Moderate</th><th>Heavy</th><th>Heavy</th></tr>
<tr><td>Asphalt thickness (mm)</td><td>100</td><td>200</td><td>330</td><td>280</td></tr>
<tr><td>Asphalt Young's modulus (MPa)</td><td colspan="4">7 500</td></tr>
<tr><td>Asphalt Poisson's ratio</td><td colspan="4">0.4</td></tr>
<tr><td>Granular layer thickness (mm)</td><td>300</td><td>250</td><td>200</td><td rowspan="3">–</td></tr>
<tr><td>Young's modulus of granular material (MPa)</td><td colspan="3">200</td></tr>
<tr><td>Granular layer Poisson's ratio</td><td colspan="3">0.3</td></tr>
<tr><td>Cement bound base layer thickness (mm)</td><td colspan="3" rowspan="3">–</td><td>200</td></tr>
<tr><td>Cement bound base Young's modulus (MPa)</td><td>10 000</td></tr>
<tr><td>Cement bound base Poisson's ratio</td><td>0.2</td></tr>
<tr><td>Sub-base Young's modulus (MPa)</td><td colspan="4">70</td></tr>
<tr><td>Sub-base Poisson's ratio</td><td colspan="4">0.3</td></tr>
</table>

Several countries have software which calculates the constraints within pavements. These allow the aggressiveness of different configurations (axle load, type of axle…) to be evaluated for each type of pavement. Direct measurements can be also taken from instrumented pavements or on pavement fatigue carrousels.

Application of the aggressiveness assessment for typical trucks

Using Equation 1 above, the relative VWF has been calculated for each vehicle configuration described in Chapter 4 of this report.

In this study, wheel configurations (single, dual) have been taken into account. The results are presented in figures 7.3 to 7.6 for the four road structures defined above.

Figure 7.3. **Relative VWF for typical trucks on a bituminous pavement designed for a low traffic volume**

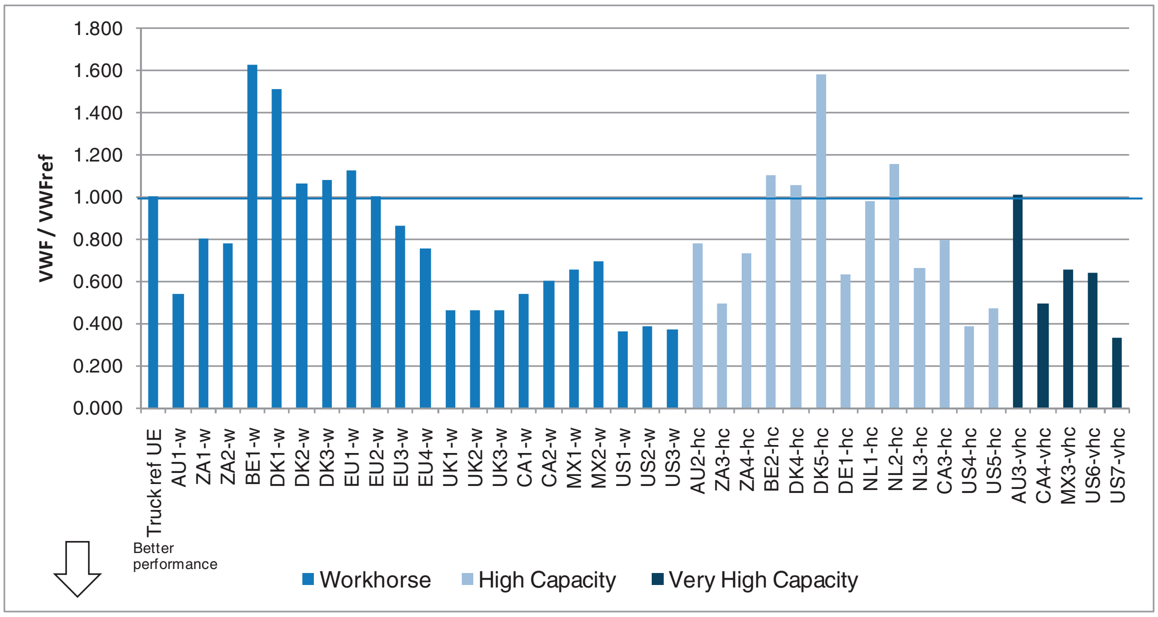


Figure 7.4. **Relative VWF for typical trucks on a bituminous pavement designed for a medium traffic volume**

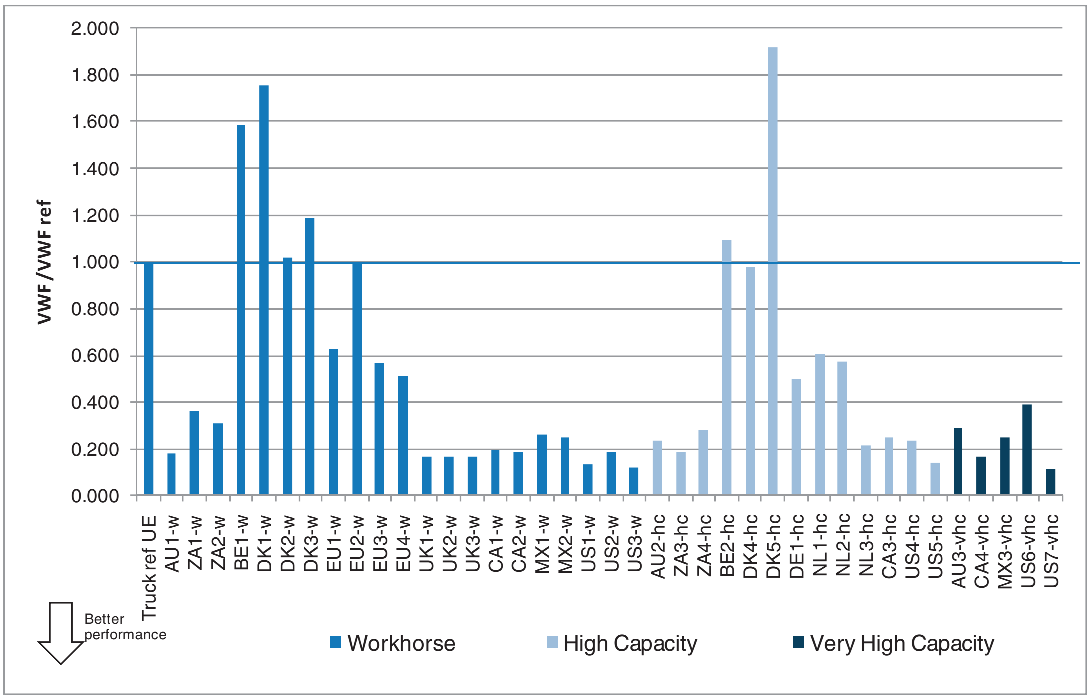


Figure 7.5. **Relative VWF for typical trucks on a bituminous pavement designed for a high traffic volume**

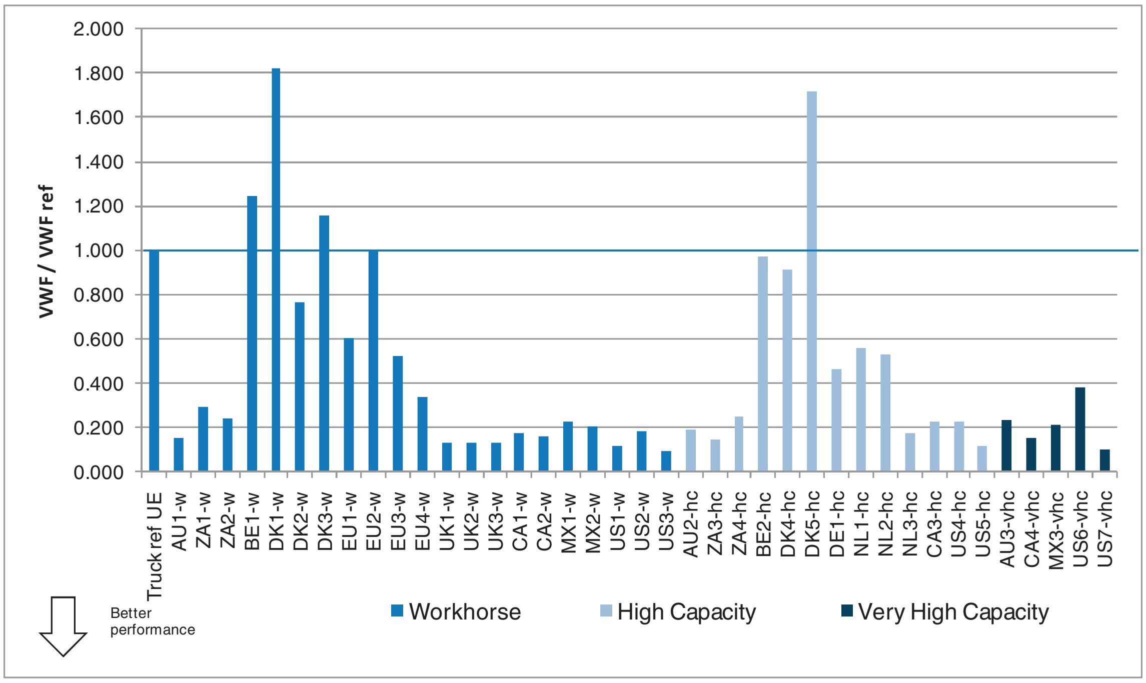
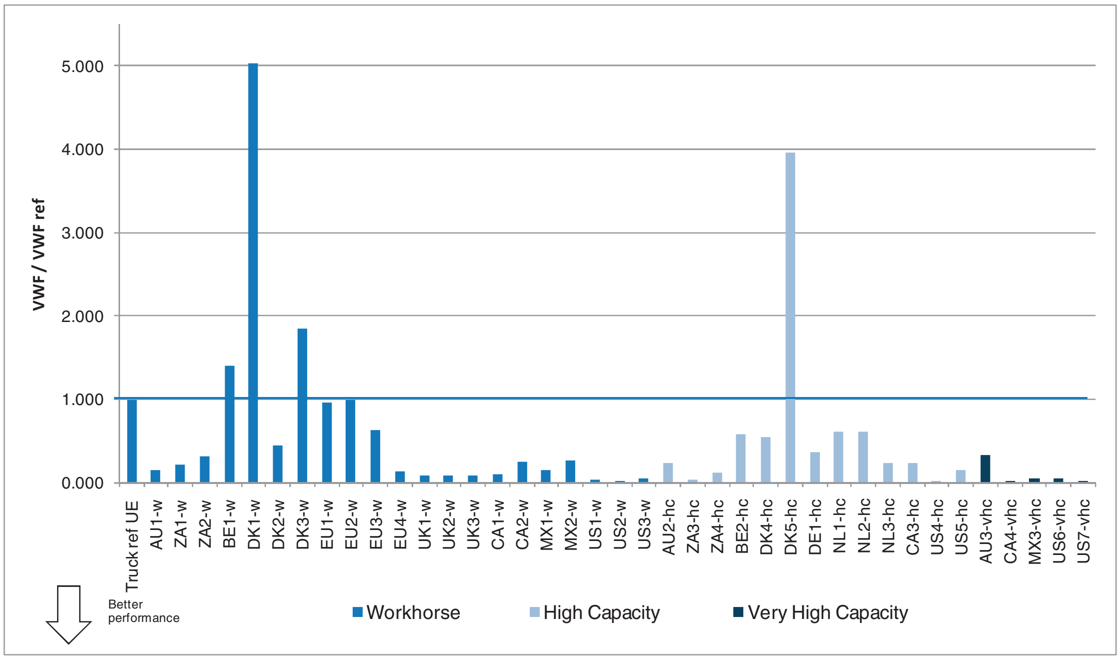


Figure 7.6. **Relative VWF for typical trucks on a cement pavement designed for a high traffic volume**



In general, it can be seen that most of the vehicles assessed are less aggressive than the reference truck (whose VWF is represented by the solid red line). For a bituminous pavement designed for a low volume traffic, 10 vehicles were found to be more ‘aggressive’ than the reference vehicle, while for a cement pavement designed for a high volume of traffic, only 4 of the 39 vehicles were more aggressive.

However, there is a large variation in the wear factor with respect to the vehicles’ shape and the type of pavement they are driving on.

This is illustrated in table 7.2, below :

Table 7.2. **Basic statistics for VWF**

		Bituminous pavement, low volume traffic	Bituminous pavement, medium volume traffic	Bituminous pavement, high volume traffic	Cement pavement, high volume traffic
Relative VWF	Min	0.335	0.116	0.098	0.010
	Max	1 631	1 917	1 818	5 032
	Ratio max/min	4 872	16 570	18 529	513 264
	Nb of trucks whose VWF > 1	10	6	4	4
	Average	0.798	0.518	0.466	0.582
	Standard deviation	0.327	0.469	0.439	0.999

It can be seen that the ratio between the less aggressive and the most aggressive trucks varies from about 5 on bituminous pavement for low volume traffic, to more than 500 for a cement pavement with a high volume of traffic. This means that for the harder type of pavement (cement pavement), the most aggressive vehicles are responsible for most of the pavement wear.

There is also no direct link between the category the vehicles belong to (workhorse/higher capacity/very high capacity) and the corresponding impact on pavements.

Whatever the type of pavement, the vehicles that are most aggressive toward the pavement do not change. Likewise, some vehicle shapes are amongst the less aggressive shapes, whatever the type of pavement.

The absolute value of the VWF is highly dependent on the type of pavement considered. The VWFs are quite similar for all vehicle configurations travelling on a bituminous pavement designed for a low volume of traffic, but they vary much more on a cement pavement designed for a high volume of traffic. The higher the α value, the more sensitive a pavement is to the heaviest axle loads, while the lowest axle loads do not affect the pavement at all.

The analysis so far has been confined only to the effect that a single vehicle has on the pavement. However, trucks perform a vital economic role so it is also essential to consider the induced pavement wear with respect to the quantity of freight that each vehicle is moving. To achieve this, the relative VWF per unit of payload is calculated by dividing the VWF(HGV_x) and the VFW(HGV_{ref}) respectively by the payload of the considered vehicle x and that of the reference vehicle. Such an analysis is reported in Chapter 4. The relative VWF per unit of payload for each vehicle type is shown in figure 7.7 to 7.10:

Figure 7.7. **Comparison of relative VWF per unit of payload for a bituminous pavement with a low volume traffic**

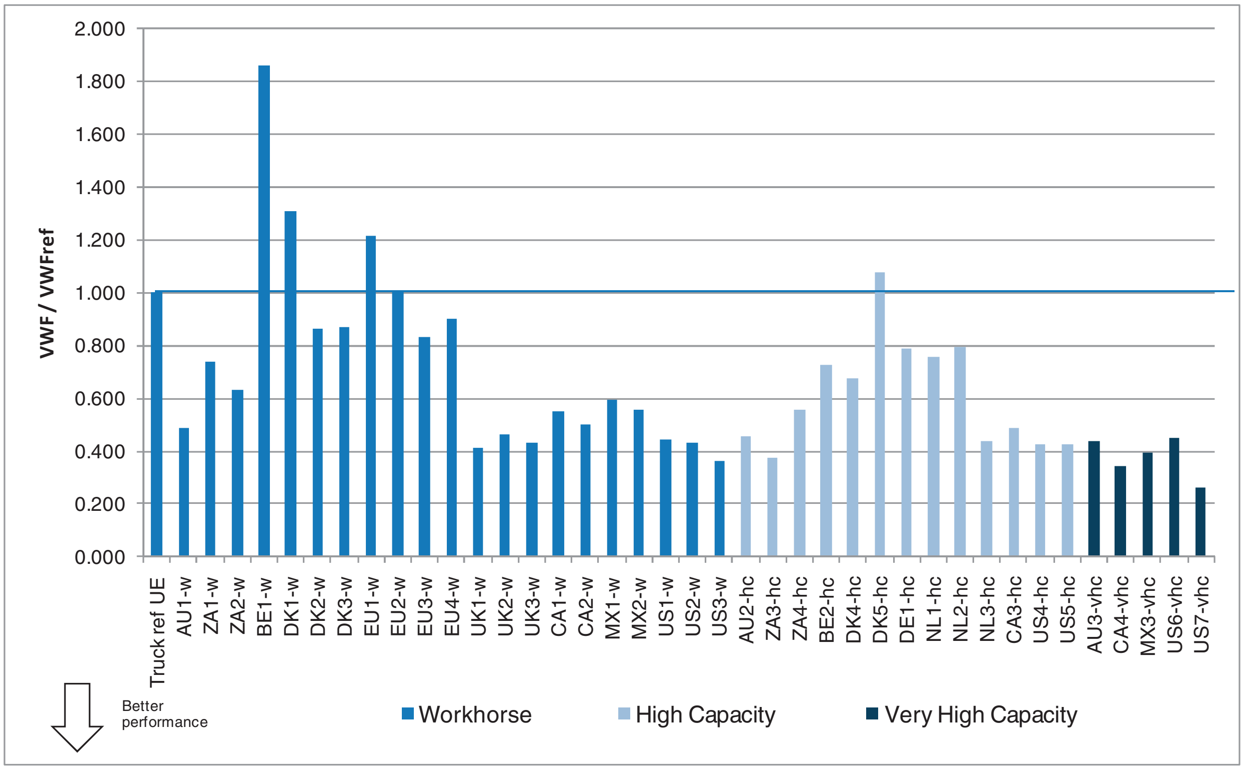


Figure 7.8. **Comparison of relative VWF per unit of payload for a bituminous pavement with a medium volume traffic**

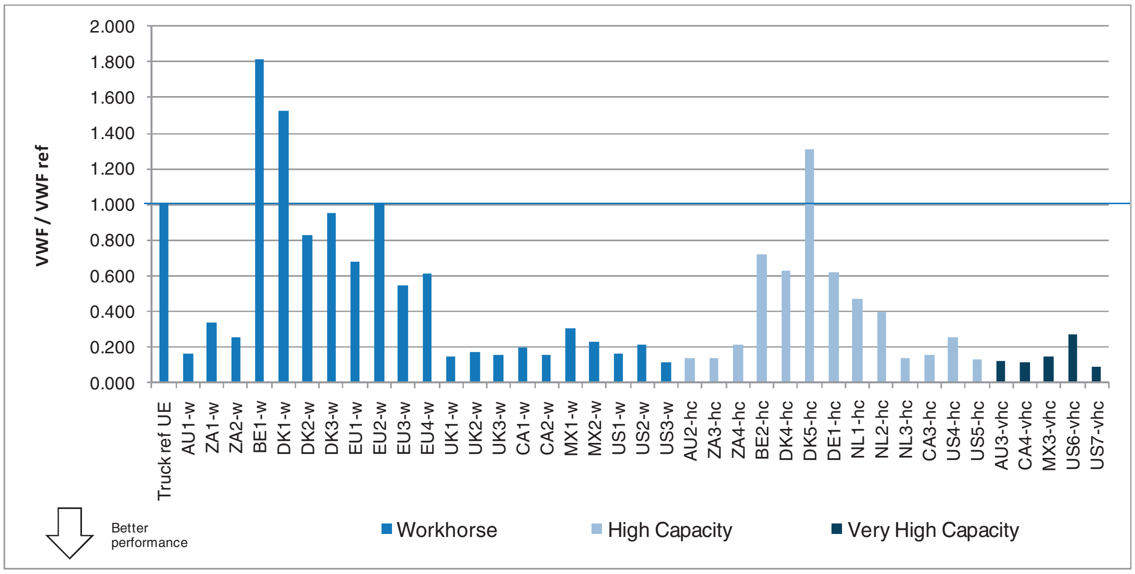


Figure 7.9. **Comparison of relative VWF per unit of payload for a bituminous pavement with a high volume traffic**

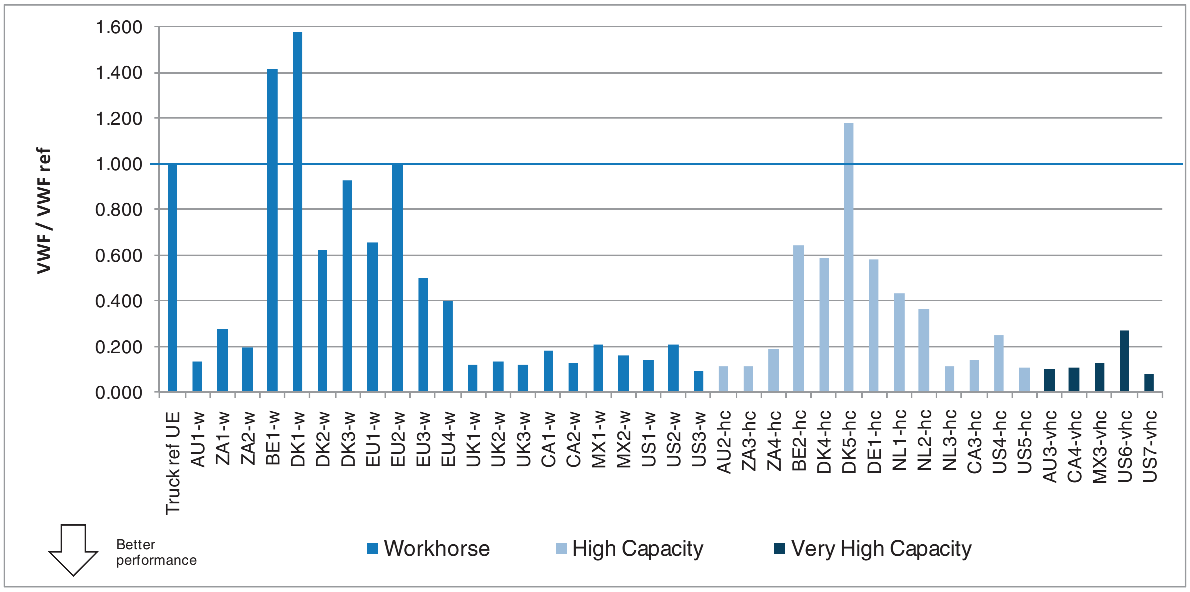
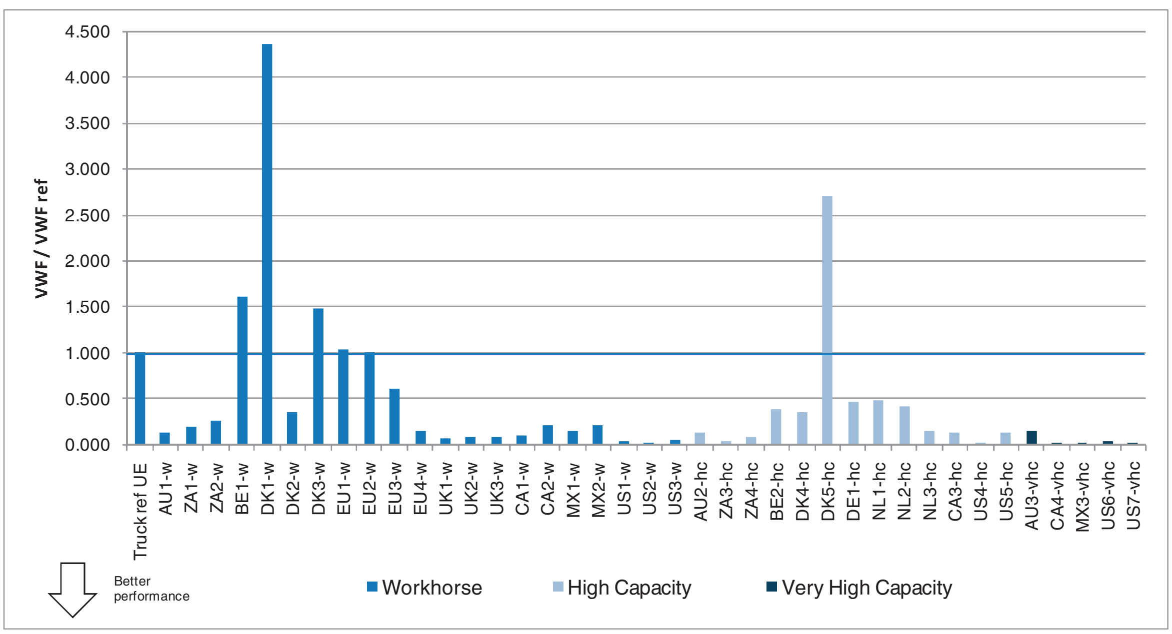


Figure 7.10. **Comparison of relative VWF per unit of payload for a cement pavement with a high volume traffic**



The same basic statistics show that, in relation to the changes on different pavement types, the same conclusions may be drawn when relating the various VWFs to the payload. A strengthening of the threshold effect could be observed because fewer vehicles have a VWF greater than 1, but at the same time the ratios of the maximum VWF to the minimum VWF were significantly greater when the VWF was related to the payload.

Table 7.3. **Basic statistics for VWF per unit of payload**

		Bituminous pavement, low volume traffic	Bituminous pavement, medium volume traffic	Bituminous pavement, high volume traffic	Cement pavement, high volume traffic
Relative VWF	Min	0.265	0.092	0.080	0.008
	Max	1 860	1 811	1 576	4 361
	Ratio max/min	7 018	19 775	19 577	561 853
	Nb of trucks whose VWF > 1	4	3	3	5
	Average	0.677	0.446	0.400	0.493
	Standard deviation	0.316	0.417	0.384	0.826

However, the conclusions are different when the different categories of vehicle are compared using the VWF per unit of payload, as shown in table 7.4.

Table 7.4. **Basic statistics for VWF per unit of payload and per vehicle category**

		Workhorse	Higher capacity	Very high capacity
Relative VWF	Min	0.028	0.027	0.008
	Max	4 361	2,705	0.447
	Ratio max/min	156 465	100 051	57 648
	Average	0.607	0.455	0.178
	Standard deviation	0.603	0.433	0.141

It can be seen that this analysis suggests that the higher, and very high, capacity vehicles tend to cause less pavement wear per unit of goods transported than the workhorse vehicles. This is particularly true for the very high capacity vehicles, where the relative VWF per unit of payload is always less than 1 (*i.e.* less than a standard EU articulated vehicle of 40 tonnes on 5 axles), unlike several other workhorse trucks. Conversely, most of the workhorse trucks have rather high VWFs and the reference truck is amongst the most aggressive per tonne of goods transported.

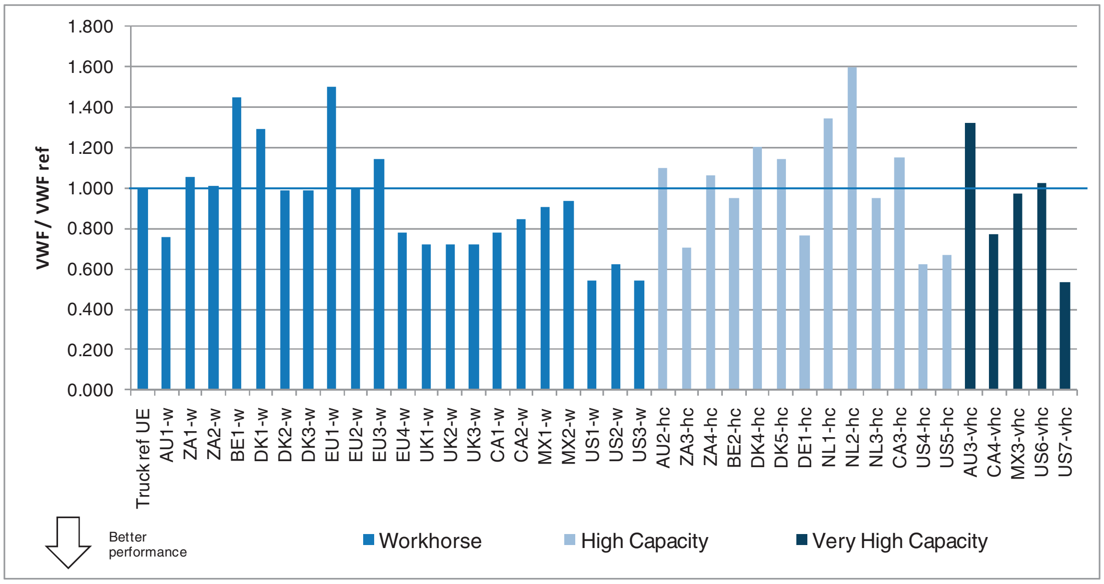
The importance of differentiating the types of pavement

By using the fourth power law, the relative VWF has been obtained for the 39 vehicle shapes. The average relative aggressiveness is 0.978, and 18 vehicles were found to be more 'aggressive' than the reference truck. The basic statistics are shown in Table 7.5.

Table 7.5. **Basic statistics for relative VWF obtained by fourth power law**

		Bituminous pavement
Relative VWF	Min	0.536
	Max	1 598
	Ratio max/min	2 981
	Nb of trucks whose VWF > 1	18
	Average	0.978
	Standard deviation	0.276

Figure 7.11. **Comparison of truck's aggressiveness for a pavement obtained by the fourth power law**



The relative VWFs values obtained by the fourth power law provides an answer that is considerably different to the relative VWFs calculated specifically for a cement pavement designed for a high traffic volume. For example, for Denmark 1, the specific value for the cement pavement is about 3.8 times greater than that predicted by the fourth power law. If the fourth power law does not take into account the type of pavement then the predicted value of aggressiveness may not be relevant to that type of pavement.

Limits of the benchmarking method

The aggressiveness of the trucks assessed in this study, was obtained for a fixed load distribution. Variations in the load distribution will affect the vehicle wear factor value, but this has not been studied. It should also be noted that, although the sample of the vehicles studied is large, it does not take into account all the special cases.

It has been shown that higher capacity and very high capacity truck combinations seem to cause less wear and tear to the road per tonne of goods transported. Conversely, most of the workhorse trucks have rather high VWFs and the reference truck is amongst the most aggressive per tonne of goods transported.

7.2.5. *Observation*

The fourth power law is too simple to evaluate truck aggressiveness on various pavement types. Using a more general power law requires first a calibration of two parameters to the pavement structure and material. If this calibration is not possible, it is necessary to document these parameters from the literature. If policy makers are considering a change to the permitted configurations of trucks, then an assessment of how aggressive each load distribution permitted by the existing and proposed regulations should be undertaken.

For a pavement designed to bear heavy traffic most of the maintenance cost is associated with maintenance of the surface layers rather than the structure. However, the mechanisms which lead to the failure of the surface layers of these pavements are very complex and are not yet well understood. So, in most cases, analysis of the maintenance cost is based on empirical approaches that are unable to differentiate the impact of different truck configurations.

To contain pavement wear, weight limits of trucks must be specified in terms of load by type of axles. The most advanced truck technologies shall be used to ensure a well-balanced load distribution among axles to reduce the pavement wear and the maintenance cost, as well as to increase the road serviceability.

Pavement wear assessment highly depends on the material and structure concerned. It is essential to improve the knowledge on surface layers behaviour under traffic loads, above all those designed for heavy and dense traffic. That would provide a background to optimise truck configurations.

7.3. The effects of trucks on bridges

7.3.1. Background and methodology

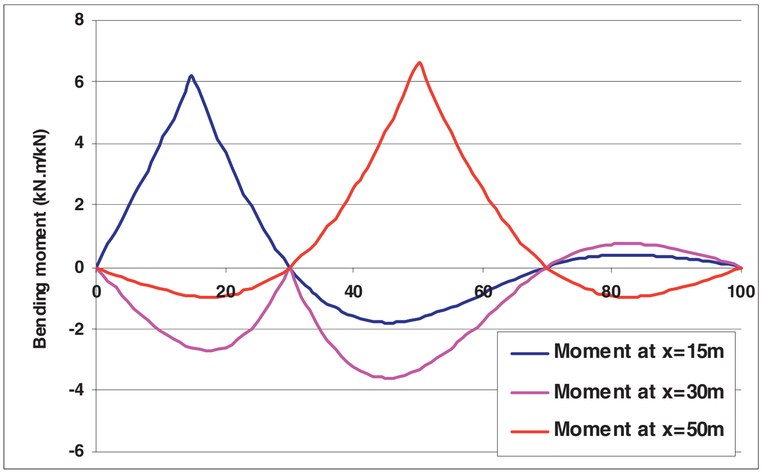
The effects of traffic loads on bridges are more difficult to assess than on pavements, because a load case usually involves more than one truck. The number of trucks involved depends on the bridge length, width (*i.e.* number of traffic lanes) and traffic density. Yet the more cars on the bridge, the less trucks, and that reduces the load effects. In addition, one load case generates an almost infinite number of load effects, *i.e.* shear forces and bending moments in each section of the bridge, pier reactions, torsion, etc. All these load effects induce strains in the structure and stresses in the materials.

The main tool used to calculate load effects, stresses or strains in bridges under traffic loads is the transfer function known as the "influence line" or "influence surface". For any given bridge section and load effect, for example a bending moment at mid-span, the influence line is equivalent to the load effect induced by a unit load applied at a point x along the bridge structure (Figure 7.12).

Then, assuming a linear behaviour of the bridge, for a set of axle loads F_i applied at the abscissa x_i, the total load effect is: $S = \Sigma_i \ F_i \ f(x_i)$.

For a number of reasons, the theoretical influence lines usually differ from the real influence lines of the bridge. Bridge weigh-in-motion systems, *i.e.* WIM systems that use instrumented bridges as the weighing scales, can be used to evaluate the real influence lines and thus optimise the evaluation of traffic loading on bridges[2].

Figure 7.12. **Bending moments at mid-span (spans 1 and 2) and on pier of a continuous 3 span (30 – 40 - 30 m) girder bridge, in kN.m/kN**



The use of influence lines to assess strains and stresses is based on the assumption that the behaviour of the bridge remains elastic, *i.e.* the strains and stresses are proportional to the applied loads. However, in some cases, such as a cracked concrete bridge where a temperature gradient exists, non-linear behaviour may occur. Influence lines are expressed in kN/kN or kN.m/kN (shear forces or moments), or in µdef/kN or MPa/kN (strains or stresses). If the load effect depends on the transverse location of the load, the influence line is replaced by an influence surface (2-D function of x,y).

Once the influence lines, or surfaces, of the main load effects to be checked are known, the induced load effects (or stresses/strains) can be easily calculated for any single load case. However, in conditions of typical free-flowing traffic (which could be measured by a set of WIM data), more complex analyses using software such as CASTOR-LCPC or POLLUX [Eymard & Jacob, 1989] is required to calculate the time history of the load effects so that the extreme values (local maxima and minima) and the so-called "level-crossing" values[3] can be identified.

To assess the lifetime of a bridge feature under repeated traffic loads (see 7.3.3 for more details on fatigue), it is necessary to know the time history of the stress cycles, or at least the "rain-flow[4]" – the distribution of the stress variations. The same software can be used to provide this for free traffic conditions.

The extreme load effects calculated, or measured, on a bridge under traffic loads need to be extrapolated all along the bridge lifetime. These extrapolated values are known as nominal values and can be expressed as values which are exceeded over a lifetime D with a probability α.Then, such a value is said to have a return period $T \approx -D/\ln(1-\alpha) \approx D/\alpha$ if α is small enough (*e.g.* 0.05). In the Eurocodes, the recommended return period for the nominal loads on road bridges is 2 000 years, which corresponds to a 5% probability of being exceeded in 100 years.

Conventional load models (design loads) for bridges increase the nominal loads by safety factors (γ_s) to allow for uncertainties that are not explicitly contained in the models. In addition, some dynamic amplification factors (DAF) are applied to the static design loads. The extent to which DAF are applied depends on the span length and, sometimes, on the bridge type (see 7.3.4).

Bridges are routinely designed for loads considerably larger than those imposed by vehicles currently in use. The use of longer and heavier vehicles would, however, mean significant differences in applied loading, dynamic effects, overloading etc. Even if the vehicle is composed of current trailer units, it cannot be assumed that its loading is automatically catered for by the current loading specifications.

The ability of a bridge to carry longer and heavier vehicles would not only depend on the axle loads and spacing, and the gross weight, but also on the length of the bridge span and the effects considered (shape of the influence lines). In addition to the vertical loads considered so far, the specifications of a bridge will also allow for the horizontal forces transmitted through the deck as a result of vehicle braking and cornering.

Therefore, to assess bridges under traffic loads, it is necessary to have detailed data on the traffic loads, *e.g.* WIM data [Jacob *et al*., 2002], the relevant transfer functions (*e.g.* influence lines and surfaces), and additional information about the expected lifetime of the bridge, the traffic trend, and a fatigue model.

7.3.2. Extreme traffic loads and load effects on road bridges

The first issue to be considered in a bridge design, or verification, is to check that none of the structural components will fail or be damaged under the maximum load effect encountered during the bridge lifetime. Most of the design codes distinguish the ultimate limit states (ULS), which correspond to failure or permanent damages, and the serviceability limit states (SLS), which correspond to strains which may affect the bridge operation (*e.g.* traffic safety) but not the stability of the structure, and are reversible. The SLS are reached under the nominal values of the loads, while the ULS are reached under the design values of the load, *i.e.* the nominal values multiplied by the safety factors.

The number of elements of a bridge that are sensitive to the live (traffic) loads is unlimited, so it is common to identify 3 scales:

- The local effects, with influence lines or surfaces of between around 1 to 3 meters in length and width, and which are only related to axle loads or bogie loads.
- The semi-local effects, with an influence area of a few meters (approximately 2 to 10 m), which are related to bogie loads or the gross weights of short vehicles.
- The global effects, with an influence area of more than 5 to 10 m, generally a whole span or even the whole bridge (if multi span). These are related to the gross weights of the trucks, and generally by the number of trucks on the bridge at the same time.

Local effects can include punching forces, some shear forces, and the bending moments of local details (*e.g.* steel plate of an orthotropic deck), etc. Semi-local effects include the shear forces of short spans, the bending moment of very short spans (less than 10 m), and the effects in cross beams, etc. The mid-span and on-pier bending moments of medium and long spans (main girders, concrete boxes), and the tension in cables (cable stayed and suspended bridges) are considered to be global effects.

The extreme values of local and semi-local effects are governed by the heaviest axle loads, or bogie loads, that are likely to occur within the lifetime of the bridge [Flint & Jacob, 1996]. The maximum permitted loads are important, but not directly linked to these extreme values, because of:

- The variable number of axles on trucks.
- Overloading (illegally loaded vehicles).
- Abnormal load vehicles, *i.e.* vehicles carrying indivisible loads of exceptional mass or length, which operate either with a permanent authorisation or under special permits.

In some countries there are frequent exceptional loads, for example the large cranes in the Netherlands. In some countries (*e.g.* France), log trucks are authorized at higher gross weights than those normally permitted (48 t on 5 axles and 57 t on 6 axles instead of 40 or 44 t).

For global effects and some semi-global effects, particularly on multi-lane bridges, the loads imposed by individual vehicles are no longer the factor that determines the extreme loads on the bridge. In these situations it is the combination of the loads imposed by two or more trucks travelling on the bridge at the same time. The gross mass, length, spacing and respective location of each truck in each traffic lane all influence the induced load effects. It is still possible to assess the "aggressiveness" of a single truck, which is of interest for span length or influence length up to approximately twice the truck length, but not for very long spans. It was found in the background studies of the Eurocode EN1991-2 [Flint & Jacob, 1996] that for span lengths up to 30 or 40 m, the free traffic case was governing the extreme load effects, *i.e.* the heaviest single truck, or crossing case of two very heavy trucks. Above this length, the congested case was dominant, with a queue of stationary heavy trucks being the worst case.

The equivalent uniformly distributed load (EUDL), which is the total truck mass divided by its total length, is an important parameter used to assess the global, and some semi-local, load effects. That is the origin of the US bridge formula which is used to limit the total mass carried by any series of consecutive axles in a truck or combination by:

$$W = 500*(L*N/(N-1) + 12N + 36) \quad \text{W in pound, L in feet} \qquad (3)$$
$$\text{or } W \approx 250*(3L*N/(N-1) + 12N + 36) \quad \text{W in tonne, L in meter} \qquad (3')$$

W = maximum allowable vehicle weight that can be carried on a group of two or more axles (permissible bridge formula mass).
L = distance between the outer axles of any two or more consecutive axles.
N = the number of axles being considered.

Figure 7.13 shows the relative aggressiveness of each of the 39 international trucks assessed in the performance benchmarking (see chapter 4), in comparison with the 40 tonne European reference truck, composed of a 2-axle tractor and a semi-trailer with a tridem axle. For each truck (the categories on the x-axis), the coefficient plotted on the y-axis is the ratio of the maximum load effect (here bending moment) under the considered truck to the maximum load effect (here bending moment) under the European reference truck. For span lengths of 50 to 100 m, the longer and heavier trucks are much more aggressive than the reference truck, but it should be noted that for such span lengths, more than one reference truck may be together on the same span.

All vehicles examined in this study comply with regional bridge loading, but these vary between different countries. In the absence of an accepted international bridge load factor measure suitable for this analysis, a simplified method of evaluation was investigated based on the US bridge formula.

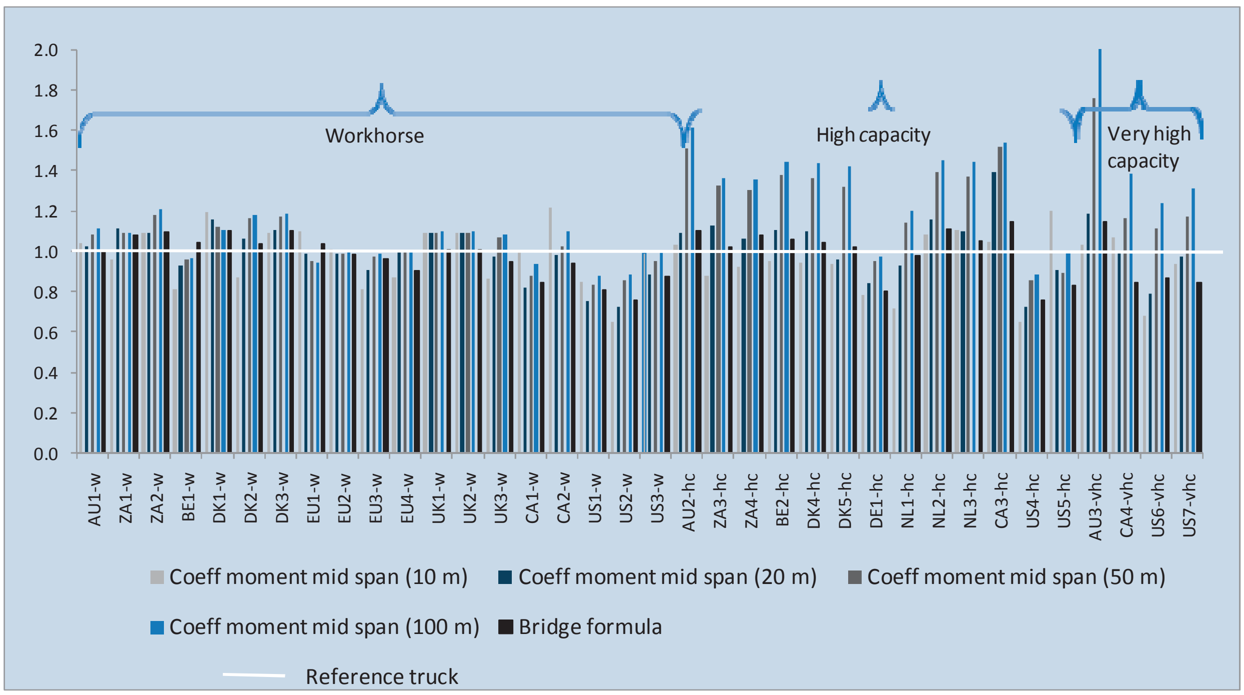
The coefficient of relative aggressiveness C_n, corresponding to the Bridge formula (black bars in the chart) are defined as:

$$c_n = W_n/W_{n,bf} \qquad c_{ref} = W_{ref}/W_{ref,bf} \qquad C_n = c_n/c_{ref}$$

where: W_n and W_{ref} are the gross weights of a given truck n, and of the reference 40 tonne truck, $W_{n,bf}$ and $W_{ref,bf}$ are the maximum gross weights of these two trucks according to the US bridge formula given in Eq. 3'. In our case, $c_{ref} = 40/33.5 = 1.194$.

C_n gives an account of the relative excess of weight of the truck n with respect to the reference truck, both related to the bridge formula load limit.

Figure 7.13. **Comparison of impacts of trucks on bridges as shown by the relative coefficients of aggressiveness***
(maximum bending moment at mid span)



* With respect to a reference truck (5 axle articulated tractor with semi-trailer, 2S3, 40 t, 16.5 m) regarding the maximum bending moment at mid span of simple supported and 2 or 3 span continuous beams.

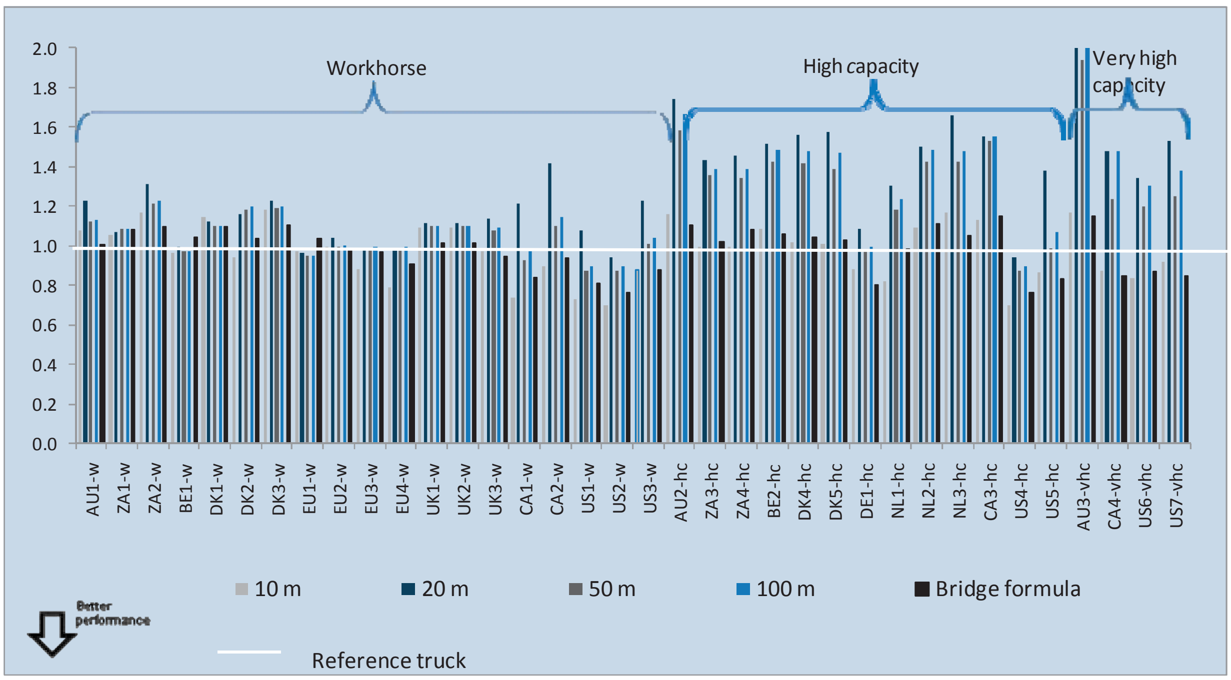
The bridge formula (black bars in Figure 7.13) almost fits the 20m span length bending moment. This means that if a truck conforms to the US bridge formula, the maximum bending moment induced by the vehicle on a 20 m span will remain almost constant whatever the truck design. However, for span lengths above 30 or 40 m, the bridge formula substantially under-estimates the extreme load effects of long and heavy vehicles, particularly the Australian 12-axle combination of 33.3 m and 90.5 t (AU3-v), two Canadian 8 or 9-axle combinations of 20.4 and 38.33 m and 62.5 t (CA3-h and CA4-v), and the European Modular System with 8 axles, 25.25 m and 60 t (NL2-h).

On very short spans (10 m), the bridge formula is also inaccurate for some trucks, such as the Canadian or US 3-axle tractor with 3-axle semi-trailer of 46.5 or 44.1 t and 21.55 or 25.1 m (CA2-w or US5-h).

These results show that the bridge formula was calibrated against the bending moment of a 20 m span, *i.e.* of an average US truck length. For shorter spans (*i.e.* 10m), this formula would apply on a subset of consecutive axles of a truck. For longer spans, the formula does not apply while more than one truck may be on the span in the same traffic lane.

Figure 7.14 suggests that the bridge formula for the on-pier bending moment was calibrated for a 2-span continuous beam of 10 + 10 m, which also corresponds with a total loaded length close to the average US truck length. For any longer spans, the formula under-estimates the load effects of most of truck combinations.

Figure 7.14. **Comparison of impacts of trucks on bridges as shown by the relative coefficients of aggressiveness***
(intermediate pier bending moment at mid span)

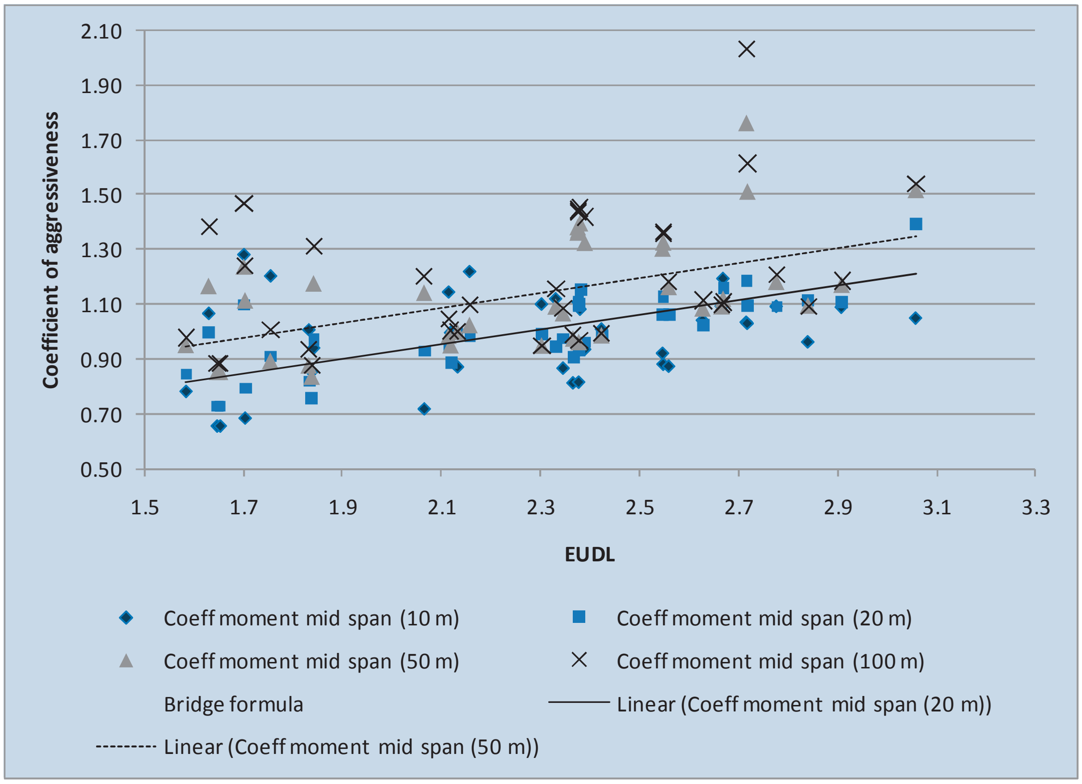


* With respect to a reference truck (5-axle articulated, tractor with semi-trailer, 2S3, 40 t, 16.5 m), regarding the span length for several load effects (mid span and over an intermediate pier bending moment for simple supported, 2 and 3-span continuous beams, and shear forces).

As the productivity of the vehicle increases the impact on the bridges tend to increases. Figure 7.13 and 7.14 show that many more bars exceed the reference truck aggressiveness (white line, C_n=1) among the higher and very high capacity vehicles than among the workhorses. (However the lowest aggressiveness was from the higher capacity vehicle group, which proves that some of these vehicles perform very well. That is the case for long, or very long, vehicles with a low ratio gross weight/length (EUDL). The worst performing vehicle was also found in the very high capacity vehicle category: the Australian 12-axle combination of 33.3 m and 90.5 t (AU3-v), with an EUDL of 2.72 instead of 2.42 for the reference truck.

Figure 7.15 illustrates the relationship between the coefficients of aggressiveness C_n and the EUDL of each of the vehicles, for each load effect and the bridge formula. It shows that the effects of the vehicles which comply with the bridge formula are directly proportional to their EUDL (this comes directly from the construction of the formula). It also shows that there is a linear trend between the EUDL and the coefficient of aggressiveness, in particular for the short and medium spans. For the longer span lengths, the points are more scattered, because of the lower impact of a single vehicle on a longer span. In other words, increasing the maximum mass of a truck, without increasing its length, significantly increases its aggressiveness to bridges.

Figure 7.15. **Coefficients of aggressiveness as a function of the EUDL (ratio of gross vehicle weight divided by the total vehicle length)**



The bridge structural indicators were developed specifically for this study in order to compare the relative bridge impact of vehicles from several countries. Given that bridge formulae differ from country to country, and that the strength of the bridge stock varies from country to country, it would be appropriate that each country use their own bridge formula as opposed to the US formula used for this generalised analysis.

Several European studies, for example De Ceuster *et al*. (2008), investigated the effect of longer and heavier vehicles on the load effects induced in bridge structures compared to those of standard trucks. It was shown that to match the effects of the reference truck the total mass must not be increased by a greater proportion than its length, thus maintaining a constant EUDL. Even when the length and mass were increased by the same proportion the aggressiveness of the truck combination tends to increase, particularly for medium and long spans, and it was shown that the European Modular System (EMS) truck of 60 t and 25.25 m was approximately 50% more aggressive on most bridges than the standard 5-axle articulated vehicle of 40 t and 16.5 m. In order for the 8-axle EMS combination to be equally aggressive as the 5-axle, 40 tonne reference vehicle, the gross weight would need to be limited to about 50 to 52 tonnes.

A report by TNO [Vrouwenvelder, 2008] is less pessimistic and tends to suggest that EMS combinations would not have too many unfavourable effects on Dutch bridges, provided that the greater weight is uniformly distributed over the greater vehicle length. However, it was suggested that in future, combinations restricted to a maximum weight of less than 60 t would help to avoid any unfavourable effects on bridges.

Glaeser *et al*. (2006) studied the likely effect of the introduction of 60-tonne, 25.25 m LHVs on German bridges and concluded that they would reduce the load reserve of current bridges but would not harm their wearing capacity. The bridges constructed from pre-stressed concrete before the 1980s were particularly at risk because they were designed for a different temperature range, and thus the combination of a temperature gradient and the maximum traffic loads could become critical.

Knight *et al*. (2008) investigated the likely effect of different LHV combinations and concluded that most of the combinations assessed would not have negative effects on current UK trunk road bridges. In fact, for some combinations (intended for increased volume capacity, not increased mass capacity) the bending moment and shear forces could actually be lower. According to the British road authorities, only some 3% of UK trunk road bridges would not be suitable for existing 44 tonne vehicles or 60 tonne LHVs. If 82 tonne vehicles were to be permitted, then up to about 25% of road bridges on the main network and a greater proportion of bridges on the local network would be at risk.

Finally, it should be noted that most of the studies based on the EUDL, the bridge formula, or even the maximum load effects induced by one truck, ignore the cumulative effects of:

- A platoon of heavy trucks, on one lane.
- Heavy trucks side by side, either crossing each other or overtaking each other on a peak of the influence line.

For bridges with more than 2 lanes, these effects could be greater. The probability of occurrence of multiple trucks on a bridge deck, with respect to the span/bridge length, the truck lengths and the traffic density, are not very well known or well modelled. Therefore, the best approach to assess the extreme load effects is to use medium or long term WIM data (*e.g.* recorded over at least a week, preferably a month or more) recorded on all the traffic lanes (used by trucks), and then to carry out the appropriate extrapolations, which are based on some stationary assumptions. However, most design standards including the Eurocode on “Traffic Loads on Road Bridges”, EN1991-2 [CEN, 2002], make some very conservative judgements about the number of vehicles on the bridge, the dynamic amplification, overloading etc., and bridges have to be designed to withstand these conservative loads for the life of the structure. These loads are much greater than anything likely to be actually observed by WIM data, even over a couple of months.

In addition to the vertical loads, horizontal forces (braking and cornering forces) and shock loading (*e.g.* collisions with piers, safety barriers, etc.) need to be considered.

7.3.3. Fatigue of bridges

Steel bridges and steel parts of composite bridges have some details (welds) that are sensitive to fatigue. Repeated traffic loads induce stress variations (cycles) which may propagate cracks, generally initiated during the construction of the bridge. Not all trucks contribute to fatigue damage, but the heaviest trucks do. For a common assessment of the fatigue resistance of new bridges, the simple Miner’s law[5] is used, combined with traffic load data from WIM sites [Jacob, 1998].

Roughly speaking, the damage (and therefore the aggressiveness in fatigue) of an axle or a truck is proportional to the 3rd or the 5th power of the load (assuming that the stress is proportional to the load, and that a single axle or truck induces one cycle), and the damage increases proportionally to the traffic density.

A bridge verification for fatigue starts by checking if, under a rather heavy load, for example the daily maximum load, the fatigue limit S_e is exceeded for the design detail under consideration. If not, there is no damage and no further checks are required. If the limit is exceeded, a lifetime calculation is necessary, and all the stress cycles with an amplitude larger than S_t must be taken into account.

As in section 7.3.2, the local effects are sensitive to the repeated axle or bogie loads. That is mainly the case in orthotropic decks. For such a structure, the lateral wheel location (wheel path) is of great importance. For local or semi-local effects, the damage increases approximately proportionally to the number of axles or trucks, and with the 5th power of the mean axle loads or gross weight. One truck mostly induces one stress cycle.

Global effects are more complex because a large proportion of cycles, particularly the cycles with the largest magnitude, are induced by the presence of more than one truck. It then becomes necessary to calculate (or measure) the real stress cycle distribution under a given traffic pattern. Main girder details (of composite bridges or steel bridges) such as vertical stiffeners welded on girder flanges are sensitive to fatigue due to the global bending moment (at mid span or on pier). Span lengths between 30 and 90 m are common for these bridges. For the shortest spans, one truck (or two trucks side by side) induces a stress cycle. For the longest spans, a small number of closely spaced trucks may induce larger stress cycles. Because of the 5th power dependence, if two heavy trucks are passing side-by-side on a bridge of *e.g.* 40 to 60 m in length, instead of two cycles of amplitude S, the fatigue sensitive detail may get one cycle of let us say 1.5 S, which induces $0.5\ (1.5)^5 = 3.7$ times more damage.

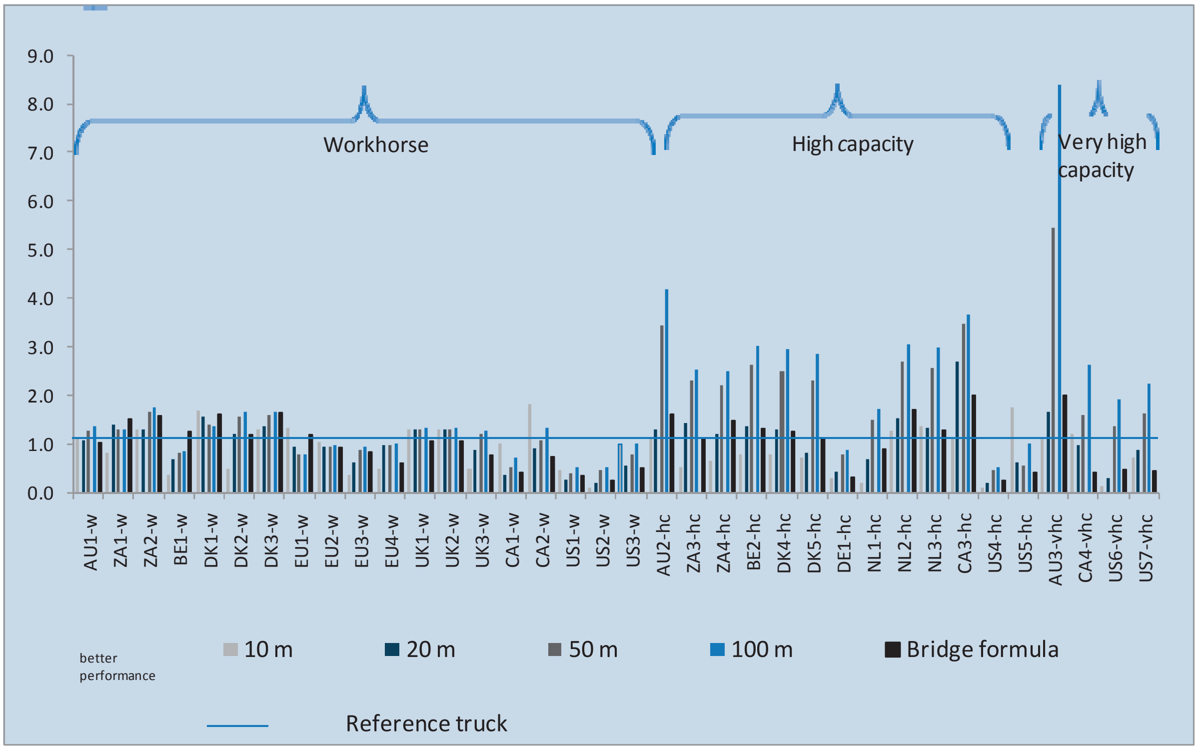
Figures 7.16 and 7.17 show the relative aggressiveness in fatigue of a single truck with respect to the reference truck, for stresses induced at mid span by bending moments, and for several load effect induced stresses, for span lengths from 10 up to 100 m. The bar charts are similar to those of figures 7.13 and 7.14, with more difference because of the 3rd or 5th powers. As for the maximum load effects, the bridge formula fits very well the results for span lengths of 20 m (at mid-span) and of 10 m (on-pier).

Compared to the reference truck (5-axle, 40 t and 16.5 m), on short, simple, supported spans (10 m) most of the longer (and heavier) trucks are less aggressive, particularly if the axle or bogie loads are decreased (figure 7.16). Short and heavy trucks or those with higher bogie loads are more aggressive. But for span lengths above 40 m (mid span effects) or even 20 m (bending moment on pier), longer (and heavier) trucks become 3 to 4 times more aggressive, and up to 10 times for the 90.5 t and 33.3 m Australian AU3-v combination (figure 7.17).

The relationship between fatigue damage and the load or stress amplitude is not linear. This means that if the total vehicle weight is increased by the same proportion (*e.g.* 10%) as the number of vehicles is decreased, then the net result is increased bridge damage and reduced lifetime. If the truck gross weights are increased, the vehicle length is increased proportionally (to maintain the same load per metre of bridge) and more axles are added (to maintain the same axle loads) then the fatigue damage on medium and long spans could still be increased. This is also the case for shorter spans where there are structural elements that are sensitive to the bending moment on pier effects (*i.e.* load effects of multiple span bridges which have influence lines of the same sign).

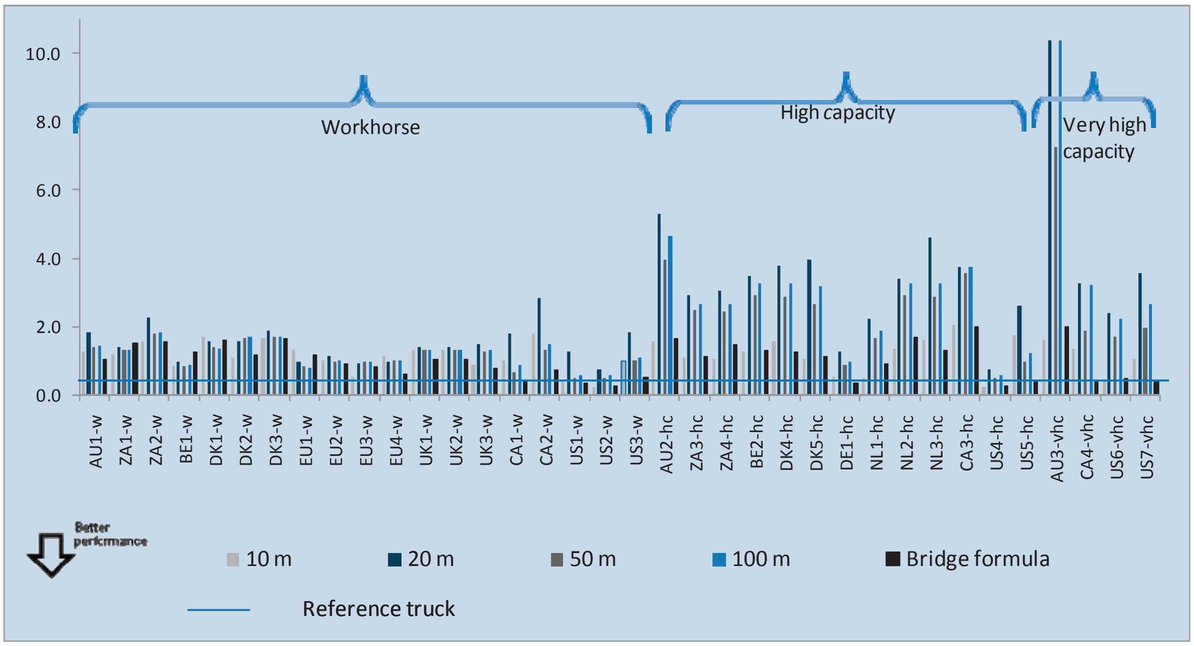
The three European Modular System trucks loaded at 60 t (BE2-h, DK4-h and DK5-h) are almost 3 times more aggressive than the reference truck for pier moment effects, and 2.5 times for the mid span moment effect on medium and long span bridges.

Figure 7.16. **Aggressiveness in fatigue of a series of international trucks***



* With respect to a reference truck (5-axle articulated, tractor with semi-trailer, 2S3, 40 t, 16.5 m), regarding the bending moment induced stresses at mid span of simple supported and 2 or 3 span continuous beams.

Figure 7.17. **Aggressiveness in fatigue of a series of international trucks ***



* With respect to a reference truck (5-axle articulated, tractor with semi-trailer, 2S3, 40 t, 16.5 m), regarding the span length for several load effect induced stresses (at mid span and on pier bending moment for simple supported, 2 and 3-span continuous beams, and shear forces).

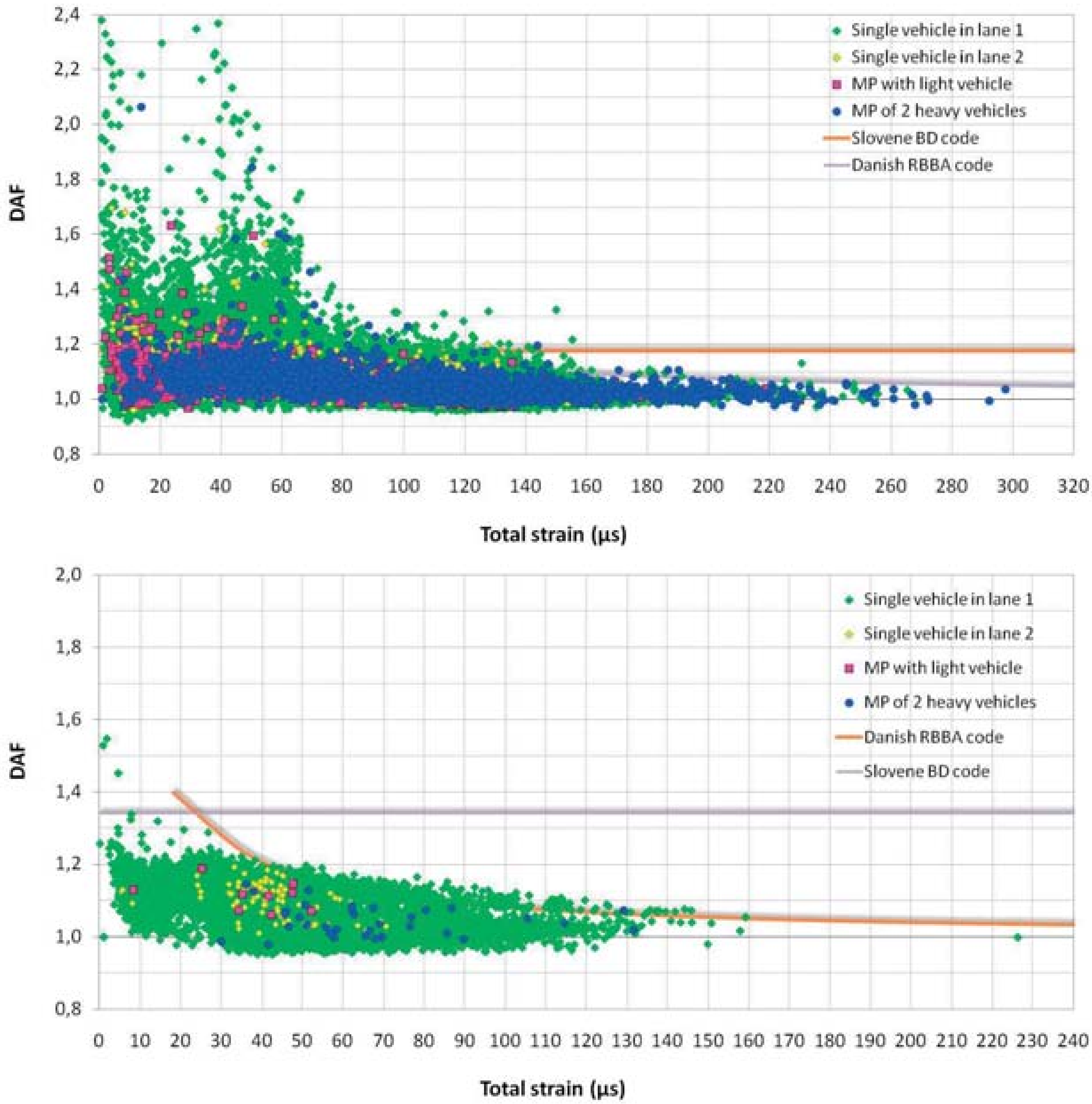
7.3.4. Dynamic truck/bridge interaction

The European ARCHES project (Assessment and Rehabilitation of Central European Highway Structures)[6], includes a task on the assessment of realistic dynamic loading of bridges. Some stresses are thought to be induced in bridges due to dynamic interaction between traffic and the bridge. In Western countries the mean allowance for dynamic amplification is up to about 30% (Cooper in the UK recommends 27% [Cooper, 1997] and the United States AASHTO code specifies 30%). If road surfaces are poorly maintained, dynamic loading is thought to be considerably higher. However, the dynamic values specified in bridge design codes are generally based on measurements of the bridge response during the passage of typical vehicles, usually when they are alone on the bridge. This does not correspond to the maximum loading situations found on bridges under normal traffic conditions (*i.e.* on bridges without load limits). There is increasing analytical and experimental evidence to suggest that the dynamics of the critical multiple vehicle events are much less – as low as 6%. Figure 7.18 shows two rather different examples of measured dynamic amplification factors (DAF). The upper graph shows DAF values of 148 000 loading events measured on a simply supported pre-stressed concrete beam bridge deck with a 24 m span. The lower graph shows DAF values for 56 000 loading events measured on a 7.2 m integral slab bridge. While DAF values of lighter individual vehicles are much higher, reaching values over 2 on the simply supported bridge with a bump over the expansion joint, DAF values of the heaviest loading events in both cases approach 1.

The diagrams in figure 7.18 demonstrate another important difference between two sites. The first measurements were done on the 10th Trans European Road corridor in Slovenia, with an average daily traffic of around 25 000 vehicles, of which around 3 000 were trucks (motorway in 1 direction). There are very few exceptionally heavy vehicles on Slovenian (and other Central European) roads, so the maximum loading events were caused by two heavy vehicles meeting around the mid-span. The second measurements were done in the Netherlands, on a motorway carrying nearly 60 000 vehicles per day, of which there were around 5 000 trucks per direction. In contrast to the Slovenian site, trucks in the Netherlands could not overtake each other. The extreme loading events in this case were caused by the exceptional vehicles, such as cranes and low-loaders, the most aggressive one being a 107-tonne low loader with 6-axles. Its 57-tonne twin axle induced strains that were almost 30% higher (the 226 μs dot in the chart above) than any other vehicle.

The ARCHES project will publish new recommendations regarding the DAF values to apply for assessment of existing bridges.

Figure 7.18. **Measured DAF factors of loading events***



* On a 24-m long simply supported span with a relatively smooth pavement (top) and on a 7.2-m long integral bridge with a very smooth pavement (bottom).
MP = multiple truck event, BD = Bridge Design, RBBA = Reliability Based Bridge Assessment.

7.3.5. Monitoring traffic load and stresses

Traffic loads are typically collected with weigh-in-motion systems [Jacob *et al*., 2002]. When using such data for bridge assessment it may be particularly appropriate to use bridge WIM systems [O'Brien *et al*., 2008] which, in addition to the traditional WIM data (vehicle gross weight and axle loads, axle distances, vehicle category etc.), can measure structural parameters, such as real influence lines and load distribution factors. Using such measured, statistically described parameters can add considerably to the optimisation of the structural models that are used for bridge assessment.

In addition to the strain transducers that are used for weighing (Figure 7.19), modern bridge WIM systems can accommodate additional sensors to acquire other data (*e.g.* temperature, deflection, acceleration) that are used in bridge assessment and monitoring. Readings from these devices can then be directly correlated to the loading that caused this deflection, acceleration etc.

Figure 7.19. **Strain measurements with a bridge WIM system on a concrete slab bridge (left) and on an orthotropic deck (right)**

The use of such advanced load monitoring systems may lead to the implementation of a heavy traffic monitoring system to reduce the worst loading cases and the damage induced to the bridges. The European FP6 project HEAVYROUTE[7] developed some strategies and tools to monitor the heavy traffic on bridges and to make short-term forecasts of the loading cases, and mechanisms were proposed to reduce the load effects on the most sensitive bridges. These could include some variable message signs or targeted messages to the heaviest trucks to increase their spacing on long- or medium-span bridges, thus reducing the total load on the bridge, or to adjust their speed to avoid some critical crossing situation where two very heavy trucks might be side-by- side at the point corresponding to the peak of the influence lines. For fatigue concerns, some more advanced strategies are also expected.

7.4. Safety barriers, piers, bridge supports and expansion joints

7.4.1. Collisions with safety barriers and piers

In Europe, safety barriers are tested and certified according to the European Standard EN 1317 [CEN, 1998]. The standard defines different containment levels for safety barriers given in Table 7.7. In the United States of America, comparable tests for safety barriers are defined [Ross *et al*., 1993].

The highest containment level given in the European standard EN 1317 is H4b, this means an impact test with an articulated truck of 38 tonnes that hits the safety barrier with an impact speed of

65 km/h and an impact angle of 20° (Figure 7.20). The test with the truck shows the level of containment and working width of the safety barrier, and the test with the small car (TB 11) is undertaken to verify that the satisfactory attainment of the maximum level (truck) is also compatible with safety for a light vehicle.

Table 7.7. **Test parameters according to EN 1317**

Containment level	Test	Impact velocity [km/h]	Impact angle [degrees]	Total vehicle mass [kg]
N1	TB 31	80	20	1 500
N2	TB 11 (car)	100	20	900
	TB 32 (car)	110	20	1 500
H1	TB 11 (car)	100	20	900
	TB 42 (rigid truck)	70	15	10 000
H2	TB 11 (car)	100	20	900
	TB 51 (bus)	70	20	13 000
H3	TB 11 (car)	100	20	900
	TB 61 (rigid truck)	80	20	16 000
H4a	TB 11 (car)	100	20	900
	TB 71 (rigid truck)	65	20	30 000
H4b	TB 11 (car)	100	20	900
	TB 81 (articulated truck)	65	20	38 000

Figure 7.20. **Example for impact tests TB 11 (left) and TB 81 (right) on a safety barrier for bridges**

The German Federal Highway Research Institute (BASt) undertook impact tests (according to EN1317) of containment level H4b to assess different safety barriers of concrete and steel intended for installation on German bridges. For the first time, these tests included measuring the forces acting on bridges [Kuebler, 2008].

The updated German regulation governing the use of safety barriers states that safety barriers of containment level H4b should be installed on new bridges over highways if an accident where a truck fell from the bridge would be likely to cause an undue hazard to a third party (*e.g.* high-density area or explosive industries under the bridge). In most other cases H2-barriers should be installed on bridges. In the central reservation of German highways, the containment level H4b shall be provided in areas where there is an increased likelihood of trucks leaving the road and/or where the truck traffic exceeds 3 000 vehicles per 24 hour period.

In several countries, the safety barriers and their anchorages are designed for older trucks that tend to be lighter than those currently in use. The up-grading of these devices would incur additional expenses, but should be considered in order to maintain the safety level provided.

When considering increasing the maximum permitted weight of trucks, the issue of containment should be considered. However, it is apparent that barriers that just comply with the minimum standards applicable in Europe are not designed to cater for the worst case that might occur (*i.e.* 40 or 44 tonne truck travelling at 90 km/h).

The possibility of heavy vehicles colliding with the pier of a bridge crossing the road or motorway is an important issue, because in the worst case it could lead to a bridge collapsing on a heavy trafficked highway or motorway. Existing bridge piers were designed for shocks from 40 t trucks or less. To withstand collisions with heavier vehicles travelling at the same speed as existing vehicles would require reinforcement or the installation of shock absorbers on the trucks or on the pier, or pier protection. However, it should be noted that the development of collision mitigation braking systems for trucks offers the potential for the collision speed of a truck to be reduced prior to impact, which could substantially reduce the risk. First generation systems are due to be mandated on new trucks in the European Union in 2013 but not all current systems will react to stationary objects so the full potential may not be realised for some years (see section chapter 6 for more details).

7.4.2. Impact on bridge supports and expansion joints

The support devices represent a significant part of the bridge maintenance cost, and the stress cycles which are applied to them is proportional to the pier reaction, and thus to the total load on a span, or on two adjacent spans in case of continuous beam or slab bridges. Therefore short span bridges will again be sensitive to the heaviest trucks, while long span bridges will suffer of a series of heavy truck accumulated at short distances.

7.5. Impacts on road traffic

7.5.1. Impacts on road perception and visibility

There are three ways in which trucks can affect road perception and visibility. The impact in terms of accidents is difficult to assess because perception causes are poorly documented in most accident reports, and may be hidden under the label "improper manoeuvring" [IRU, 2007].

The first and most obvious effect is the fact that because of their size, heavy vehicles prevent other drivers from seeing the roadway ahead, making it difficult for them to anticipate and sometimes triggering reckless behaviour, such as tailgating and overtaking without proper sight distance.

Secondly, in wet weather, trucks generate heavy splash (side throw of water away from the wheels) and spray (water from tread pickup being thrown from the tyre because of wheel rotation) which further impairs the visibility for following, overtaking or oncoming vehicles. Splash-and-spray suppression usually involves either onboard devices such as flaps and side skirts, or the use of open-graded asphalts to prevent the formation of a water film on the pavement surface, although these solutions both raise maintenance problems [Manser *et al*., 2003]. However, Knight *et al*. (2005) showed that certain aerodynamic improvements, such as those reviewed in section 2.1.4.3, could also substantially reduce the quantity of splash and spray as well as delivering the fuel consumption benefits previously discussed.

Thirdly, in night-time driving conditions, the high-mounted headlamps of heavy vehicles (up to twice the mounting height of light vehicles) are prone to dazzle the drivers of lower vehicles, causing visual discomfort and disability. While dazzling headlights constitute a transient problem for opposing traffic, preceding drivers are likely to experience long-term reflected glare and high interior brightness adaptation if their eyes and mirrors are located below the cut-off of the projected beam. Glare mitigation involves lower headlamp mounting height [SAE, 1996] and lower headlamp aim [Lenard *et al*., 2008], although the latter may lead to inadequate headlamp illumination.

7.5.2. Trucks and congestion

Trucks may have a negative impact on road congestion because of:

- The speed difference with passenger cars.
- Their length, which reduces the visibility for other road users and increases the overtaking distance.
- Their limited manoeuvrability, which may cause difficulties on some roads.
- After a loss-of-control event, *e.g.* roll-over or knife-jacking, a truck may block several traffic lanes for extended periods.

In many countries speed limits for trucks are lower than for passenger cars, *e.g.* 80 to 90 km/h on highways and motorways in most of the EU countries instead of 90 to 130 km/h for cars. Some specific trucks, such as those carrying dangerous goods or exceptional loads, may have even lower speed limits. In ramps or curves, for power or stability reasons, many trucks operate at reduced speed. Therefore the speed difference with cars becomes significant, and if overtaking is difficult or impossible for safety reasons, a queue is formed behind the truck. If a slow truck is followed by other trucks in the queue, overtaking by cars becomes more difficult and the congestion increases. On four-lane highways or motorways, and during truck overtaking, the same phenomenon occurs, particularly during peak traffic hours. In a traffic jam or stop-and-go situation, the truck accelerations are lower than those of the cars, which induces more perturbations. Some stakeholders have suggested harmonising truck speed limits as a way of reducing some of these negative impacts.

On narrow and bending roads or in intersections, in entrances or exits off highways and motorways, the reduced manoeuvrability of long trucks or truck combinations (compared with cars) can also induce congestion, or even block the traffic (for example if another vehicle is badly parked). These problems can be exacerbated by higher productivity vehicles if manoeuvrability is permitted to reduce in comparison to workhorse trucks, but can be avoided in a number of different ways:

- The road layout can be improved to accommodate trucks with low manoeuvrability.
- The manoeuvrability of trucks can be improved, for example by using steerable axles.
- Access to certain roads can be limited to certain trucks.

All three approaches above are embodied in the Australian performance-based standards system, where roads are divided into four categories and the manoeuvrability of trucks is graded. The most manoeuvrable trucks can access all roads, but the least manoeuvrable are restricted to remote areas with low traffic volumes and suitable roads.

The analysis of heavy truck crashes (see chapter 6) showed that rollovers are the most frequent single truck crashes, particularly in curves and access ramps. Jack-knifing can also be a problem for articulated trucks and truck combinations, particularly for older vehicles not equipped with ABS on slippery road sections. These crashes, even when they do not lead to fatalities or severe injuries, cause heavy congestion, above all in urban areas or on heavily trafficked roads during the peak hours. For example, a truck roll-over on an expressway in a large city area during the peak hours may cause up to more than 100 km of traffic jam (queue) in less than an hour. Such a situation can also last for a rather long time because it requires special equipment to remove the truck, and it may be difficult for that equipment to get through the traffic jam. On rural roads or motorways, the time to ship such a crane may also be rather long because of the distance.

Therefore, the development and installation on trucks of prevention systems such as ABS, yaw stability control and roll stability control (generically referred to as ESC) are also expected to have substantial congestion benefits. It should be noted that ABS has been mandatory on new trucks for many years, while stability controls are now voluntarily fitted to significant numbers of trucks[8]. In case of a crash, quick traffic re-routing and emergency devices to clear the traffic lanes are essential. Such devices shall be adapted to the trucks' weights and dimensions.

7.5.3. ITS and access control systems

The availability of vehicle telematics technology provides the opportunity to increase the levels of compliance with road transport laws, which should result in higher levels of safety, improved road use efficiency and lower enforcement costs. This technology provides a means for road authorities to better match individual vehicles to the differing capabilities of the road network. As a result, road authorities can grant improved access to selected parts of the road network, confident that the conditions of this access will be adhered to. Such intelligent access programmes (IAP) provide a 'win-win' outcome for all parties. The concept is explained in Chapter 10.

7.5.4. Overtaking limitations

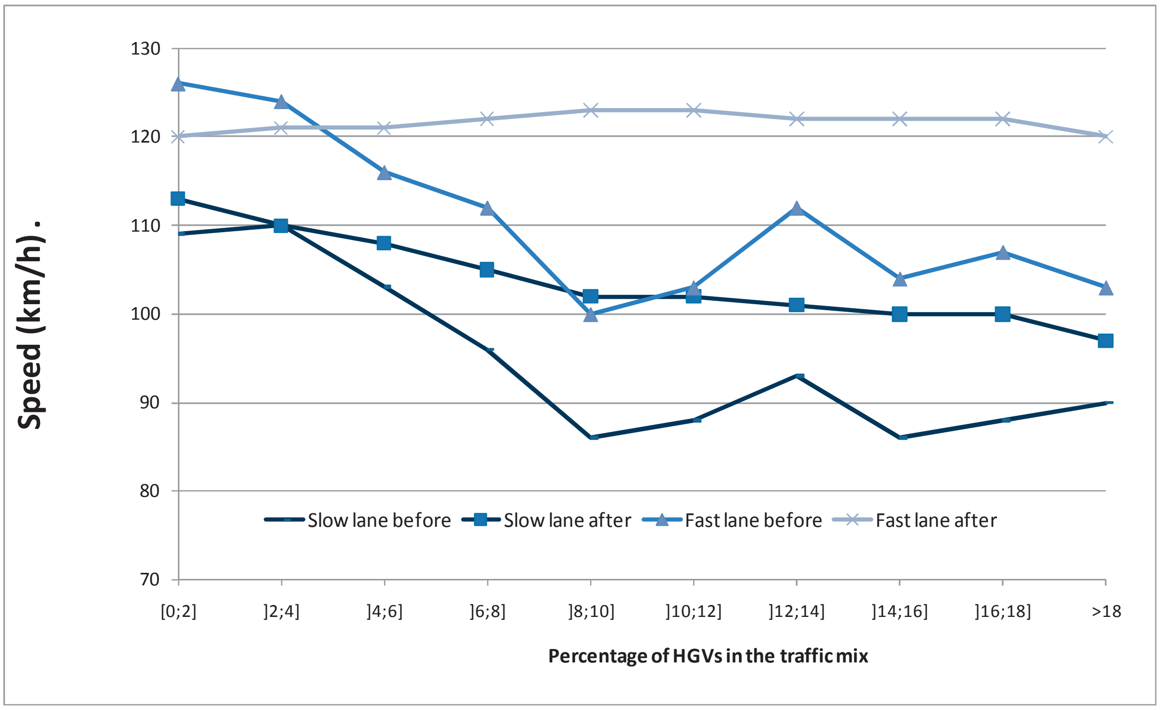
A SETRA study [Bereni, 2008] shows that an overtaking ban for trucks over distances of several kilometres can improve the coexistence of heavy and light vehicles on highly trafficked roads, in particular on interurban 2x2 lane roads. Such bans have been implemented in The Netherlands and France among other countries and can be static (permanent or intermittent) or dynamic.

Permanent overtaking bans are shown by a fixed sign and may apply to certain categories of vehicles (*e.g.* whose weight or dimensions exceeds some limit). Modulation of the ban according to the time of day transforms the ban into an intermittent overtaking ban. A dynamic overtaking ban is triggered at predetermined activation thresholds, based on the collection and analysis of data on traffic and/or meteorological conditions (*e.g.* total traffic flow or proportion of trucks). Users are informed about dynamic overtaking bans by means of variable message signs (VMS).

The Netherlands has a heavily trafficked road network with a high proportion of trucks and first tested intermittent overtaking bans at peak periods in 1997 on 185 km of 2x2 lane motorways. It was extended by an additional 750 km of 2x2 lane motorways in 1999 and a further 400km in 2002-3. Since 2005, a dynamic overtaking ban has been on trial on two 2x2-lane motorway sections with a theoretical capacity of 4 600 vehicles per hour (veh/h) in each direction. The activation thresholds were: 2 600 veh/h and 250 trucks/h (9.6%). The deactivation thresholds were 2 300 veh/h and 230 trucks/h (10.0%).

Figure 7.21 shows the benefit of an overtaking ban on a 2x2-lane French motorway in Eastern France. The traffic density in one direction is between 1 500 and 2 000 veh/day.

Figure 7.21. **Effect of an overtaking ban on the average speed on each lane of a French motorway (A4)**



It can be seen that the ban smoothed the mean speed throughout the day, and allowed an increase of 10 km/h between 8:00 am and the evening (the speed limit for cars is 130 km/h). The proportion of trucks on the fast lane was reduced from 15% to 5% during this period, *i.e.* the ban was not fully respected during the peak hours. Such bans were implemented on long and heavily trafficked routes, such as the highway between Poitiers (north of Bordeaux) and the Spanish border in Southwest France.

Germany introduced overtaking bans to overcome congestion problems in the 90s. It started with a permanent ban on approximately 75 km of 2x2 lane motorways, distributed over 12 sections in the West and South of the country. It was shown that sections with ascending slopes and more than 2 000 veh/h (2x2 lanes) were the most appropriate cases.

The overtaking ban was then extended to a major part of the German road network, with permanent, intermittent and dynamic bans on app. 750 km of motorways in Bavaria and a similar length on the Baden-Württemberg network. The BAST set up some recommended activation and deactivation thresholds, which may be used by default (Table 7.8).

Table 7.8. **Activation and deactivation thresholds for the dynamic HGV overtaking ban**

Cross Section		2x2 lanes	2x3 lanes	2x4 lanes
Activation	Flow in v/h (per direction)	3 200	4 000	4 400
	% trucks	25	20	20
Deactivation	Flow in v/h (per direction)	2 900	3 600	3 900
	% trucks	15	10	10

Additional European experience has been reported by the United Kingdom and Denmark. The bans are mainly implemented on short (10 km) sections with intervals of the same length. The output seems to be positive with more homogeneous speeds, particularly on the fast lanes. There is no significant decrease of the crash rate.

Experience in the Netherlands tends to confirm that dynamic overtaking bans provide greater benefit than static bans. The acceptability of this measure among all types of motorists is considerably increased by the fact that it is activated during the most appropriate periods, without it being any less effective. Permanent bans are preferred on sections with truck crash problems, while intermittent or dynamic bans are favoured on sections with congestion and traffic problems. Finally, the impact of such a measure on the transfer of truck traffic to other roads should be investigated and anticipated.

7.5.5. Parking, resting and refuelling facilities

Current situation

The issue of trucks' parking became more difficult on the main highways when the levels of traffic increased and the legislation for work and rest hours was implemented. The lack of secure parking with adequate facilities has been a problem since the 90s. These difficulties have been known to lead to some dangerous behaviour, such as trucks parked on access driveways or, even worse, in the emergency lanes. There is a possibility that liability for incidents could be attributed to the state and a more general need to maintain road safety for all road users.

As an example, the current parking lots in Europe are designed for 16.5 to 18.25 m trucks, as limited by the European Directive EC96/53. If longer vehicles were introduced, these existing problems could be exacerbated by the need to increase the size of parking areas or to re-design the layout of the existing parking lots, with a reduction in the number of slots.

The extent to which finance is available to provide facilities is strongly dependent on the type of road and the legal framework.

Conceptually, the process starts with an analysis of the needs of users, continues with analysis of the available opportunities, and ends with proposals (create new parking area, reorganise an existing area, public-private partnership etc.) to use the best opportunity to meet the demand.

A number of difficulties can be encountered when trying to meet this objective, including:

- The fact that there is often no specific budgetary planning for rest and service areas.

- The analysis of the available opportunities becomes more complex because of other parking areas close to the routes.

- Finding concessionary companies interested in the new service area can be difficult because of increasing competition, a low return on investment, and other constraints. In addition such concessionary companies are often petrol companies which already finance the service area.

- The responsibility for extending existing areas as the traffic volume increases lies with the concessionary companies and such extensions are rare.

The following ideas for the development of parking lots on the concessionary network have been proposed:

- Build or extend parking lots outside of, but close to, the motorways.
- To monitor continuously the available parking capacities in the area and to inform the truck drivers about their location along the route.

For the public network a similar approach as on the concessionary network seems appropriate:

- To evaluate the existing resources, the demand, the public and private offers, and to plan the required installations.
- To adjust the financial resources by incorporating the area in the new infrastructure planning, by taking part in the financing of concessionary service facilities, by looking for partnership (with local authorities, chambers of commerce, etc.), and by contracting with external bodies.

Thus, road safety is strongly dependent on the availability of enough parking lots for all types of vehicles. It is necessary to first identify any undersupply of parking areas/space on concessionary and public networks, by main itinerary routes. Where undersupply is identified it is necessary to build more parking lots in the most critical zones, with the appropriate budget. In general, the parking capacity needs to increase with the traffic volume.

It is also desirable to develop transport centres on the main network nodes. These centres shall offer all the required services (gas station, food, lodging, telecommunication, etc.) near the parking area.

7.5.6. Winter operation

In winter, trucks can suffer greater problems of traction and stability than passenger cars. Trucks can frequently lose traction on snow or ice covered uphill slopes, which means they have to stop and can become an obstacle for other vehicles with better capabilities in slippery conditions. In some countries (*e.g.* France) it has been specified that the driven axles of a truck must not carry less than 25% of the truck or truck combination gross weight in order to provide certain minimum quantities of traction. Several countries also restrict the use of trucks on motorways in conditions of snow or ice.

On the main motorways and highways, accurate information shall be given to the truck drivers in advance of encountering slippery conditions in order to prevent their exposure to high risks of skidding. Parking lots may be required to store the trucks during winter crises (worst weather conditions).

7.6. Tunnels

7.6.1. The influence of truck size on the design of tunnel structures

Many structural parameters of tunnels are dependent on the characteristics of the largest expected trucks. For instance, the geometry and weight of the largest trucks determine the vertical and horizontal clearance (and ultimately the whole tunnel cross-section), the thickness and bearing strength of the pavement and, where applicable, the slab below the pavement (the pavement is built on a slab in a number of tunnels, notably all those excavated with tunnel boring machines). When designing a tunnel, any increase in the size of the trucks that it is intended to accommodate will lead to an increase in the requirements for a number of structural parameters, often with large cost implications because of the additional excavation required. Conversely, once a tunnel has been built, these parameters will limit any future increase in the size of truck that can pass through it (increasing a tunnel cross-section after it has been built is either impossible or at least prohibitively expensive).

7.6.2. Risks associated with trucks in tunnels

While the aforementioned issues also affect open roads (typically with smaller consequences), the specific concern with trucks in tunnels is safety, mainly fire safety. This topic has been extensively studied by numerous national, European and international projects, which have resulted in recent international recommendations and national and European regulations. Current best practice gives a large role to safety management, relying notably on risk analysis and feedback from experience.

Well-designed tunnels do not suffer an increased number or severity of accidents, compared with open roads. However in some very rare cases, tunnel events may degenerate into catastrophes, especially when a fire occurs. Victims of fire have only been reported where at least one truck (or a bus in one case) was involved. Trucks generally suffer fires more frequently than passenger cars, and particularly high fire rates are recorded in mountain tunnels situated after long slopes. Most fires are caused by the self-ignition of the vehicle or its cargo, but fatalities generally occur in fires caused by an accident (with important exceptions, especially the Mont Blanc tunnel fire which resulted from the self-ignition of a truck and was the worst road tunnel fire with 39 fatalities).

Truck fires tend to be much larger than passenger car fires and are very variable in size. The maximum energy that can be released (potential heat, expressed in GJ) and the heat release rate (HRR, expressed in MW) depend on the vehicle, the fuel it carries and its cargo. As orders of magnitude, a truck with no cargo or non-combustible cargo, may release a maximum energy of approximately 50 GJ with a maximum HRR of approximately 30 MW. Most current truck fires are found in practice to release no more energy than this. However in exceptional cases, a current truck with a very combustible cargo (although not classified as dangerous goods) can release an energy in excess of 400 GJ with a HRR of more than 100 MW. Where dangerous goods are allowed, a full petrol tanker has an energy potential of about 1000 GJ with an HRR which may exceed 200 MW. Trucks larger than the current ones can be expected to produce larger fires.

Large tunnel fires have consequences on the tunnel equipment and structure (mainly due to heat) and the people inside the tunnel (as a result of heat, smoke and toxic gases). These consequences are strongly dependent on the HRR, and thus on the size and combustibility of the truck and cargo. For this reason, a report from a UN group of experts on tunnel safety [UNECE, 2001] recommended that the weight and dimensions of trucks should not be increased.

The transport of dangerous goods through tunnels leads to additional risks, mainly large explosions and releases of toxic gases (or volatile toxic liquids). These events are difficult to contain once they have occurred. International regulations make it possible to ban dangerous goods transport partly or totally, on the basis of a comparative analysis of their risks in the tunnel and the risks on possible alternative routes.

7.6.3. Measures regarding tunnels

A number of mitigation measures can be implemented to reduce the consequences of a tunnel fire: detection, communication, ventilation, emergency exits, fire resistance, hydrants, well-trained, exercised and organised operators and emergency services, etc. Important research is ongoing on fixed fire fighting systems (especially water mist) in order to limit the size of truck fires, although the results to date suggest that fires with high HRR cannot always be avoided. In any case, the first minutes after ignition are essential, before the fire reaches unmanageable size. Appropriate behaviour of the tunnel users and operators is crucial to minimize the human consequences by self-evacuation before the fire can be extinguished. Mitigation is more difficult in some tunnels, where it is difficult to deal with very large fires (*e.g.* bi-directional tunnels).

Trucks significantly heavier than the current ones, with the risk of larger fires, would require additional or larger equipment (ventilation, fixed fire fighting systems, fire resistance, etc.). This would be possible for new two-tube tunnels, but much more difficult and expensive for existing tunnels: a number of them are currently being upgraded according to existing new standards, and further upgrading would be very expensive, and even impossible in some cases. This would lead to limitations in the size and weight of trucks allowed through these tunnels (limitations are already applied for some tunnels due to either vertical / horizontal clearance or fire safety).

7.6.4. Measures regarding trucks

Recommendations to improve the safety of trucks when they pass through tunnels have already been made, both in the aftermath of large tunnel fires and in the aforementioned UN report. They include:

- Ensure high maintenance level, periodic services and compulsory safety inspections of trucks.
- Study and implement automatic fire detection and if possible automatic fire suppression equipment in trucks.
- In addition to appropriate position inside the vehicle, ensure sufficient fire-resistance of fuel tanks.
- Reduce the maximum quantity of fuel a vehicle can carry when it is not classified as transport of dangerous goods.
- Prohibit the use of highly inflammable materials in the construction of vehicles (including refrigerated vehicles).
- Ensure appropriate education, training and check of truck drivers, including on safety-relevant aspects of vehicles and safety in tunnels.

7.7. Intermodal terminals

7.7.1. The need for intermodal terminals

Intermodal terminals (IMTs, Figures 7.22 and 7.23), are locations for the transfer of freight from one transport mode to another, for example between road and rail. They are a key to shifting the balance between the modes. IMTs will not eliminate road transport but will provide viable alternatives and encourage more efficient transport choices. Each mode of transport has its own characteristics, relative advantages, and disadvantages and IMTs allow each mode to contribute to the building of combined transport chains which are more efficient, cost effective and sustainable.

Figure 7.22. **Operation at Kewdale Rail Terminal***

Figure 7.23. **Combined transport terminal in Dourges**

* Largest road-rail intermodal terminal in Australia – 400 000 containers per year.

7.7.2. Intermodal terminal challenges

Public policies favour intermodal transport, so the debate regarding IMTs is focussed on questions such as:

- What location suits IMTs best?
- How can their design meet future requirements?
- What type of access regime will serve industry best?

More generally, a range of issues have been identified. These issues can be grouped under six main themes: (1) Design, (2) Location, (3) Land use planning, (4) Access, (5) Operational and (6) Information exchange. The issues discussed here primarily relate to metropolitan IMTs rather than rural IMTs.

Design

Design, that is, the physical features of IMTs, tends to be static because changes require considerable investment. In contrast, the transport industry is very dynamic because of its highly competitive nature. Therefore to safeguard operational efficiency, IMTs are continuously in need of review. The dynamic nature of industry as opposed to the static nature of design includes the following discussions:

- ***Terminal dimensions (truck).*** Advancements in vehicle configuration pose substantial challenges for IMT design and layout. In order for IMTs to safeguard operational efficiency it is crucial to adapt their services and on-site infrastructure accordingly. For instance, the introduction in Australia of 12-axle 33.3 m vehicles (B-triples) as well as the move towards Performance Based Standard (PBS) vehicles has increased the size of trucks, both in terms of length and the width needed to operate. The impact is two-fold. Firstly, the bigger trucks tend to take up more physical space: during the practice of loading/unloading, while parked on-site, while turning and reversing etc. Secondly, increased truck dimensions require IMTs to process larger quantities of freight, which is likely to result in IMTs reaching capacity (in terms of space/storage) more rapidly.

- ***Terminal length (rail)***: The train side of IMTs poses similar challenges. Rail productivity generally tends to be linked to distance and train length. Longer trains (subject to double-stacking) operating longer distances are likely to be more sustainable than short trains operating short distances. Therefore, in order for IMTs to enhance rail productivity, it is important that the terminal length is sufficient. Ideally, terminals should have the capacity to receive, load and unload push-pull unit trains without dividing them for processing. Again, larger quantities require adequate capacity in handling services as well as sufficient size to accommodate empty container parks on-site.

- ***Standard dimensions***. With freight transported over long distances (domestic and international) infrastructure dimensions are likely to vary. IMTs operate as freight hubs, so it is important that on-site design and services are standardised. For example, until relatively recently IMTs in the State of Victoria, Australia, were only able to cater for broad gauge rail track. With other States subject to standard gauge, this clearly limited efficiency.

Location

In order for IMTs to be viable, location is key. The following characteristics are important:

1. Proximity to markets.

2. Proximity to main lines, dedicated rail freight lines and arterial road networks.

3. The location relative to other IMTs.

Proximity to main lines isn't just a matter of distance. In order to cater for the trucks and trains sufficiently, this requires adequate infrastructure from door to door. That is, as long as 'the last mile' (the issue of the larger trucks being able to use the main road network, but not 'the last mile' to their depot or warehouse) doesn't allow B-triples to make use of roads, it defeats the purpose of being closely located to the main line.

Land use planning

IMTs are continuously challenged by urban encroachment. Like the IMTs, residential areas tend to expand and thereby absorb substantial space. Therefore, in order to cater for the future freight task, both land reservations and corridor preservation are key to allowing IMTs to grow and expand in numbers.

This requires proper master planning processes that are sufficiently long term: (i) quarantine space, (ii) corridor preservation, and (iii) proper planning processes to endorse community acceptance.

Access

There is an ongoing debate as to whether or not privately owned terminals should provide access to third parties. The origin of this debate relates to market power. An intermodal terminal is a critical element in the intermodal supply chain. Only a limited number of terminals can be sustained in the market place, so they can act as a power resource and strategic asset to create competitive advantages for the owner. Excluding third parties from usage, therefore, exhibits potential features of a monopoly [SFC, 2007]. Two approaches have been used in the OECD countries to promote fair and equal access to the terminal for all competitors: open access and vertical separation [Lu, 2001].

Information exchange

IMTs are a segment within the supply chain. More specifically, they are the place where different participants meet. To facilitate the transfer of freight from one participant to another in an efficient and timely manner requires adequate exchange of information. Proper visibility is a potential driver of efficiency. Traditionally, the exchange of information between businesses (producers) and service providers (transport companies) has been by phone, fax or in person and has been documented on paper forms. Increasingly, over the last two decades, there have been attempts to exchange information (and manage the process) using electronic means.

To overcome these or similar inefficiencies, improved coordination and tailored information systems are key. There is a vast body of literature dealing with the issue of how to enhance visibility and the role of IMTs [SFC, 2007]. Recent studies have identified that greater coordination together with information sharing could improve the performance of supply chains. A lack of shared information is constraining the optimisation of short-term operations as well as long-term investment decisions. For example, in Australia the states of Queensland and NSW coal industries have experienced considerable capacity constraints. These have been resolved through the development of 'logistics chain coordination teams' comprising all participants within the specific supply chain. This model has proven many capacity issues can be overcome through better supply chain coordination.

Importantly though, cooperation and information sharing between private companies is not always in line with competition policy. Supply chain performance could be significantly improved through better coordination, cooperation and information sharing between private companies. This would be dependent upon clearly distinguishing coordination from collusion under relevant competition laws. If this can be achieved, there is no reason why the supply chain efficiency gains experienced in the Australian coal sector cannot be replicated.

7.8. Conclusions

Truck traffic must be adapted to the road design, geometry, traffic, capacity, and particularly to the pavement and bridge assets. In turn, these assets should be developed to facilitate the optimal use of road capacity by trucks, funded by financial mechanisms that support such use. Regulatory systems should encourage the use of trucks that are less aggressive to the infrastructure and the models used to assess the aggressiveness should be improved so that pavement characteristics are more accurately considered than is the case with traditional "fourth power law" methods.

For pavement fatigue and wear assessment, axle loads and configurations are much more important than the gross vehicle mass (GVM). It is therefore essential that this is reflected in the regulation of vehicle weights and dimensions. If gross vehicle masses were to be increased then it would be necessary to increase the number of axles to ensure the axle loads remained the same or reduced. Distributing the load more evenly amongst all the axles can also substantially reduce the truck aggressiveness and thus the pavement damage and maintenance cost.

Load effects, strains or stresses of traffic loads on bridges must be analysed on several scales which involve axle loads, single vehicle gross vehicle mass and a series of consecutive or adjacent vehicles' gross vehicle masses. Moreover, these effects depend on the bridge type, span length, and bridge section or detail considered. The extreme (maximum) loads govern the brittle failure (ultimate limit state) while the repeated heavy loads have the most influence on fatigue damage assessment.

Bridge and road wear both vary significantly with changes to the maximum GVM of the vehicle. However within this correlation, it is also possible for vehicles with a lower GVM limit to have a higher infrastructure impact than vehicles with a higher GVM limit. This suggests that by optimising the vehicle configuration it is possible to both improve the productivity and simultaneously reduce the impact on the infrastructure.

The aggressiveness of a single truck increases approximately linearly with its gross vehicle mass for (extreme) load effects, and with a 3^{rd} to 5^{th} power of its gross vehicle mass for fatigue damage, but decreases with its length for a constant mass. Thus to contain bridge damage, increases in gross mass should be accompanied by proportional increases in length and the number of axles. The use of a bridge formula, as in North America, provides a useful means of ensuring an appropriate relationship between gross mass, length and number of axles for short and medium span bridges, or for local and semi-local load effects. However, such formulae must be adapted to the bridge conditions and designs in the region to which it is applied.

For medium and long span bridges (above 50 m), enforcing a minimum gap between trucks that exceed certain gross mass limits would reduce bridge damage and the risk of deterioration or failure. For short and medium span bridges, it would be beneficial to avoid two very heavy vehicles crossing or overtaking at critical positions. ITS systems, including WIM and GPS, and variable message signs could provide the mechanism required to achieve such positional control.

When increasing the GVM of trucks, containment is an issue. Barriers currently in use which just comply with minimum standards are not designed to cater for the worst case that might occur with trucks even today. The risks of trucks colliding with the pier of a bridge will also grow and is an issue because it may lead to a bridge collapsing on a trafficked road underneath. The development of collision mitigating braking systems for trucks offers the potential for the speed of a truck to be reduced before impact, which could substantially reduce the risk.

Overtaking bans for trucks and other speed-limited vehicles on specified road sections can be permanent, limited to certain time periods or dynamic. Studies and accumulating experience have shown that such bans can improve the coexistence of heavy trucks and light vehicles on heavily trafficked roads and improve the utilisation of the road capacity. Dynamic truck traffic management, *e.g.* overtaking ban depending on traffic density, speed and road condition, or dynamic lane allocation, has the potential to reduce congestion and improve safety. It will require advanced infrastructure-to-vehicle communication and strict compliance. The Intelligent Access Programme now being deployed in Australia is a first practical example of such a supervisory system.

The availability of enough parking facilities is a high priority for safe, legal and efficient truck operations and the demand grows with the volume of truck traffic as well as the size of the trucks. It is necessary to identify the proper need of parking areas/space by main itinerary routes on public as well as concessionary networks. Where undersupply is identified it is necessary to build more parking lots in the most critical zones.

Intermodal terminals serve a balance of modes and need to be designed according to the current and future truck and train characteristics, *e.g.* weights and dimensions, performances, etc. They must be located in the right place for the logistic chain, and above all well connected to the various transport networks (road, rail and waterborne). Access rights and operating hours are very important issues. Land use planning needs careful consideration, especially in urban and peri-urban areas.

NOTES

1. COST (European Cooperation in the field of Scientific and Technical Research) is a European programme supporting cooperation between scientists and researchers across Europe; it is the first and widest European intergovernmental network for coordination of nationally funded research activities. COST 323 was aimed at defining pan-European requirements for heavy vehicle weigh-in-motion (WIM), and for the development of associated systems. COST 333 aimed at developing a coherent, harmonised and cost-effective European road pavement design method, which was to open new possibilities for industry to collaborate in the field of pavement design and construction. COST 334 studied the effects of Single Wide Tyres and Dual Tyres.

2. Ref. ARCHES report no D16, in finalisation.

3. In a "peak crossing" counting method, the turning points in a load-time trace are classified according to their load level. A "level crossing" counting method counts the number of time a load-time trace crosses a certain level either in a positive or negative direction.

4. A range-pair counting method counts load variations directly for fatigue issues. Ranges are counted as range pairs. It searches for full-load cycles that are contained within main load variations. The "rain-flow" counting method is a particular "range-pair" counting method which takes into account some "memory" as a scanning window, adapted for fatigue problems.

5. Palmgreen-Miner's rule is based on a linear damage hypothesis, and states that where there are k different stress magnitudes in a spectrum, S_i ($1 \leq i \leq k$), each contributing $n_i(S_i)$ cycles, then if $N_i(S_i)$ is the number of cycles to failure of a constant stress reversal S_i, failure occurs when: $\Sigma_i \, n_i/N_i = C$ (C is experimentally found between 0.7 and 2.2, usually for design purposes, C is assumed to be 1). This can be thought of as assessing what proportion of life is consumed by stress reversal at each magnitude then forming a linear combination of their aggregate. Though Miner's rule is a useful approximation in many circumstances, it has two major limitations:
   - It fails to recognize the probabilistic nature of fatigue and there is no simple way to relate life predicted by the rule with the characteristics of a probability distribution.
   - There is sometimes an effect in the order in which the reversals occur. In some circumstances, cycles of low stress followed by high stress cause more damage than would be predicted by the rule. It does not consider the effect of overload or high stress which may result in a compressive residual stress. High stress followed by low stress may have less damage due to the presence of compressive residual stress.

6. See http://arches.fehrl.org

7. See www.heavyroute.fehrl.org

8. It will become mandatory for new trucks in the EU from 2012.

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CHAPTER 8. CURRENT USE OF HIGHER CAPACITY VEHICLES

Abstract

This chapter reviews the status regarding the use of higher capacity vehicles in Australia, Canada, Europe and the United States, and summarises the results of recent studies which have assessed the impact of these vehicles on productivity, pavements and bridges, the environment, modal shift and safety.

8.1. Introduction

Higher Capacity Vehicles is the term used in this report to describe vehicles with weights and/or dimensions outside that permitted in conventional regulation. This term embraces European 'Longer and/or Heavier Vehicles', North American 'Long Combination Vehicles' and Australian 'Higher Productivity Vehicles'.

In recent years, there have been many assessments of relaxing weight and dimension limits for heavy vehicles. These studies have examined the productivity, safety, environmental and infrastructure impacts of allowing increased access to the road system for vehicles which are longer and/or heavier. A comprehensive review of relevant literature has not been undertaken for this report and the studies reported below are intended to be illustrative, although some general comments can be made.

In a competitive system, removal of regulatory restrictions will lead to increased technical efficiency. All studies have found that increased road transport productivity would be likely if weight and dimensions limits were to be relaxed. The degree of the productivity gain will depend on the nature of the freight task and on the nature and the degree of change of the existing regulation.

Most studies have modelled increased route access for existing vehicle types. Examples include wider access for longer combination vehicles in the United States and Canada, and wider access for the European modular system. An advantage of this approach is that the characteristics and operating costs of these vehicle types are known empirically. However, these vehicles are still defined through prescriptive regulation.

8.2. Status regarding the operation of Higher Capacity Vehicles in OECD/ITF countries

8.2.1. Australia

In Australia, higher capacity vehicles are referred to as higher productivity vehicles and include B-doubles (at 26 m in length and 68.5 t GCM), B-triples and road trains. Double and triple road trains (up to 53.5 m and 125 t) have been widely used in remote areas for many years. In urban areas and more populous areas, the road freight task is undertaken primarily by tractor-semitrailers and B-doubles.

Prime movers with four trailers, with various forms of coupling, are used in some applications in remote areas. Australian B-doubles generally have eight or nine axles, with increasing interest in Quad-axle B-doubles for some applications, including the carriage of two 40 foot containers through urban areas. The Quad-axle B-double has the quad-axle at the rear of the lead trailer. There is increasing interest in the B-triple as a vehicle with better performance characteristics than the double (A-coupled) road train and BAB quads (two B-double trailer sets joined by a converter dolly) as a better performing vehicle that the conventional triple (A-coupled) road train.

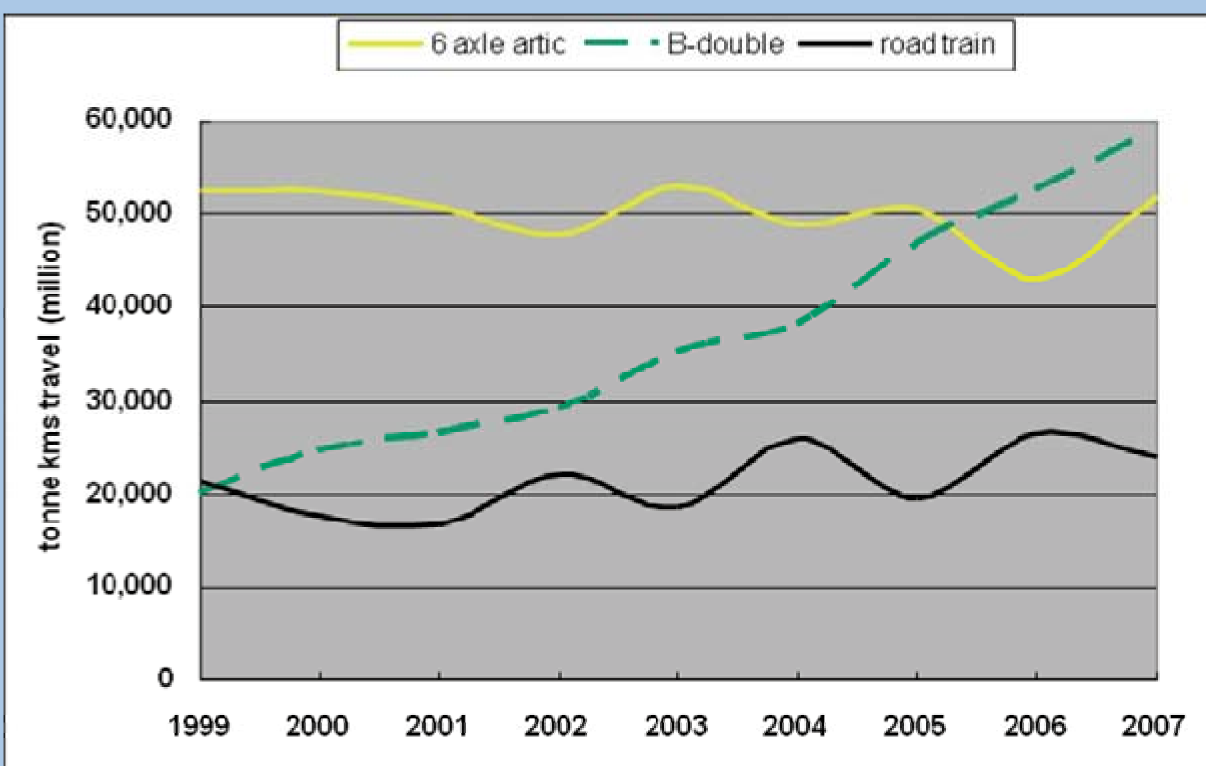
Box 8.1. **Higher Capacity Vehicles case study – the uptake of B-doubles in Australia**

In **Australia**, B-doubles (vehicles comprising a tractor towing two B-coupled semi trailers – now generally permitted a length of 26 metres and gross combination mass of 68.5 tonnes in most applications) were introduced in 1984, based on a Canadian design. Between 1996 and 2006, the number of B-doubles increased almost tenfold (from 1 265 to 11 400) whilst there was little growth in the number of other articulated trucks (from 54 198 to 58 200).

Based on conservative assumptions, it is estimated that if Australia had not introduced B-doubles, an additional 6 700 articulated vehicles would have been required to undertake the same road freight task. Use of B-doubles is estimated to have reduced fuel consumption by the articulated fleet by 11%. (Source: *Freight Futures: Victorian Freight Network Strategy*, State of Victoria, 2008, p.53). However, more recent estimates have put the reduction in articulated trucks at between 15 000 and 20 000 (Pearson, 2009).

In the period between 1999 and 2007, the whole of the growth in the articulated truck freight task was taken up by B-doubles (see figure 8.1). B-doubles are permitted extensive network access, including major roads in urban areas.

Figure 8.1. **Articulated freight task, Australia**
1999 - 2007



Source: Pearson, B, *B-doubles: the first decade in Australia*, November 2009.

In September 2009, a trial of 'next generation High Productivity Freight Vehicles' was initiated in Victoria. These vehicles are primarily Super B-doubles with up to two quad-axles, a permitted length of 30 m and GCM of up to 77.5 t and the capacity to carry two 40 foot containers. They will operate on a small number of defined routes through the city of Melbourne (containers) and into the regional port of Portland (woodchips). Operations will be subject to route restrictions, time restrictions (no peak hour operations in Melbourne), compliance conditions (monitoring through the Intelligent Access Program, see section 5.3.2) and accreditation under the national Mass Management scheme. Vehicles and operations must be assessed through the PBS process.

8.2.2. Canada

Higher capacity vehicles are referred to in Canada as Long Combination Vehicles. They consist of a tractor and two or three trailers or semi-trailers where the length of the combination exceeds the normal limit of 25 metres specified by provincial truck size regulatory schemes.

The three types of LCV are Rocky Mountain Doubles (RMDs), Turnpike Doubles (TPDs) and Triple Trailer combinations (triples). Depending on the type of LCV, gross masses between 53.5 and 62.5 tonnes and lengths of up to 38 metres are permitted. LCVs allow increased cubic capacity but do not allow additional gross or axle mass relative to standard configurations.

Long Combination Vehicles (LCVs) are operated under permit in certain Provinces (Alberta, Saskatchewan, Manitoba and Quebec). In addition, a pilot study of LCVs has recently been initiated in Ontario. LCVs are generally restricted to travel on four lane highways.

8.2.3. United States

Similarly to Canada, in the United States, higher capacity vehicles are referred to as Long Combination Vehicles and comprise Rocky Mountain Doubles and Turnpike Doubles. In contrast to the situation in Canada, the permit for an LCV in the US can also represent an increase in mass over the usual statutory limits.

LCVs were first used in the United States during the late 1950s with the introduction of tandem trailers on limited routes. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) effectively froze the LCV network as of 1 June 1991. At that time 21 states allowed the use of at least one form of LCV.

In 2009, LCVs were allowed in certain States but not on interstate network.

In 2002, a study of the Transportation Research Board (TRB, 2002) focused on weight and dimensions requirements and found that:

- *Opportunities exist for improving the efficiency of the highway system through reform of federal truck size and weight regulations. Such reform may entail larger trucks to operate.*

- *Present federal standards are for the most part the outcome of a series of historical accidents instead of a clear definition of objectives and analysis of alternatives. The regulations are poorly suited to the demands of international commerce; their effectiveness is being eroded by ever-expanding numbers and types of special exemptions, generally granted without evaluation of the consequences; and freight traffic is bypassing Interstate highways, the safest and most efficient roads, to use secondary roads where limits are less restrictive, but the costs generated by that traffic are higher. The greatest deficiency of the present environment may be that it* *discourages private- and public-sector innovation aimed at improving highway efficiency and reducing the costs of truck traffic because vehicle regulations are inflexible and because highway users are not accountable for all the costs they generate.*

Key recommendations of the Committee were:

- *Congress should create an independent public organisation with a charter to observe and evaluate commercial motor vehicle performance and the effects of size and weight regulation.* (p.5)

- *Congress should authorise the Secretary of Transportation to approve pilot studies involving temporary exemptions from federal motor vehicle size and weight regulations for vehicles operating within alternative limits, operated by motor carriers that agree to participate in evaluation of the safety and other impacts of the alternative limits.* (p.6)

- *Federal law should allow any state to participate in a federally supervised permit programme for the operation of vehicles heavier than the present federal gross weight limit, provided the state satisfied the requirements...* (p.8)

None of these recommendations has been implemented.

8.2.4. Europe

Higher capacity vehicles are generally referred to in Europe as Longer and/or Heavier Vehicles (LHVs). The most common examples of LHV in Europe are combinations of standard vehicles known as the European Modular System, *i.e.* as combinations of trucks, tractors and trailers with standardised load spaces.[1] They consist of vehicles of up to 25.25 metres in length and up to 60 tonnes gross mass. These vehicles are used in Sweden (since 1972), Finland and Norway (not a Member of the EU) and under trial conditions in Belgium, Denmark, Germany and the Netherlands.

In 2007, the European Commission initiated consultations and discussion on possible revision of Directive 96/53/EC on the weights and dimensions of heavy commercial vehicles within the territory of the European Union. The Commission funded a study on the effects of changing the directive to provide for the use of longer and/or heavier vehicles in international transport on key parts of the European road network. A report was published in November 2008 (TML, 2008). The conclusions of this study are the subject of wide ranging and continued debate, particularly regarding the assumptions on demand elasticities and cross-elasticities between road, rail and other modes. As a result, the European Commission has initiated further, more detailed, studies of both the economic and technical implications of potential changes. These studies are due to be undertaken in 2010.

Finland and Sweden

On the accession of Sweden and Finland to the European Union in 1995, it was agreed that the use of longer and heavier freight vehicles could continue. Swedish and Finnish vehicles are permitted a maximum mass of 60 t, maximum length of 25.25 m and maximum height of 4.5 m. The 25.25 m length is consistent with the European Modular Systems and maintains inter-changeability of trailers with other EU members. Most public roads in Sweden and Finland are open to vehicles of 25.25 m length and 60 t mass.

The Netherlands and Denmark

Longer and heavier vehicles are operated under trials in the Netherlands and Denmark. The first Dutch trial of longer and heavier vehicles was undertaken from 2001 to 2003, with only four vehicles. This was followed by a larger trial (66 companies and 100 vehicles) between 2004 and 2006. The current 'Experience Phase' commenced in 2007 and will last until 2011. There are currently 139 companies and 330 vehicles participating in this phase. A three-year trial began in Denmark in November 2008 with approximately 250 modular vehicles can today be operated under Danish registration.

Other countries

The possibility of authorising longer and heavier vehicles has been discussed in other European countries (including Germany, Belgium, France and the United Kingdom). The German Government plans trials, while the UK Government decided not to permit them "*for the foreseeable future*" after an initial desk study. Both Germany and the UK are also considering the possibility of permitting small increases in the length of existing semi-trailers.

Figure 8.2. **Examples of higher productivity vehicles in Australia, North America and Europe**

Australia	Canada	Europe
Super B Double	*Turnpike Double*	*European Modular System*

8.3. Assessment of impacts of Higher Capacity Vehicles: overview and conclusions of main studies

8.3.1. Productivity

Most studies have examined the prospective impact of the introduction of HCVs, so have had to calculate per-vehicle productivity benefits and estimate industry uptake by market segment. However, studies based on actual vehicle operations are available for Sweden, Canada and the United States. In general, these studies validate the proposition that considerable productivity improvements and emissions reductions result from the use of HCVs.

Box 8.2. **Higher Capacity Vehicles – efficiency impacts**

A **United States** study (Woodrooffe *et al.*, 2009) surveyed a number of US companies operating private fleets and found that companies would derive operational benefits from increased mass for current workhorse vehicles and from access for longer combination vehicles to the full network of Interstate highways. For each company, the extent of the benefit would depend on the nature of the regulatory change and whether current operations 'weigh out' or 'cube out'. The average fuel and emissions saving was estimated to be 34.9%.

A study by a **Belgian** working group (Debauche, 2007) showed that in comparison to a truck/trailer combination at 18.75 m and 44 t, an LHV at 25.25m and 60 t would yield a gain in payload capacity (tonnes) of 38% and a gain in load space (m3) of 39%. In comparison to a tractor/semitrailer combination at 16.5 m and 44 t, the same LHV would yield a gain in payload of 38% and a gain in load space of 61%. The study identified reductions in vehicle kilometres travelled as the main benefit, but found that with the present state of knowledge it was impossible to quantify the possible benefits for Belgium and that only an extensive LHV trial could be conclusive in this respect.

A **Swedish** study (Vierth *et al.*, 2008) considered the impact in Sweden of restricting road freight to vehicle types permitted under EU directives for use in international trade, *i.e.*, with a maximum length of 18.75 t, maximum mass of 40 t (although 44 t is permitted in some applications in the EU) and maximum height of 4.0 m. The study found that provided that the same quantity of freight is to be transported, shorter and lighter trucks mean that the transport cost per vehicle is reduced but that the number of vehicles needed increases. The cost per truck is estimated to decrease by five to twelve per cent in the various commodity groups and the number of trucks to increase by 35-50%. On average, 1.37 trucks of maximum EU size are required to replace one truck of maximum Swedish size. The cost of transportation by truck is estimated to increase by 24%.

Box 8.3. **Higher Capacity Vehicles – impact on fleet size, costs and congestion**

An **Australian** study (Wright *et al*, 2008) modelled the use of B-triples and Super B-doubles (a B-double with sufficient length to carry two 40 foot containers). Use of these vehicles in the modelled linehaul operations, replacing tractor-semitrailers and B-doubles, was estimated to result in a reduction in travel of 22%, cost savings of 22% and a reduction in fleet size of 30%.

In another **Australian** study, Manders (2009) modelled the cost benefits from the use of B-triples in place of B-doubles on a 740 km trip from the outskirts of Adelaide to the outskirts of Melbourne. The Australian B-double is permitted a maximum mass of 68.5 t (with road-friendly suspension) and a maximum length of 26 m. The modelled B-triple has maximum mass of 83 t and a length of around 34 m. The result of the modelling was that the replacement of three B-doubles with two B-triples for the full trip was a reduction in operating costs of 19%. This benefit would be reduced considerably if it were necessary to break the B-triples into B-doubles for access to the final depot.

In a **Canadian** study, Woodrooffe (2001) found that the use of single semitrailer configurations in Alberta (Canada) in place of LCVs would lead to an 80% increase in truck movements and truck kilometres on those routes and would result in a 40% cost increase for shippers currently using LCVs. The study found that in the period between 1987 and 1998, the number of 4 and 5 axle trucks registered in Alberta increased by 57% (from 15 447 to 24 216), while the number of trucks with 6 or more axles (LCVs) increased by 321% (from 2 547 to 8 174). The increased use of LCVs has enabled Alberta's growing freight task to be serviced by a smaller number of heavy vehicles. From an economic efficiency and societal benefit point of view, the use of the larger LCV truck configurations in Alberta was found to represent a significant reduction in the number of movements taking place on the highways, a significant transportation cost efficiency for users of truck transportation services, a major reduction in fuel use and greenhouse gas emissions and a large reduction in pavement wear.

The Longer Combination Vehicles Nationwide scenario study in the **United States** (FHWA, 2001) modelled the impact of permitting Rocky Mountains Doubles, Turnpike Doubles and Triple Trailer combinations at gross mass of up to 148 000 pounds (67 t) on a defined national network. This scenario resulted in an aggregate reduction of shipper costs of 11.4%. All of the scenarios considered in this study resulted in large (greater than 70%) reductions in travel by the current US 'workhorse' vehicle, the five-axle tractor-semitrailer, and very large increases in travel by LCVs. Widespread use of LCVs was estimated to lead to a reduction of more than 20% in total truck travel.

8.3.2. Infrastructure

Infrastructure impacts of HCVs depend on the specific vehicle type under consideration, the proposed vehicle and axle masses and the characteristics of the existing infrastructure. In all known applications to date, operation of HCVs has been restricted to elements of the network with suitable infrastructure characteristics. Infrastructure modifications required for the operation of HCVs span the full range from those that can be achieved immediately to those that take considerable periods of time. Potential infrastructure modifications are wide ranging, including simpler measures such as painting lines on roads, reprogramming traffic lights, and changing roadside signs right through to reconstructing roundabouts or construction of new links. Investment to adapt infrastructure is a component of many changes in vehicle mass limit regulations. For example, in Sweden an infrastructure strengthening programme to support the traffic of longer and heavier vehicles cost a total of SEK 13 billion (EUR 1.5 billion), primarily for bridges, which was recovered from the transport companies by a general truck taxation. In Denmark, the cost of modifying the Danish national roads to allow the 25.25 m 60 tonne longer and heavier vehicles amounted to approximately EUR 17 million for approximately 1 500 km of roads.

The number of heavy vehicles is likely to be limited so the prospect of linking their operation to sophisticated road pricing systems, based on mass and location, is more likely. This has the potential to provide a means to fund infrastructure expenditure through specific charges related to the operation of HCVs.

Box 8.5. **Higher Capacity Vehicles – impact on infrastructure**

The **US** Comprehensive Truck Size and Weight Study (2001) found that (p.ES10) *nationwide use of LCVs* [long combination vehicles] *would entail significant infrastructure costs*. These costs comprised substantial geometric costs and smaller bridge costs, with little change in pavement costs.

The TML (2008) report for the **EU** found that (p.10):

> *The only negative impact* [of the introduction of LHVs] *is the high costs to road infrastructure. Higher investment in maintenance and bridges will be needed, though these investment costs are lower than the savings in the transport sector, and in society (emissions and safety).*

The TRL report (2008) for the **UK** found that introduction of vehicles of 60, 63 and 82 t may require investment to protect bridge supports, may require strengthening of some trunk road bridges and would be likely to require investment in parking facilities. Whilst the study estimated substantial productivity benefits from the operation of these vehicles, it found that (p,vi):

> *given that the cost of the necessary infrastructure improvements is likely to be very high, but could not be reliably quantified, it is uncertain as to whether the benefit to cost ratio would exceed one.*

Infrastructure issues would include provision of parking facilities, the establishment of suitable routes and, for the 82 t vehicle scenario, the load capacity of some medium span bridges. The potentially large but unknown infrastructure cost means that it is not certain as to whether the benefit cost ratio would exceed one (TRL, 2008).

An **Australian** study (Austroads, 2009) estimated the pavement impacts of the migration of the current Australian heavy vehicle fleet to a fleet comprising both workhorse vehicles at higher axle masses and HCVs. The study found that (p.ix):

- *The ... scenario is associated with a reduction in annual pavement wear, relative to the base case, leading to savings in agency costs. The SAR* [*i.e.* ESA loadings] *values for the individual vehicles of the new fleets are higher than the vehicles being replaced. However, their impacts are outweighed by the reduction in the number of vehicles due to the productivity gains.*
- *The largest savings in agency costs are associated with cemented pavements followed by asphalt pavements and then granular pavements.*

8.3.3. Environment

In principle, the operation of higher capacity vehicles should lead to a reduction in the number of truck miles travelled and thus overall fuel consumption per unit of freight transported (measured either by mass or volume), as indicated in the earlier sections of this chapter. The potential is large in relation to incremental improvement in fuel efficiency through improvements in engines, drivetrains, auxiliary equipment, aerodynamics and tyres.

Box 8.4. **Higher Capacity Vehicles - environmental impacts**

A **Canadian** study (Tardiff, 2006) indicates that Turnpike Doubles offer fuel savings of about 30 % when compared to movements of single-trailer configurations, thereby reducing Greenhouse Gas (GHG) emissions.

Preliminary results from the trials undertaken in **the Netherlands** (Arcadis, 2006) showed that: *"Compared to regular vehicle combinations (18.75M/50T), the average fuel consumption of an HCV per vehicle kilometre is 17% higher: 5% higher for vehicles which are longer (with no increase in mass) and 22% higher for vehicles which are both longer and heavier. However, due to the higher capacity of these vehicles, fuel efficiency (measured in relation to load) increases by between 11% (for longer combinations) and 41% (for combinations which are both longer and heavier)".* As a result of the reduction in fuel consumption there are less emissions. Emissions of CO_2 are reduced by 3.0% to 5.7%, emissions of small particulates (PM10 and PM2.5) are reduced by 1.2 to 2.3% and emissions of NO_x are reduced by 1.9 to 3.7%.

The **UK** TRL study (Knight *et al.*, 2008) concluded that the increased carrying capacity of longer and heavier vehicles would reduce fuel consumption and emission per unit of goods moved by between 8% and 28%, depending on the scenario. This would contribute to a reduction in internal operational cost per unit of goods moved of between 18% and 43%. It was considered that this cost reduction would, overall, generate only a very small amount of additional freight movement. However, it was also found that the larger vehicles presented a significant risk of causing adverse environmental effects as a result of mode shift from rail, particularly in the deep sea container market. Limiting the increase in vehicle mass would be expected to substantially reduce this risk.

8.3.3. Modal shift

A key issue in some countries is the impact on rail of the adoption of HCVs for road freight. Concerns include:

- Diversion of freight to road could threaten the viability of some rail lines.
- Despite improvements in safety and emissions outcomes for road freight, aggregate transport outcomes may deteriorate due to the relative safety and emissions performance of rail freight.

These issues are prominent in studies undertaken by the European Union and some of the studies undertaken in the United States. They have not been prominent in Canadian or Australian assessments of the impacts of HCVs.

Full analysis of potential modal impacts would require detailed data on the door-to-door costs of the various freight options (considering that many rail freight tasks require one or more road links) and an assessment of the full cost of rail freight on the relevant links (including the cost of possible capacity expansion).

The scale of the potential environmental and safety benefits HCVs might bring by reducing vehicle kilometres travelled depends on the impact of changes in the cost of transport on demand for freight transport services and on modal shift. As Chapter 1 concludes, these effects are often small but vary greatly between commodities and markets. Variations in the cross-elasticity between road and rail freight are particularly large. They are highly sensitive to the relative size of road and rail freight shares in the market segment of interest and poorly researched. Differences between European, Japanese, North American and Australian markets are pronounced and the results of studies are not easily transferable from one market to another.

Box 8.6. **Higher Capacity Vehicles - impact on modal share**

Recent studies of the impact of the use of higher capacity vehicles on modal shift have been undertaken mainly in **Europe**.

A TRL study (Knight 2008) found that a blanket decision to permit 60 tonne vehicles with more than one trailer for general haulage might cause between 8% and 18% of all rail tonne km (including forecast growth) to migrate to road transport. This would present a substantial risk of adverse environmental effects. If such multi-trailer vehicles were restricted to around 50 tonnes, or less, the likely magnitude of mode shift would be much reduced and largely confined to the deep sea container market. The risk of adverse environmental effects would therefore be much lower.

The study by the European Commission (TML, 2008) on the ***Effects of Adapting the Rules on Weights and Dimensions of Heavy Commercial Vehicles as Established within Directive 96/53/EC*** found that on average across the EU, 3.8% of freight would shift from rail to road (by 2020) if LHVs were authorised, so rail would grow by about 56% as opposed to 60% if there were no truck size/weight increase and for IWW the shift would be 2.9%.

Accounting for modal shift and additional demand induced by the lower cost of road freight consequent on the productivity increase (rebound effect) the study estimated that there would be 13% fewer trips than there would be if current truck sizes were given the task of coping with the baseline 50 % estimated freight demand increase.

These findings were challenged by a number of stakeholders and Member States on the basis that there was an unsatisfactory treatment of demand elasticities and cross-elasticities between road, rail and other modes. Further modelling illustrated the effect of changing average demand elasticity (substituting -0.7 for the initial -0.42) although no analysis was provided to support a preference for either value. The most authoritative examination of freight transport elasticities in Europe was undertaken by Graham and Glaister (2004) on the basis of a literature review. It concluded that elasticities vary enormously by market (see Chapter 1.5.3), depending on the type of freight involved. It made no recommendation on appropriate average values, recommending instead that analysis use specific values for separate parts of the market. However, the initial average elasticity value used by the TML study lies within the range of average values reported in the literature and is not in itself a reason to reject the results modelled.

8.3.4. Safety

Assessment of safety impacts of the adoption of HCVs is hampered by lack of detail in the road safety data routinely collected. In general, operation of these longer vehicles is restricted to roads determined to be suitable. This will usually be in non-urban areas and on divided highways and major arterial roads. Operation of HCVs will generally be restricted to roads with favourable geometric characteristics. Driver selection, operational controls and higher levels of safety equipment contribute to significantly better safety records for these vehicles on the road. The workhorse vehicles, with which the safety of HCVs is to be compared, do not face such restrictions on their operation. Data on the safety of workhorse vehicles on similar routes to HCVs is not generally available.

Due to lack of specific data on HCV crash characteristics, causation and exposure it is difficult to assess crash risk for this vehicle class. However, there have been a few significant studies on the safety performance of HCVs that provide insight into their safety performance. The province of Alberta in

Canada commissioned a study to examine the safety performance of HCVs operating under special permit in that province. Woodrooffe *et al.*, (2001), compared the crash rate of the various HCVs configuration types and found that HCV crash rates were significantly lower than the common workhorse tractor trailer. The study controlled for road type and vehicle configuration and evaluated crash rates comparatively on discrete road sections throughout the province. Regehr *et al.* conducted a follow-up study eight years later and found similar safety outcomes. The crash rate for HCVs in the studies ranged from 2.5 to 5 times lower than the standard workhorse tractor semi trailer. Woodrooffe *et al.* (2004) attributed the bulk of the safety benefit to the policy governing the HCV operations that was implemented by the government. It was designed to minimise crash risk by imposing specific requirements on driver qualifications and vehicle operation. The findings from this research clearly demonstrate the very significant safety benefits that such policy can provide.

Another detailed assessment of vehicle safety impacts was undertaken in the TRL study (Knight *et al.* (2008) – see below). This study found that casualty rates per unit of goods moved would reduce slightly and additional safety gains could be made through requirements for safety technologies, specific vehicle types and manoeuvrability standards.

The stopping distances for trucks are considerably longer than for passenger cars and their braking capacity is a safety issue. The axle load distribution and greater number of axles on most higher-capacity vehicles provide them with proportionally greater brake capacity for the legal GVM when compared with common workhorse trucks. This extra brake capacity would be likely to result in less brake fade, assuming good maintenance of the brake system (Danish road safety, 2005) and, depending on the relationship between axle load and available brake torque, could reduce emergency stopping distances (Woodrooffe, 2006). Knight (2008) reported that where vehicles were equipped with pneumatic braking systems, increased length was also likely to increase the reaction time of the brakes, thus tending to increase the stopping distance. However, appropriate design and, in particular, the use of electronically controlled braking systems is likely to mean that HCV brake performance is very similar to a similarly equipped workhorse vehicle (and better than existing workhorse vehicles not fitted with electronic braking technology.

In most studies of the potential impact of HCVs, it has been assumed that the crash risk of HCVs per vehicle km is the same as other heavy trucks, so that reduced aggregate vehicle kms will lead to proportionate safety benefits. The modelling reported in chapter 4 suggests that HCVs can perform at least as safely as the workhorse vehicles they may replace, particularly if suitable operating conditions are imposed. The Alberta experience strongly suggests that the safety performance of HCV depends to a large extent on the policy that governs their operation.

Box 8.7. **Higher Capacity Vehicles – safety impacts**

Canadian studies (Barton *et al*., 2003, Woodrooffe *et al*., 2004, Montufar *et al*., 2007; Regehr, 2009) have found that accident involvement rates of higher productivity vehicles are less than those of single trailer trucks in general operations; mainly because of the strict operating conditions placed on their use, and the special driver requirements. A study on the use of HCVs in Alberta showed that for a fixed quantity and density of freight transported by articulated trucks, each HCV replaces one and one-half to two standard five-axle semitrailers, which, over the same period, had higher collision rates than HCVs. In this sense, HCVs operating in Alberta in this period provided increased freight productivity and reduced the number of collisions that would have occurred if standard configurations had been used to haul the same freight.

The **United Kingdom** (TRL) study found that the casualty rates per vehicle km would be expected to increase for most, but not all, of the options considered and there was evidence to justify restricting the use of the higher risk vehicles to safer types of road. However, in all cases the casualty rates per unit of goods moved would be expected to reduce slightly and if new safety technologies, specific to vehicle configurations, and existing manoeuvrability standards could be mandated, then this would mitigate many of the risks, increase the reduction in casualties per unit of goods moved, and encourage wider use of new technologies in the standards goods vehicle fleet.

Debauche (2006) found that although there was insufficient data available at that stage to permit a full assessment of the impact of HCVs on road safety in **Belgium,** the first estimates indicated that HCVs would not compromise road safety and could even slightly improve it. However, the report still recommended that strict safety conditions should be imposed if HCVs were to be permitted. The recommended conditions related to infrastructure; driving conditions; driver selection and training; and the technical requirements for vehicles.

8.4. Conclusions

Whilst international experience in the use of higher capacity vehicles has been limited, the rapid uptake of these vehicles in Canada and Australia and their operation in some parts of Europe and the United States demonstrates that the road freight industry is quick to seize opportunities to improve efficiency, and that the use of more productive vehicles can mitigate potential growth in vehicle numbers. In addition to their productivity benefits, it is clear that the use of these vehicles can have beneficial impacts on sustainability (through reductions in fuel use and emissions) and safety, provided that their use does not lead to significant diversion of freight from other modes.

Infrastructure impacts of the introduction of HCVs will depend on the vehicle types permitted, the current state of the infrastructure and the extent of network access provided. Where substantial infrastructure upgrading is required, costs can be high. The potential benefits resulting from the operation of HCVs must be assessed against these costs. Whilst the use of HCVs may require additional infrastructure expenditure, it is likely that infrastructure expenditure per unit of freight moved will be reduced in the longer term.

Analysis of international experience with HCVs confirms that the development of trucks and road networks should be harmonised. Truck traffic, truck configurations, truck access limitations, road design, junction geometry and the strength of pavements and bridges should be considered as a system and designed to produce the optimum economic, safety and environmental outcome. In many cases, particularly in the shorter term, this will involve matching the truck characteristics and access limitations to the available infrastructure in order to minimise wear and tear on the infrastructure. In other cases, particularly in the longer term, it will involve investing in infrastructure to enable productivity improvements in the truck fleet. Required infrastructure expenditure could be funded by financial mechanisms that recover additional cost from the operation of the higher capacity vehicles that benefit from these developments.

Lack of detailed data makes it difficult to assess crash risk on an individual truck basis. The various studies and experiences from recent years agree that a transfer of goods to trucks with higher cargo capacity should result in a reduction in casualties per unit of goods moved. In addition, analyses and practical experience with higher capacity vehicles have concluded that their safety performance is no worse than that of traditional workhorse trucks. Further research is needed into a number of safety aspects of trucks, including the potential aggravation of the consequences of accidents when higher capacity vehicles are involved. The safety performance of HCVs can be significantly influenced by the regulatory policy governing their operation. The potential for further safety benefits depends on operational controls and the extent to which new, available, safety technology is successfully introduced with these types of trucks, *e.g.* as part of a legislation package through which they become permitted. Some of these technological safety measures can equally be applied to the current workhorse trucks, while others are inherent in the configuration of the higher capacity trucks.

NOTE

1. See Aurell, J and T Wadman (2007) for a description of the European Modular System.

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CHAPTER 9. REGULATING FOR IMPROVED PERFORMANCE

Abstract

This chapter explores new and developing concepts that could be considered by regulators in the future, and includes a discussion on how 'thinking outside of the regulatory box' may provide options for an improved regulatory framework that contributes to more efficient outcomes and responds to increased demands for road transport productivity, as well as addressing community concerns over adverse impacts of heavy trucks. It examines case studies of the introduction of more flexible heavy vehicle weights and dimensions regulation in Canada, Australia and South Africa. Each of the applications has involved the uses of performance standards, though there have been significant differences in approaches. Factors leading to the successful application of performance based standards are discussed.

9.1. Types of regulation

Regulation can be categorised into a spectrum that ranges from self-regulation (no formal government regulation) through quasi-regulation (codes, guidelines, etc), to explicit government regulation (formal rules and regulations).

Safety and environmental concerns about heavy vehicles using public roads almost certainly require explicit regulations to ensure the public is protected. On the other hand, issues such as incentives to improve heavy vehicle productivity can be left to self-regulatory arrangements and normal market forces. Competitive pressures within the trucking sector can be expected to provide sufficient incentives to operators to minimise their costs and improve productivity. Nevertheless, these same pressures can lead to some operators taking safety risks and cutting corners, to the detriment of the environment and road and bridge infrastructure.

Regulatory requirements may be formulated in a number of ways (NRTC, 1994, p.7):

- A prescriptive standard specifies in precise terms the means by which the regulatory objective is to be achieved. Prescriptive standard applied to trucking include vehicle length, width and mass.

- A performance standard specifies in precise terms the objective to be achieved, but leaves the means flexible.

- A principle-based standard describes the objective in general terms, but without specifying either the means for achieving it or precise measurements for deciding whether it is met. This is determined by another body, usually a court, by measuring particular conduct against acceptable prevailing or technical practice. An example of a principle-based standard, common in the occupational health and safety context, is to provide 'a safe system of work'.

Under prescriptive regulation, industry participants have little flexibility to determine how the objectives underlying these regulations are to be met. Extensive prescriptive regulation, typical of current regulation of heavy vehicle weights and dimensions, can achieve safety goals at an unnecessarily high cost to productivity. By addressing prescriptive measures rather than the performance measures which are more closely related to safety outcomes innovation in vehicle design is hampered.

The objective of prescriptive weights and dimensions regulations is to help, in combination with other regulations, to limit congestion, crash damage, emissions etc. (but also to produce harmonised vehicle designs that are interoperable in different regions). However, while many of the other standards are based on performance measures, aiming to influence these objectives directly, weights and dimensions regulations only aim to control them indirectly, which can cause higher limitations than necessary on productivity and innovation.

Under a performance-based approach to regulation, standards would specify the performance required from vehicle operations rather than mandating how this level of performance is to be achieved. There are two types of performance-based standards: performance-based prescriptive regulations and performance standards which are applied directly, through specifying the required performance measure.

Performance-based prescriptive regulations are prescriptive regulations based on performance analyses. Under this approach, specific criteria for performance are developed, as they are for Performance Standards. Prescriptive regulations that deliver the same performance are then established. For example, if a performance standard is developed that specifies the swept path a vehicle can occupy when undertaking specified manoeuvres, prescriptive regulations limiting length, width and wheelbase, so that vehicles do not exceed the swept path envelope, would form performance-based prescriptive regulations. However, even when prescriptive regulations are based on performance standards, they may be sub-optimal because they do not allow for innovative designs and equipment that might allow a vehicle to stay within the same swept path even if the prescriptive limits were exceeded.

Performance-based regulation has been adopted internationally in other sectors, such as occupational health and safety and food standards and is now well established as the approach preferred for effective and efficient regulation.

Current applications of performance-based regulation of trucking intend to provide greater flexibility than the existing prescriptive standards, but are not expected to shift far up the hierarchy of standards at this time. However, moving closer to a principles-based system of regulation presents some potential opportunities, including a higher degree of flexibility.

9.2. Performance-based regulation for trucking

Whilst many vehicle technical standards are performance-based, most requirements relating to vehicle weights and dimensions are prescriptive. Whilst some prescriptive standards have been based on performance assessments, the origin of many current prescriptive standards is uncertain.

Performance-based standards could be used to either replace or supplement prescriptive standards for truck weights and dimensions.

The approach used in New Zealand and Canada has been to use prescriptive standards to describe a set of vehicles, following assessments to ensure that these prescriptive standards achieve intended performance standards. In some Canadian provinces and some Australian states this approach is also used to assess vehicles which operate under exemptions or permits.

Australia is also developing a broader approach to performance standards. There has been national agreement on a set of performance standards and a process for national approval of vehicles and vehicle operations against these standards. Whilst some prescriptive standards will still apply, the Australian approach is intended to achieve a parallel regulatory stream based on performance-based standards.

Performance-based approaches allow the interactions of vehicles with the roads they use to be taken into account more explicitly. In determining whether a specific vehicle can operate on a particular road, the vehicle's capabilities and the relevant road standards and traffic conditions can be examined jointly, to decide whether the operation will produce the outcomes desired. In addition, vehicle designers are able to innovate to meet safety standards whilst maximising productivity.

Application of performance-based standards will facilitate a shift towards the tailoring of vehicle types to operational needs, infrastructure characteristics and operating environments.

For example:

- A vehicle with a relatively high load transfer ratio might be restricted to routes with no sharp curves, or might be restricted to a maximum speed around tighter curves.

- A vehicle with relatively high road damage potential could be limited to routes with stronger pavements and bridges. In this case, a performance standard for pavement damage would have to be derived, taking into account static effects (ESAs) and dynamic effects (suspension characteristics).

It is likely that effective implementation of these kinds of conditional or restricted access to the road system will require the development of innovative forms of compliance. Conditional access is unlikely to be acceptable unless road owners, road users and the general community are confident that the conditions are being complied with. Conditional access is likely to require the development of auditable compliance systems, possibly involving precise knowledge of time and vehicle position so that route and speed compliance can be established. Methods of compliance based on Global Positioning Systems are under development. Enhancements to these systems would enable assessment of compliance with conditions relating to:

- Load/vehicle mass, through on-board scales or load control systems.

- Driver attributes (through electronic licences and or operator records).

- Route and time of day restrictions.

Development of these types of innovative compliance arrangements will improve the productivity of the road freight system, through tailoring of vehicle characteristics and vehicle operation to network characteristics.

9.3. Industry partnerships: Canada – Saskatchewan[1]

Bulk Commodity Policy

In 1977, Saskatchewan became the first jurisdiction in North America to use commercial vehicle weight and dimension policy as an economic development tool. The initial policy enabled industry to use commercial motor vehicles with weights and/or dimensions that exceeded legal limits on condition that the motoring public and taxpayers were not adversely affected by this traffic. The policy substantially reduced truck transportation costs in some applications and also reduced rail rates on potash by providing a truck connection to the U.S. rail system. Except for incremental road and bridge costs, all of the benefits from the policy accrued to the private sector.

Changes in the economic and financial environment in Saskatchewan and increased demands on the highway system from grain traffic and other commodities led to a review of the 1977 Bulk Commodity Policy.

Transportation Partnership Policy

The Transportation Partnership Policy was implemented in 1994, to ensure a highway system that was safe, reliable, efficient, environmentally sound, and financed by a combination of public and private sector funds.

The cornerstone of this initiative was the creation of partnerships with private sector companies to reduce truck transportation costs. The savings generated from these partnerships were to enable the company to be more competitive and provide new revenue for making improvements to the specific highways used by their vehicles. The initial objectives of the Transportation Partnership Policy were to:

- Support economic development in Saskatchewan.
- Provide additional revenue for road improvements on specific routes used by a particular transport company.
- Promote the use of more efficient road friendly vehicle technology.
- Ensure that the taxpayer and motoring public were not adversely affected by industrial traffic.

New vehicle configurations are identified that will reduce trucking costs by optimising the vehicle with the highway system as well as the material handling facilities. New vehicles are evaluated on the basis of safety, road and bridge impacts, and haul savings. The Transportation Association of Canada (TAC) performance measures are used to pre-screen candidate vehicles. If the vehicle concept represents a major departure from existing vehicles, field demonstration projects are undertaken to confirm the analysis prior to full implementation. If the study results are favourable, the Department enters into a comprehensive transportation partnership agreement with the industry that contains:

- Vehicle configurations, including weights and dimensions.
- Vehicle standards and specifications.
- Haul routes.
- Vehicle operating and maintenance procedures.

- Driver qualifications.
- Truck haul savings to be used for road improvements.
- Highway improvement projects.

After the agreement is signed the Department issues a permit to enable the client to operate vehicles within the terms and conditions of the agreement. The Department conducts safety and financial audits to ensure compliance.

Truck haul savings are determined by taking the difference in transportation costs associated with using vehicles that comply with regulation weights and dimensions and the cost of using overweight and/or over-dimension vehicles. All incremental road and bridge costs associated with using the overweight vehicles and any incremental costs to the client are deducted from truck haul savings. In the initial programme, the client retained 50% and the other 50% was used for road improvement projects. The road contributions do not revert to the consolidated fund of the province but are deposited in separate accounts that disperse the money for the highway improvement projects that have been mutually agreed to by the Department and the client.

In September 2008, the structure of the Transportation Partnership Program was changed. The objective of delivering revenue, which related to sharing the freight savings, was removed from the programme. The change was largely due to a change in government and an enhanced transport budget for the province.[2]

Programme benefits

The 5-year objective for the partnership programme was to generate an additional CAD 15-20 million per year for highway improvements. As of December 1, 1997, the Department had negotiated 9 partnership agreements that would collectively generate approximately CAD 4.4 million per year. An additional 12 agreements are in the negotiation stages. Examples of vehicles operated under the agreements are:

B-double log trucks, at GCM of 92.5 t, replacing tractor-semitrailers operating at 40 t, with haul cost savings of 50%

B-double trucks for bulk transport, at GCM of 72 t, replacing tractor-semitrailers at 40 t, with haul cost savings of 33%.

9.4. Weights and dimensions review: Canada – interprovincial

Background

Canada's ten provinces and three territories have responsibility for vehicle size and weight regulation. As Canada is a large country with a sparse population, an efficient transport system is important for the achievement of economic and social goals.

Whilst key Canadian roads and bridges were strengthened through the 1970s through a national highway infrastructure initiative, it was recognised by the early 1980s that Canadian road freight efficiency suffered as a result of substantial variation in truck size and weight regulation between provinces.

As a result, the Road Transport Association of Canada (RTAC) and the Canadian Council of Motor Transport Administrators (CCMTA) initiated the Vehicle Weights and Dimensions Study, which ran from 1983 to 1986.

Weights and Dimensions Study

This was the first study to attempt systematically to quantify the relationship between vehicle weights and dimensions, vehicle performance and safety outcomes. In addition, the study initiated an experimental pavement test programme which established the influence of axle spacing on pavement response and undertook laboratory testing of suspension dynamics for road friendly vehicles.

Principle findings of the study were:

- The tridem axle group was proven viable for Canadian road and bridge structures and the loads permitted were dependent on axle spread.
- The B-train was found to have significant safety performance improvement over the A-train especially for shorter trailers.
- A set of engineering principles was generated to promote consensus on configurations that would harmonise weight and dimension regulations in Canada.

The key performance measures identified were:

- Steady-state roll stability.
- Rearward amplification.
- Load transfer ratio.
- High-speed off-tracking.
- High-speed transient off-tracking.
- High speed friction utilisation.
- Low-speed off-tracking.
- Low-speed friction utilisation.

Following the study, an Implementation Planning Subcommittee was created to develop a plan to assist each jurisdiction in implementing uniform vehicle weight dimensions and configuring regulatory principles, developing schedules for proposed implementation of the recommendations and monitoring the progress of implementation. The Implementation Planning Subcommittee developed a set of vehicle stability and control performance criteria, which specified target performance levels associated with the performance measures identified in the study (Implementation Planning Subcommittee, September 1987). These performance measures and levels have formed the basis for subsequent specification of prescriptive standards for heavy vehicles in Canada.

The recommendations of the Implementation Planning Committee then led to the establishment of the Task Force on Vehicle Weights and Dimensions Policy. The Task Force is a national committee composed of officials from the federal, provincial and territorial transportation departments responsible. The purpose of the Task Force is to pursue greater national and/or regional uniformity of policies, regulations and enforcement practices for heavy vehicle weight and dimension limits within Canada, and to represent Canada in regulatory harmonisation discussions being carried out under the North American Free Trade Agreement (NAFTA).

Outcomes

The Task Force drafted, and now maintains, the Federal-Provincial-Territorial Memorandum of Understanding on Interprovincial Weights and Dimensions, which was endorsed in February 1988. The MoU, which has since been amended several times, determines national standards for the size and weight of heavy vehicles used in interprovincial transportation. Access is provided, for these vehicles, to a designated network determined by Provinces and Territories.

The MoU currently provides, for seven truck types: Tractor Semitrailer, A-Train Double, B-Train Double, C-Train Double, Straight Truck, Truck–Pony Trailer and Truck–Full Trailer. The dimensions of these vehicles are described prescriptively (length, width and height) but these prescriptive requirements are based on assessments against the performance measures and targets listed above.

The MoU prescribes minimum standards for these vehicle configurations for interprovincial movements (Task Force, April 2008). This does not restrict the configurations and specifications of trucks that an individual jurisdiction may allow on its roads. It only requires that the province/territory allow the trucks defined in the MoU. Jurisdictions can, and do, also allow variations (typically higher load limits or different trailer configurations) for intra-provincial movements, or in some cases with neighbouring provinces/territories.

9.5. Safe, Productive and Infrastructure-Friendly (SPIF) vehicles: Canada – Ontario[3]

Background

Ontario is the largest of Canada's 10 provinces with a population of over 12 million people. It has a diverse economy with a significant manufacturing base. Ontario is bordered by two Canadian provinces and three U.S. states, all of which have somewhat different truck weight and dimension regimes.

Ontario's Vehicle Weight and Dimension Reform Project is a long-term, multi-phased project which is fundamentally changing the type of heavy trucks and trailers operating on Ontario highways. Reforms have three primary objectives:

- To reduce avoidable infrastructure damage.
- To improve highway safety through use of performance-based vehicle designs.
- to maximise road freight productivity.

Key challenges include developing new vehicle standards as well as ensuring a smooth and fair transition from existing vehicles.

Truck weights and dimensions

In Canada, size and weight limits for trucks are set at the provincial level in an environment where there are significant differences in truck weights and axle configurations in different Canadian provinces and U.S. states. As Ontario allows some of the highest axle and gross weights in North America, a major focus is to harmonise allowable weights and dimensions with other jurisdictions for the free movement of trucks.

Ontario has previously allowed a wide array of vehicle configurations as long as they have been consistent with general length, width and height limits. Allowable weights were determined from a complex series of axle and gross weight tables based on number and spacing of axles. Maximum gross weight was set at 63 500 kg. Axle and gross weight tables were based on bridge and pavement constraints with little regard for vehicle dynamic performance.

This permissive regime, which was seen as productive and was well received by industry, resulted in multi-axle configurations that made extensive use of lift-able axles in order to allow vehicles to turn. These configurations caused excessive and avoidable infrastructure damage as well as unacceptable rates of collisions. As a result, in the late 1990s, Ontario began a programme of vehicle weight and dimension (VW&D) reforms.

Truck weights and dimensions reforms

The Ontario project was divided into four phases, each dealing with a different group of vehicles. Stakeholders, including vehicle and component manufacturers, vehicle operators, shippers and neighbouring jurisdictions were extensively consulted. The primary interest of stakeholders was maintaining vehicle productivity, harmonising with neighbouring jurisdictions and ensuring a 'level playing field' during any transition.

Three of the four phases (representing all tractor-trailers) have been implemented. Work is progressing on the final phase 4, which is aimed at addressing rigid trucks and their trailers. Reforms are designed to force a migration to vehicles designated as 'Safe, Productive and Infrastructure-Friendly' (SPIF). All new tractor-trailers are to be built to SPIF standards. These standards are prescriptive but are based on performance standards (Implementation Committee, 1987). Grandfather rights will permit the continued use of existing vehicles for the remainder of their reasonable working life. The entire transition is expected to take around 25 years.

There are a wide variety of SPIF vehicle configurations designed to meet diverse industry needs, including maximising productivity within infrastructure and realising safety constraints. To protect infrastructure, multi-axle vehicles are now equipped with self-steering axles in place of rigid lift-axles. All axles on semi-trailers must now automatically share the weight, without driver intervention. The design and weights of SPIF vehicles are based on performance standards and guidelines developed in Canada.

Expected results

The result of all these efforts is that trucking productivity will be maintained or improved. Furthermore, meeting national performance standards is expected to reduce the number and severity of heavy vehicle collisions. It is anticipated that straightforward prescriptive SPIF standards will improve compliance and enforcement, resulting in both highway safety and infrastructure protection.

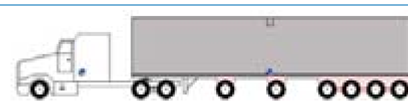
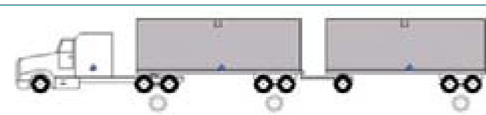
Different vehicle configurations and emerging technologies can be accommodated in the Ontario approach by special permit or amendment to the laws. However, the onus is on proponents to show how proposed vehicles meet SPIF requirements.

Acceptability of proposed SPIF vehicles depends on safety and infrastructure impacts rather than economic and environmental benefits.

The future

The Ontario weight and dimension reforms have been generally well-received by stakeholders and the transition to SPIF vehicles is progressing. Policy work has commenced on Phase 4 and changes are likely to impact trucks and trailers built from 2011 onward.

Table 9.1. **Ontario: Safe, Productive and Infrastructure Friendly (SPIF) Vehicle Configurations – Examples**

SPIF Vehicle	Description (VW&D Reforms Phase)	Schematic (alternative axles shown in shadow)
#1	**Fixed-Axle Semi-Trailer:** (Phase 1, 2, 3) – single axle – tandem axle – tridem axle	
#2	**Self-Steer Triaxle Semi-Trailer** (Phase 1, 2)	
#3	**Self-Steer Quad Semi-Trailer** (Phase 1, 2)	
#7	**6-Axle Self-Steer Semi-Trailer** (Phase 3) **(1-1-4)**	
#11	**A-Train Double** (Phase 3)	
#12	**B-Train Double** (Phase 3)	

9.6 Performance Based Standards (PBS) Scheme: Australia[4]

The PBS approach

The PBS project has developed desired performance outcomes as a set of 16 safety-related standards and four infrastructure-related performance standards. These act as an alternative to existing mass and dimensional limits. The PBS standards align the performance capabilities of vehicles with those acceptable by the road network on which they may operate. This approach aims to improve safety and provide for productivity increases without unduly increasing infrastructure costs for a specific transport task. The processes for certification to Performance Based Standards are documented in four sets of rules and guidelines:

- Standards and Vehicle Assessment Rules.
- Network Classification Guidelines.

- Assessor Accreditation Rules.
- Vehicle Certification Rules.

These rules have been developed to set out how accredited assessors must assess vehicles against these standards, using either numerical modelling or field testing or a combination of both. The 15 safety-related and 4 infrastructure protection standards are shown in Table 9.2.

Table 9.2. **Performance Standards - Australia**

	Standard	Description
Vehicle stability	Static rollover threshold	Ensures that geometry and suspension provide a set level of vehicle stability
	Directional stability under braking	Ensures that vehicles remain controllable when braking in a turn
	Yaw damping coefficient	Ensures that vehicles do not suffer excessive roll oscillation after manoeuvres
Trailer dynamic performance	High-speed transient off-tracking	Ensures that trailers follow the path of the prime mover during unbraked avoidance manoeuvres
	Rearward amplification	Ensures that trailers of multi-articulated vehicles do not swing excessively after avoidance manoeuvres
	Tracking ability on a straight path	Ensures that trailers do not deviate from intended straight line path when driven on a rough road
Vehicle powertrain	Startability	Ensures that the fully laden vehicle may start on a hill of set grade
	Gradeability	Ensures that the fully laden vehicle may maintain speed on a hill of set grade
	Acceleration capability	Ensures that a vehicle may accelerate at an appropriate rate to clear traffic lights etc
	Overtaking provision	Transferred to Network Classification Guidelines
Vehicle manoeuvre-ability	Low-speed swept path	Ensures that a vehicle may safely manoeuvre around corners typical of those found on its compatible network without cutting the corner
	Frontal swing	Ensures that a vehicle may safely manoeuvre around corners typical of those found on its compatible network without contacting the rear of the vehicle
	Tail swing	Ensures that a vehicle may safely manoeuvre around corners typical of those found on its compatible network without contacting the rear of the vehicle
Vehicle ride and handling	Steer-tyre friction demand	Ensures that steering axle will be effective in changing the course of the vehicle as required by driver input
	Handling quality (understeer/ oversteer)	Ensures that the vehicle does not show any adverse handling properties with respect to steering inputs – under development
	Ride quality (driver comfort)	Ensures that vehicle ride quality does not have adverse whole-body vibration effects on driver – under development
Infrastructure	Bridge loading	Ensures that vehicle mass is compatible with bridge infrastructure for set route
	Pavement vertical loading (interim standard)	Ensures that vehicle mass as transferred to the pavement is compatible with road infrastructure for set route
	Tyre contact pressure distribution	Ensures that pressure transferred to the road surface by the tyres is compatible with road infrastructure for set route
	Pavement horizontal loading	Ensures that horizontal force transferred to the road surface by the tyres is compatible with road infrastructure for set route

Handling and ride quality are not assessed at this point in time as suitable standards and limits have not been developed to test these attributes objectively.

Network classification

Many of the safety-related standards specify four different performance levels - 'Level 1' through 'Level 4' – where Level 1 is the most difficult to achieve. The purpose of providing the various performance levels is to match the on-road performance of the vehicle to the risk environment that it will be operating in, whilst making optimal use of available capacity in the network (*i.e.* on urban routes where there is more traffic and more restrictive roads in terms of lane width and available turning space the standards are tighter than for rural environments).

Network Classification Guidelines have been developed to assist road owners (*i.e.* State/Territory road agencies and local governments) in classifying routes into one of four levels. While the guidelines are based on technical assessment of route capability, road owners should also consider local policy issues and limitations (*e.g.* proximity to schools) when classifying roads.

With vehicles assessed as meeting one of the four performance levels, network access may be granted to the corresponding network level. Approximate descriptions of the four levels of road classification are: Level 1 – General Access; Level 2 – B-double routes; Level 3 – Double Road Train routes; Level 4 – Triple Road Train routes.

It is intended that the majority of major freight routes in Australia (*i.e.* B-double and road train routes) will be classified and mapped for publication. Vehicle operators seeking access to particular routes are then able to design vehicles to meet the performance levels required for access to those routes. While state governments are primarily responsible for the mapping process, there will be cases where PBS vehicle operations require access to local government-owned roads. It will be the responsibility of local governments to determine access to these roads using the Network Classification Guidelines.

Bridge assessment

Allowable bridge loading significantly limits the productivity gains that PBS can deliver. In simple terms, the bridge loading standard limits the total mass that may be transmitted by a heavy vehicle over a given length (of the vehicle, or bridge section). The PBS bridge loading standard is divided into three tiers, the assessment process for which increases in complexity with each tier:

- Tier 1: bridge formula to be applied.
- Tier 2: comparison to a reference vehicle.
- Tier 3: case-by-case assessment of each bridge and/or vehicle along a chosen route.

Tier 1 assessments essentially correspond to those applying to standard (non-PBS) heavy vehicles operating within the prescribed axle group mass limits. They specify a linear relationship for maximum mass and the distance between the axle groups through which it is transmitted. While the Tier 1 assessment is the simplest and most practical option, it is also the most restrictive in terms of its potential for unlocking productivity. Compliance with a Tier 1 assessment is impractical for many types of higher productivity vehicles seeking to operate at higher mass limits than standard heavy vehicles.

To achieve higher productivity, vehicle designers are thus required to utilise tier 2 and 3 assessment methods which require individual assessments of each bridge on the intended route. This process can be expensive and time consuming. The transparency and timeliness in which tier 3 bridge assessments are carried out by authorities responsible for conducting them will have a direct affect on the success and uptake of the scheme.

Application of Performance Based Standards (PBS) allowed a redesigned vehicle to deliver up to a 5.5 tonne payload advantage for quarry industry truck operators. Under Australian national prescriptive mass and dimension regulations, the permitted mass of a truck and quad dog trailer combination was limited to 48.5 tonnes. This permissible mass is lower than would be achieved by allowing each axle group to carry the maximum permitted axle load due to the need to meet bridge formula requirements and ensure safe handling and on-road performance. Increasing the gross mass required an increase in length to meet the bridge formula. Increasing the length and mass of a vehicle, however, has implications for dynamic handling and manoeuvrability.

Design work was undertaken by ARRB Group to ensure the vehicle met PBS standards for safety and infrastructure protection. The minimum length capable of meeting the bridge standards was 19.6 metres. Application of PBS standards demonstrated that the truck and quad dog design was able to safely meet road access requirements due to the truck and dog combinations having much better swept path performance when cornering compared to standard 19 metre tractor-semitrailers.

Figure 9.1. **PBS case study: high payload truck-trailer for quarry operations**

The revised design allows the truck and quad dog trailer to match the payload capacity of a standard 19 m B-double with a vehicle which has lower tare weight and better swept-path performance.

The design and certification work has been done and this vehicle is now commercially available. The design with its 19.6 m length has national approval for General Access at 50.3 tonnes with no need for route restrictions. The gross combination mass can be increased to 54 tonnes and still meet the requirements for access to PBS level 2 roads (corresponding to the section of the network that is open to B-doubles).

Institutional arrangements

The PBS institutional arrangements provide a framework within which PBS vehicles are considered for access to the road network.

All PBS vehicle applications will begin with an accredited PBS assessor making an assessment of the proposed vehicle design against the performance standards. However, as final access approval may be affected by local policy issues and limitations, applicants are encouraged to first consult with jurisdictions (state and local government authorities) to ascertain attitudes towards the granting of access for the proposed vehicle to the requested routes.

Following assessment of the vehicle against the relevant requirements, a formal application is sent to the PBS Review Panel – a body with representatives from federal and state road authorities, led by an independent chairperson and deputy chairperson, via a dedicated secretariat and housed initially within the NTC. The Panel is charged with the responsibility of determining the level of network access granted and any particular operating conditions which must be observed to control the potential for non-compliance. For example, vehicles that require a particular loading limit to meet static rollover requirements will be required to participate in mass-management accreditation as an operating condition.

Determination by the Panel does not mean that access is granted. Final access approval is determined by the relevant road authority, considering the decision of the panel and any local policy issues and infrastructure limitations.

PBS effectiveness

The scheme was approved in its current form by the Australian Transport Council (ATC) in October 2007. To date there have been 64 successful PBS design approvals, involving approximately 140 PBS vehicles. Although this number is low, particularly when reviewed against a backdrop of sales volumes of around 15 000 heavy trucks per year, it represents a scheme that in operational terms remains in its infancy.

To date, over forty per cent of applications have been for truck-trailers. The most common reason for truck-trailer operators submitting PBS applications is to qualify for increased mass limits or to overcome state-based inconsistencies in allowable mass limits. PBS has provided the possibility to operate above 50 tonnes on Level 2 routes and also 20 m overall length on Level 1 routes. However, these productivity gains have not been realised in all states.

PBS has also proven effective as an access enabler for more innovative high productivity vehicles (for example, 30 m B-doubles which transport two forty-foot containers around the ports). It has also inspired the development of new technologies that improve both low speed directional and high speed dynamic performance.

In terms of vehicle types, current applications to the PBS scheme can be categorised broadly in two ways:

- Those with a generic transport task, seeking productivity improvements, *e.g.* 30 m B-double and 20 m truck-trailers.
- Those with a specialised transport task that makes compliance with standard heavy vehicle regulations difficult.

The PBS scheme is designed to provide a robust risk management tool to give regulators confidence that high productivity vehicles are safe to operate on suitable roads.

Next steps

Industry reaction to the PBS scheme has been mixed. The majority of industry members have taken a ‘wait and see’ approach to participation, largely because early adopters have not realised the desired network access. Whilst some operators have been quick to utilise the opportunity to achieve higher productivity, others industry members regard the scheme as unnecessarily slow and expensive. The original objective of a single national decision-making process has not been met, with road agencies making the final decision on local access.

Road network access and bridges continue to be the biggest obstacle to a wider uptake of PBS. Until road authorities can provide the means by which operators can obtain certainty of access, the PBS scheme will continue to have a limited effect on productivity.

A review of the PBS scheme has recently been undertaken, with a focus of recommending an application process which will be a more streamlined, quicker and less costly pathway to unlocking productivity within an increased proportion of road freight operations whilst maintaining appropriate levels of safety and asset protection (NTC, December 2008 and NTC July 2009).

9.7. Performance Based Standards demonstration projects: South Africa[5]

Demonstration projects

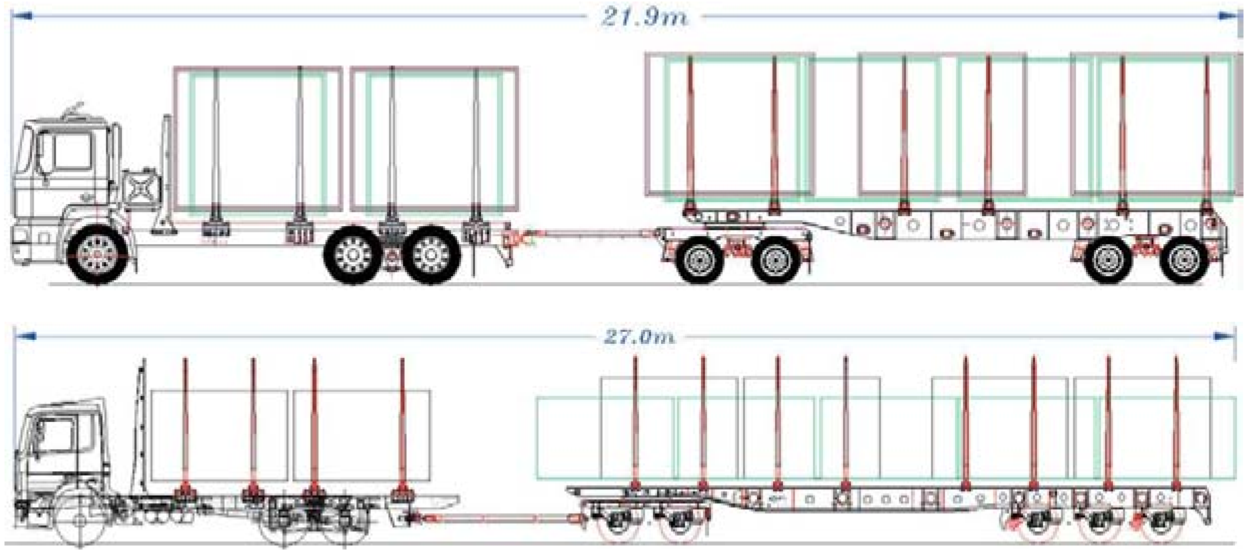
The Road Transport Management System (RTMS) self-regulation scheme (see s6.3) was initiated in the forestry industry, which was, therefore, considered to be the logical industry to start with PBS demonstration projects in South Africa.

Two concept vehicle designs, a truck/trailer and a B-double, were initially developed and considered. At the outset a number of important design parameters were decided; some were outside the direct control of the project team, while others – set by the transport operator – were directly related to the timber product (log lengths) and the requirements of the current and expected future log transport task. For example, maximum overall length was controlled by the regulators, maximum axle loads and spacing was consistent with the prevailing pavement and bridge load requirements, and safety items linked to the current regulations were retained. While there was a clear focus on productivity, in view of the number of rollovers and crashes reported by operators, safety performance was given a high priority, so much so that a loss of productivity was considered to be acceptable if it meant a higher level of safety could be achieved. Therefore, it was a primary design goal and requirement that the vehicle should have acceptable safety performance and meet all of the applicable PBS safety standards.[6] The provincial Abnormal (indivisible) Load Permit Offices, which are responsible for approving routes for abnormal load vehicles, are also responsible for approving the routes for the PBS demonstration vehicles.

Using the current log transport vehicles as a baseline and the concept designs as proposal PBS vehicles, numerical modelling was used to establish benchmark performance levels and to guide and assess the new designs to achieve performance levels that would satisfy the PBS performance requirements and the transport task.

The truck/trailer concept vehicle, comprising a three-axle rigid truck towing a five-axle drawbar trailer, was selected in favour of the B-double, and after a number of iterations a satisfactory vehicle design was achieved. At an overall length of 26.4 m and 27.0 m for the 4 and 5-bundle trailer log-loads, respectively, and a combination mass of 67.5 t, the truck/trailer combination satisfies the PBS performance standards considered and delivers an increase in payload capacity of 15%. By contrast, the baseline vehicle with both a lower gross weight (58.8 t) and payload capacity was not able to satisfy several PBS performance requirements, as described in the following section.

Figure 9.2. **Baseline (top) and PBS (bottom) vehicles at 58.8 t and 67.5 t GCM, respectively**



Standards and assessments

Drawing on the PBS standards developed in Australia jointly by the National Transport Commission and Austroads, the following performance measures were considered in the performance analysis. These are a subset of the complete set of PBS standards (NTC, July 2007) and relate specifically to safety performance relevant to this assessment:

- Tracking Ability on a Straight Path.
- Low-Speed Swept Path.
- Steer Tyre Friction Demand.
- Static Rollover Threshold.
- Rearward Amplification.
- High-Speed Transient Offtracking.
- Yaw Damping Coefficient.

For PBS assessment, numerical models were created to represent the truck/trailer combination, the B-double combination and the baseline vehicle. In the final analysis, only the truck/trailer design was taken through to manufacture. In the modelling, mechanical properties were assigned to components (sprung and unsprung masses, suspension, tyres, etc) consistent with components on each vehicle considered.

A range of simulations were performed using the numerical models and the precisely defined test conditions specified under PBS. The simulations demonstrated that the baseline vehicle (current truck/trailer) fails to achieve the required PBS performance level on two of the safety standards: Static Rollover Threshold and Rearward Amplification. By contrast the proposal truck/trailer (4 and 5-bundle variants) satisfies the PBS performance requirements at PBS Level 2. In addition, the baseline vehicle has a significantly higher value for High-Speed Transient Off-tracking, achieving a performance outcome consistent with PBS L3 road network access. In Australia vehicles assigned PBS Level 3 status are generally restricted to road train routes. The only area where the proposal vehicle performs significantly worse than the baseline vehicle is in low-speed turns, where its' longer overall length and, in particular, much longer trailer, means that the Low-Speed Swept Path width is greater.

Operation and driver feedback

The two PBS vehicles commenced operations in November and December 2007. Detailed monitoring of the vehicle and comparison with the control vehicle are ongoing. Monitoring parameters include payload, trip times, fuel efficiency, average speed (empty and laden), drive train maintenance costs, tyres, accidents/incidents and feedback from other road users. Table 9.3 provides a summary of measured benefits based on 8 months monitoring data of the two vehicles.

Table 9.3. **Summary of monitoring results of two PBS vehicles in South Africa**

Performance indicator	Measured result
Payload	Average improvement: 19.3 %
Payload Efficiency Factor	Increase from 69.3 % to 70.5 %
Fuel efficiency (per tonne-km of payload)	Average savings: 12.7 %
Fuel savings (based on 700 000 tonnes/annum contract)	485 000 litres per annum
Fleet size	Reduction of 17 %
Incidents/accidents*	Reduction from 3.1 to 1.1 per month
CO_2 emissions (based on 700 000 tonnes/annum contract)	Reduction of 1 280 tonnes of CO_2 per annum
Road wear (per tonne.km)	Reduction varies from 2 to 23 %

* Based on a fleet of 45 new vehicle combinations incorporating a number of PBS design features.

Initial feedback from the drivers has been very positive in terms of stability and manoeuvrability, which supports the improved performance features evidenced in the PBS vehicle compared with the baseline vehicle. Based on the performance of the two demonstration vehicles, the provincial road authority has supported an expansion of the demonstration project in the forestry industry by approving an additional 30 PBS permits. Some of the new vehicles will be identical to the existing PBS vehicles while others will be based on new designs. The additional vehicles are expected to come into operation during the latter half of 2009. Other PBS demonstration projects in various other industries are still in the concept stage.

Experience gained from the demonstration projects is also being used as input for the development of documentation (rules, standards, guidelines) for the possible introduction of PBS as a permanent feature in the heavy vehicle transport industry in South Africa.

9.8. Geographical and jurisdictional considerations

The Canadian Weights and Dimensions Review and more recent national processes, the earlier Saskatchewan development of industry partnerships, the development of Safe Productive and Infrastructure Friendly vehicles in Ontario, the recent applications of performance-based standards in Australia and the pilot scheme in performance-based standards in Australia are all examples of the application of more flexible regulatory approaches.

The Canadian national process and the Australian process have both occurred in federal systems where state/provincial governments have most or all of the power over road transport regulation, but there is a widespread recognition of the importance of achieving national consistency. In both Canada and Australia, formal bodies have been established with state/provincial representation and federal participation and with the aim of achieving national harmonisation of key areas of road transport regulation. In both countries, states and provinces have been prepared to fully or substantially implement the outcomes of the national processes. In both cases, the establishment of institutional arrangements has recognised that regulatory reform in road transport is a process of continuous improvement rather than a one-off action.

It may be no coincidence that both of these countries are large, sparsely populated and resource dependent, with heavy reliance on freight, particularly road transport.

In both cases, it has been demonstrated that if regulatory arrangements can present flexibility, whilst meeting community expectations of road safety, industry will respond by operating the most efficient vehicle combinations. The evaluations that have been undertaken demonstrate that this has resulted, in these countries, in improvements in safety and environmental outcomes, as well as productivity. In these two countries, there appears to have been widespread community acceptance of the operation of larger freight vehicles, provided that their operation is managed effectively. Beyond that the national processes in Canada and Australia present some interesting contrasts.

The Canadian national process was initiated some 15 years before the Australian PBS process (although there were two previous national reviews in Australia[7]).The Canadian process pioneered the use of performance standards and used them to develop prescriptive standards for a set of heavy vehicles considered most appropriate for use in interprovincial operations. The initial set of vehicles comprised four types of truck. A later amendment added three more truck types and an intercity bus. The Canadian process provides certainty to transport operators and vehicle suppliers and facilitates enforcement of vehicle weights and dimensions, but limits innovation outside of the current set of MoU vehicles.

The Australian PBS scheme has been developed in a more fundamental way by substituting performance standards for many prescriptive dimensions, whilst retaining some prescriptive standards (including height and width). The Australian approach has required the development of certification and accreditation processes covering vehicle design and manufacture. Whilst the Australian approach has a higher degree of flexibility and allows for more innovation in vehicle design, industry concerns over the expense and difficulty of the initial process have led to review and a recommendation to simplify the process. The difficulty of enforcing performance standards through traditional mechanisms has led to greater reliance on certification and accreditation.

In Canada, higher capacity vehicles outside the MoU are subject to provincial processes, though there is some consistency in approach across regions.

In Australia, the relationship between vehicles which are approved through the PBS process and non-PBS permit vehicles subject to the approval processes of individual jurisdictions has not yet been resolved.

Development of SPIF vehicles in Ontario, outside the national process, is another example of the use of performance standards to develop prescriptive standards for a set of vehicles designed to meet the needs of the road freight industry and the community, in this case within a single province.

The earlier approach in Saskatchewan is an example of a more collegiate process between industry and regulators, which may be best suited to a smaller jurisdiction.

The PBS demonstration projects in South Africa are an example of the use of pilot projects to investigate the feasibility of an alternative approach to the use of heavy vehicles on the road network. If the road authorities in South Africa support this approach in the long term, a more structured and formal approach will need to be developed and implemented.

9.9. Conclusions

Regulatory solutions should respond to freight needs whilst meeting the expectations for improved health, safety and quality of life.

This will require governments to adopt regulatory mechanisms that promote innovation and provide the flexibility for transport operators to improve productivity, at the same time improving road safety, minimising emissions and optimising the use of road infrastructure. In the road freight sector, this must include a more sophisticated approach to heavy vehicle regulation.

The principles which should be applied in the development of improved approaches to the regulation of road freight operations are:

- Minimum regulation.
- Regulation that is most closely related to aims: performance-based.
- Pricing signals to direct road use and provision of infrastructure.
- Comprehensive regulatory assessment processes, that take into account all relevant factors.
- Harmonisation of regulatory requirements, where the benefits of standardisation outweigh the benefits of variations.
- Compliance mechanisms to support regulatory requirements.

If supported by adequate compliance assurance mechanisms, differentiation of access conditions could be based on:

- Infrastructure characteristics, *e.g.* bridge capacity, pavement capacity, radius of curves, camber.
- Vehicle type, *e.g.* length, width, height, mass.
- Vehicle use, *e.g.* speed, perhaps related to nature of road.
- Time, *e.g.* urban deliveries at night, perhaps subject to noise limitations.
- Combination of the above, *e.g.* access dependent on recovery of all costs of road use.

It is not difficult to demonstrate that the more widespread use of larger heavy vehicles has the potential to result in improved safety, productivity and environmental outcomes (provided that the improved competitive position of road freight does not result in an excessive shift of goods from a more environmentally efficient mode of transport). Despite this, there is widespread community concern over the safety and amenity associated with larger heavy vehicles. In addition, network access for heavy vehicles presents issues for infrastructure providers and network managers.

A way forward for road transport regulation is to package up:

- Performance standards, to allow higher productivity with maintenance or improvement in safety.
- Pricing, to provide appropriate signals within the mode and between modes and to demonstrate to politicians and public that heavy vehicles are paying their way.
- Improved compliance.
- Improved safety.

The key to effective utilisation of trucks is to demonstrate to the community and their political leaders that these vehicles comply with route restrictions, deliver high safety and environmental outcomes and recover all costs associated with their use of the network. The tools to deliver these requirements are available. The challenge for regulatory agencies is to implement an integrated and effective approach to the regulation of trucking.

NOTES

1. Source: Woodrooffe *et al*., 2005.
2. Source: NTC, January 2009, p.72.
3. Source: Transportation and Policy Branch, Ministry of Transportation, Ontario; and McQuaig (2007).
4. Source: National Transport Commission, Australia.
5. Source: Nordengen *et al*., 2008.
6. The PBS safety standards developed in Australia have been adopted for the purpose of the demonstration project.
7. NAASRA (1976) and NAASRA (1985).

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10. COMPLIANCE AND RESPONSIBILITY

Abstract

The chapter reviews the approaches used to achieve compliance and the role of enforcement. It describes the traditional approaches of enforcement, based on designated officers observing an offence (though increasingly this observation has been by electronic means – speed cameras and the like) and taking subsequent action, and it describes compliance technologies and discusses the new approaches to compliance, where compliance is seen as an enabler for achieving more flexible network access for heavy vehicles.

10.1. Introduction

In order to ensure compliance with regulatory requirements, all countries employ a wide range of compliance and enforcement measures. This chapter will present a range of current and emerging approaches to achieving compliance with road transport regulatory requirements, explain the sanctions and penalties for non-compliance, explain the need for enhanced monitoring of compliance levels and consider how compliance can best be achieved.

It is argued that improved technology, more flexible sanctions and incentives, the use of information technology to target enforcement activities and the extension of legal requirements to others in the transport chain (beyond drivers and transport operators) will lead to rapid improvements in levels of compliance with regulatory requirements. The application of these compliance tools will result in compliance becoming an 'enabler' of better societal outcomes for trucking.

Early enforcement measures usually required direct observation of a breach and immediate action against the party directly responsible for the breach. For example, a weight breach could be detected by roadside weighing and a fine imposed on the vehicle driver.

In recent years, methods of detection of vehicle-related offences have become more sophisticated and often use electronic means both for detection (*e.g.* speed cameras) and subsequent action (*e.g.* electronically generated offence notices).

Heavy vehicle enforcement is usually undertaken at State/Provincial level in federal systems (Australia, Canada, United States) and at national level in other countries, including member countries of the European Union. Police have powers for on-road enforcement of heavy vehicles, but in many cases dedicated heavy vehicle inspectorates have been established. The enforcement effort includes coverage of vehicle condition, driver licence and registration status, speed, hours of service, route restrictions and vehicle mass and dimensions.

Box 10.1. **Intelligent Access Program (IAP) - Australia**

Transport Certification Australia (TCA) was established in August 2005 by Australian road authorities to implement and administer all aspects of the Intelligent Access Program (IAP).

Most vehicles in Australia operate under general access – a right to access the entire road network. Other vehicles, due to their dimensions, configuration, mass or load are only allowed access to limited parts of the road network. This is known as restricted access. The IAP allows participating transport operators improved access to the road network in return for their compliance with agreed access conditions. This is known as intelligent access.

The IAP is a strategic means of utilising existing and new technologies in dealing with Australia's growing freight task, meeting industry demands for greater productivity and more efficient use of infrastructure, and addressing issues of community, government and industry confidence.

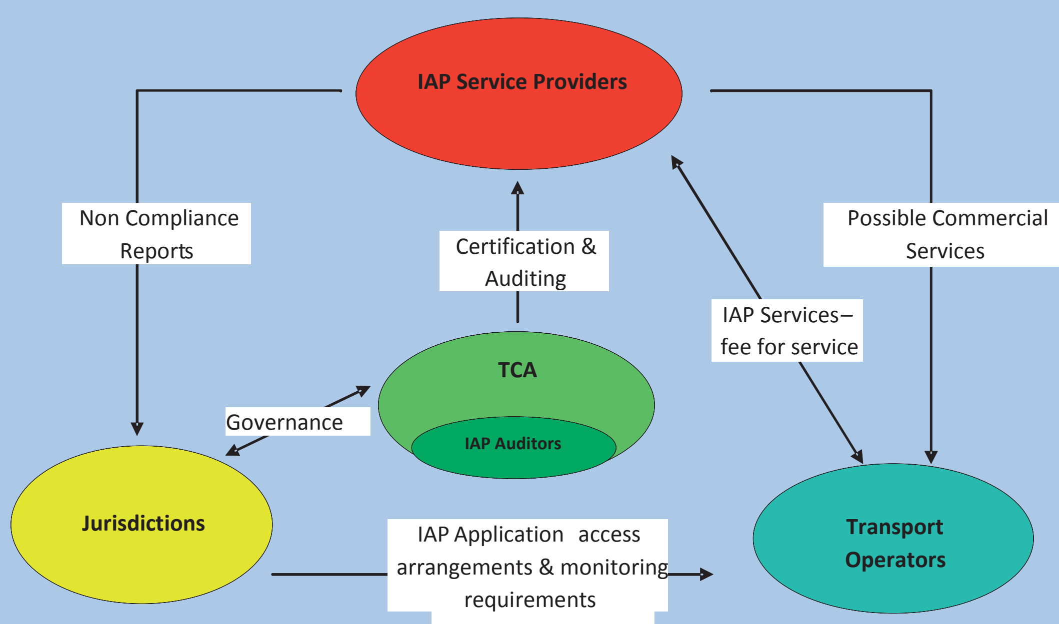
The IAP uses satellite monitoring of heavy vehicles to give transport operators flexible access to the Australian road network to suit their specific business and operational needs. In return, the IAP provides road authorities with greater confidence that heavy vehicles are complying with the agreed road access conditions.

The IAP serves as a nexus between the needs of the road transport industry – improved access, reduced trip times, higher permitted loads – and the requirement of road authorities and government to protect their infrastructure assets, and the industry compliance needed to achieve this.

IAP Service Providers are certified and audited by TCA. Transport operators link with Service Providers for monitoring of compliance conditions (*e.g.* route restrictions) and any other services which may be agreed. Service Providers must monitor compliance conditions and pass on any non-compliance reports to road agencies.

Under the IAP, monitoring is always for non-compliant activity (*i.e.*, breaches of regulatory requirements). Even though a vehicle is monitored continually, the road authority is only provided with data that demonstrates non-compliance. If an IAP vehicle is detected as being non-compliant, the IAP Service Provider generates a non-compliance report, which is then sent to the relevant road authority. All non-compliance reports are treated on a case-by-case basis, with the road authority deciding whether any action is warranted. A non-compliance report does not necessarily signify that an offence has occurred.

The IAP is governed by a national legal and policy framework, implemented by each State and Territory government through local legislation.



A growing number of partially automated technologies have become available to the enforcement of regulations of weighs, speeds and driving hours. These systems and other modern tools which the enforcement authorities may now share with the operators for the benefit of both are reviewed in 10.3.

Penalties for non-compliance with road transport law are generally higher for offences related to heavy vehicles than light vehicles, reflecting a higher degree of public risk resulting from non-compliance by heavy vehicles. Penalties range from fines to removal of the right to drive (licence suspension or cancellation) and removal of the right to operate (suspension or cancellation of the operator licence). In some cases, jail terms are provided for severe offences (*e.g.* culpable driving).

In most countries, the driver and/or the transport operator is held responsible for breaches of road transport law. Under operator licensing approaches, the operator can be held responsible for patterns of behaviour within the operation as well as for individual offences. A right to continue road transport operations may be made conditional on the implementation of improved safety practices.

10.2. Approaches to compliance and enforcement

10.2.1. Traditional approaches

Traditional regulatory responses to road transport breaches have been oriented towards enforcement rather than compliance, tending to be overly reliant on the physical detection and prosecution of offenders and on increasing the level of monetary penalties. As well, the driver and vehicle owner have been the ‘soft’, and usually the only, targets of heavy vehicle enforcement policies.

In general, existing heavy vehicle legislation imposes liability for breaches of the road transport requirements only on drivers and/or operators and owners of heavy vehicles. The role played by other parties in the transport chain is usually not addressed, other than by way of offences which are indirect (*e.g.* ‘cause or permit’ and ‘aid or abet’), which are not only difficult to prove, but which lack sufficient specificity to be effective as deterrent measures (McIntyre, 2000). Hence existing road transport legislation tends to have limited deterrent effect on those other parties, many of whom may have a significant bearing on the activities that affect compliance with the road laws.

In some countries, traditional enforcement has been bolstered by operator licensing or safety ratings regimes, which have required operators to develop more proactive safety and compliance systems.

In many countries, road transport legislation has not been fundamentally reviewed for decades and has not kept pace with other forms of regulation, such as occupational health and safety laws and environment protection laws, in terms of compliance and enforcement mechanisms. In road transport, the ‘compliance’ debate has traditionally focused on increased on-road enforcement, ramping up penalty levels and operator licensing schemes.

These traditional road transport regulation and compliance approaches have not proved effective in reducing public concerns over the on-road behaviour of heavy vehicles. Traditional enforcement and monetary penalties are inadequate to ensure safety and resolve systemic problems (McIntyre and Moore, 2002, p.1):

- *Fines, no matter how high, will not have a sufficient deterrent effect when the chance of detection is slight and the potential profits from offending are high.*

- *Targeting only the truck driver and operator has no deterrent impact on the many 'off-road' parties who have a significant influence on on-road compliance and leads to a perception amongst drivers and operators that they are being treated unfairly.*
- *In an industry characterised by high levels of competition resulting from low barriers to entry and a large number of small operators, the survival of operators who attempt to achieve levels of compliance higher than industry standards will be threatened.*
- *A culture founded on confrontation between the regulator and the regulated is not conducive to promoting voluntary compliance.*

By failing to provide regulators and the community with the necessary degree of compliance assurance, traditional enforcement approaches have not been conducive to enabling productivity advancements in road transport.

The effectiveness of conventional enforcement based on direct observation of offences is increasing rapidly due to the development and implementation of new technology. Offences which could previously only be detected by enforcement officers on-site can now be detected electronically, with breach processes also processed electronically. Improved information technology enables more rapid and efficient processing of detected breaches and the development of risk profiles of operators. These risk profiles enable the targeting of high-risk operators, either through operator licensing schemes or using other powers, if available.

10.2.2. Operator licensing / safety ratings

Operator licensing or safety ratings schemes are designed to improve safety and compliance outcomes by requiring operators to systematically manage operating practices in order to achieve these outcomes.

Such systems are in place in all countries of the European Union, many other European countries, Canada, United States, Japan and New Zealand. Under these systems, truck operators must register with regulatory agencies and meet various safety-related requirements in order to operate road freight services. These systems may be used to target enforcement resources, for example by assisting in the selection of vehicles for roadside enforcement or by identifying operators who are then subjected to audit.

Operator licensing requires extensive and up-to-date databases on all operators, their vehicles, their drivers and any breaches of road transport law. Many countries do not currently collate any of the necessary data at the national level and do not yet have adequate national data collation, storage and retrieval systems in place. Operator licensing schemes have the benefit of providing data to enable targeting of high risk operators, using that information to focus on the safety systems utilised by transport operators and accessing a range of flexible interventions and sanctions. Operator licensing schemes face the disadvantage that they can be cumbersome, data intensive and expensive to operate effectively.

A recent study (Ironfield, 2001, Summary) found that:

> *Certainly, licensing road freight operators imposes additional compliance costs on businesses and requires substantial public resources, both financial and human. The extent of the additional compliance costs will depend on the complexity of the licensing processes, the nature of the information to be collected and assessed and the compliance effort required. Importantly, in federal*

jurisdictions the costs and threats to the effectiveness of operator licensing systems seem to be amplified.

The quality of information systems used to monitor operator performance has been a major problem in operator licensing systems, particularly in federal systems where data has to be transferred between governments. However, improvements in data collection, analysis and reporting systems are enabling the more effective targeting of high-risk operators. In particular, the US Federal Motor Carrier Safety Administration has developed systems to identify and target high-risk operators (see Box 10.2).

Box 10.2. **Comprehensive Safety Analysis 2010 – USA**[1]

The United States Department of Transportation (DOT), Federal Motor Carrier Safety Administration (FMCSA) and its State partners utilise performance based systems to efficiently and effectively allocate enforcement staff efforts toward reducing fatalities, injuries, and hazardous materials incidents and crashes involving commercial trucks, buses and drivers operating in the United States.

The foundation for these performance based systems is roadside inspection, crash and compliance review data that is linked to individual motor carriers and maintained centrally by the FMCSA. Each year, the FMCSA and its State partners conduct approximately three million roadside inspections. The vast majority of these roadside inspections are conducted by State partners and are uploaded to the FMCSA's centralised information system. They are supported by a grant programme (80% Federal funds, 20% State) called the Motor Carrier Safety Assistance Program. Furthermore, the State partners upload approximately 140,000 crash reports each year involving commercial motor vehicle crashes that have resulted in a fatality, injury, or disabling damage to a vehicle requiring a tow from the scene. In addition to this on-the-road performance data, Federal and State safety personnel conduct approximately 16,000 compliance reviews at motor carrier places of business. Through these compliance reviews, additional regulatory violation data is linked to individual motor carriers and uploaded to the FMCSA's centralised information system and one of three possible safety fitness ratings are assigned: Satisfactory, Conditional, or Unsatisfactory. Motor carriers that receive a final unsatisfactory safety rating are declared "unfit" and are ordered to discontinue operations in interstate commerce.

The FMCSA uses the above performance and compliance data to effectively concentrate compliance and enforcement activities on "high-risk" motor carriers by utilising an automated system known as the Safety Status Measurement System, or SafeStat. SafeStat evaluates the relative safety status of individual motor carriers with respect to the rest of the motor carrier population in four analytic Safety Evaluation Areas (SEAs): Accident; Driver; Vehicle; and Safety Management.

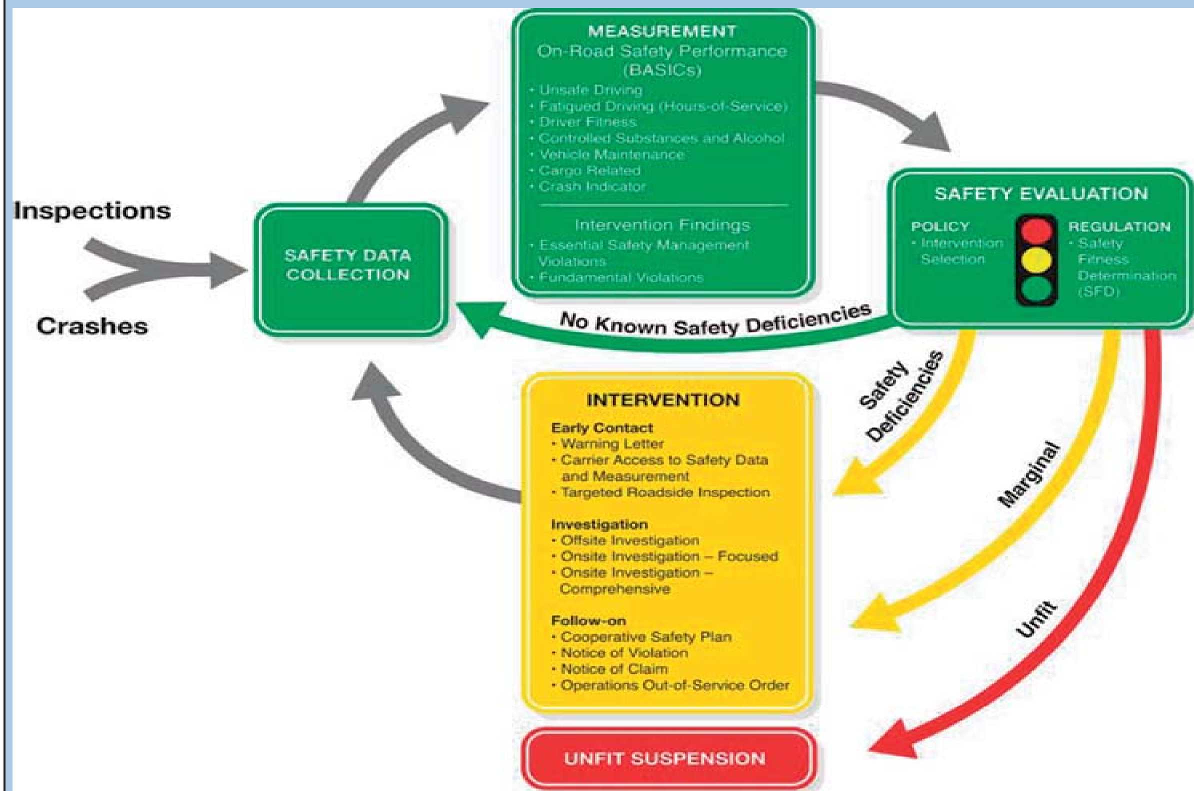
The four SEA values are then combined into an overall safety assessment, known as a SafeStat score. Motor carriers with the highest SafeStat scores (*e.g.* those with poor performance in 3 of the 4 SEAs) are deemed "high-risk" and are top priority for compliance reviews at the motor carrier's place of business. An effectiveness study demonstrates that motor carriers identified by SafeStat as "high-risk" have significantly higher future crash rates than motor carriers with good performance records. In fact, the U.S. Congress has mandated that "high-risk" motor carriers receive compliance reviews. SafeStat data is distributed to roadside systems so that motor carriers with identified deficiencies in the SEAs are also targeted for increased roadside inspections.

While these approaches have proven effective, the FMCSA is moving toward implementing a new operational model beginning in 2010. Comprehensive Safety Analysis 2010, or CSA 2010, is a major initiative to improve the effectiveness of the FMCSA's compliance and enforcement programmes. The CSA 2010 operational model is characterised by:

- A more comprehensive safety measurement system to replace SafeStat that will evaluate motor carrier and individual driver performance in seven Behaviour Analysis Safety Improvement Categories (BASICs): Unsafe Driving; Fatigued Driving, Driver Fitness; Vehicle Maintenance, Cargo Securement, Drug and Alcohol, and Crash.

- A more performance based safety fitness determination process that will provide for proposed adverse safety fitness determinations based solely on roadside performance to replace the current safety rating methodology that prevents rating changes without a full on-site compliance review at the motor carrier's place of business.

- The compliance review will be replaced by a broader array of intervention/investigative tools that will be applied commensurate with risk.



The CSA 2010 operational model will extend the reach of FMCSA compliance and enforcement programmes to more carriers and drivers, make motor carriers and drivers more accountable for sustained safe operations, and ultimately result in a greater reduction in fatalities, injuries, and hazardous materials incidents and crashes involving commercial trucks, buses and drivers.

10.2.3. Accreditation

'Accreditation' can be used to refer to a range of government or non-government compliance assurance or quality assurance arrangements. Its most basic meaning refers to the simple fact that a person or persons is to be trusted – or accredited – in some way or for some purpose. Accreditation is based on external validation through an audit process.

In road transport, accreditation has varied functions. They include matters as diverse as:

- A mandatory requirement before certain types of heavy commercial vehicles (restricted access vehicles) are permitted to access public roads.

- A compliance assurance requirement for:
  - Operators who seek access to certain regulatory concessions (for example, higher mass limits).
  - Managing compliance with performance-based duties.
  - Managing risks associated with transporting dangerous goods and chemicals.

  - Caring for livestock in accordance with animal welfare laws.

- Demonstrating that a freight customer or operator has met extended responsibility requirements of road transport law.
- Meeting occupational health and safety and environmental statutory duties.
- Industry-based safety schemes.
- Business quality and efficiency management.

Many industries and governments use accreditation, and the applications of accreditation can be both regulatory and non-regulatory. As such, the aims and outcomes of these uses of accreditation can differ. However, in all cases accreditation is used with the aim of improving outcomes by requiring a systematic approach to an issue (*e.g.* safety) in return for a regulatory privilege or in return for increased commercial attractiveness or credibility.

A key feature of heavy vehicle accreditation is external validation that agreed standards or agreed processes, rules and procedures are being adhered to. This usually involves elements of ensuring both that a process is followed (*e.g.* internal processes of fault reporting) and that outcomes/indicators are met (*e.g.* inspection of a sample of vehicles by auditors).

In a regulatory environment, accreditation imposed as a mandatory requirement can be characterised as a process regulation. That is, where required by regulation, accreditation may be said to achieve an outcome because the processes it imposes are designed to lead to a minimum level of performance.

Industry accreditation schemes occupy a different position within the spectrum of policy instruments; such schemes may be classified as voluntary self-regulation. The voluntary industry accreditation schemes are driven by market forces (*i.e.* being accredited is good for business) but they can also be influenced by the prevailing regulatory environment such as that embodied in the Chain of Responsibility (see 10.3.5).

Accreditation has been used both as a complement and a substitute for operator licensing.

In Australia, accreditation has become quasi mandatory for some operators because it is used to grant regulatory concessions (*e.g.* increased road access, higher mass, reduced incidence of vehicle inspections) to operators who can demonstrate high levels of compliance with specific regulatory requirements (see Box 10.3). Scheme effectiveness is demonstrated through external audit.

Non-regulatory accreditation or certified quality control schemes are also available in many countries.

A recent review of accreditation in Australia found that vehicles accredited under either NHVAS or the industry scheme (TruckSafe) are significantly safer than vehicles which are not accredited. Accredited vehicles were estimated to have between 50% and 75% fewer crashes than non-accredited vehicles (Baas and Taramoeroa, p.ii). In examining whether this was because better operators chose to accredit or the accreditation process improved safety, the study found that operators improve safety performance through the process of becoming accredited. This suggests that the process of systematically reviewing operating procedures leads to improved safety outcomes.

Box 10.3. **National Heavy Vehicle Accreditation Scheme (NHVAS) - Australia**[2]

The National Heavy Vehicle Accreditation Scheme was conceived as an ‘alternative compliance’ mechanism: a voluntary alternative to conventional enforcement. It allows heavy vehicle operators to demonstrate, through audit of their transport management systems and vehicle or driver assessments that their vehicles and drivers comply with regulatory standards. By doing this, operators gained access to some variation from compliance and enforcement practices.

Heavy vehicle operators who could demonstrate, by reports of an independent auditor, that they were meeting specific standards, were not intended to be subjected to the levels of on-road compliance monitoring that applied to non-NHVAS accredited operators.

The original objectives of the scheme were to:

- Improve efficiency for scheme members by reducing the impact of conventional regulatory enforcement.
- Raise levels of compliance for non-accredited operators through more effective deployment of enforcement resources.
- Reduce accelerated road infrastructure damaged caused by overloaded vehicles.
- Improve road safety.
- Increase the productivity of the transport industry through adoption of good management practices.

Since the introduction of NHVAS in 1999, the use of accreditation by jurisdictions has expanded beyond ‘alternative compliance’ and, in some States, accreditation has been specified as a requirement for access to various regulatory benefits or concessions.

The Australian National Heavy Vehicles Accreditation Scheme (NHVAS) has three modules, which can be chosen separately by transport operators:

- **Maintenance Management**, providing exemptions from annual inspections for operators who can demonstrate systematic and effective systems of vehicle maintenance.
- **Mass Management**, providing higher (concessional) mass limits for operators who can demonstrate accurate control over mass.
- **Fatigue Management**, providing additional flexibility in working hours for operators who can demonstrate higher levels of control over factors leading to driver fatigue.

Satisfactory audit reports demonstrate that the standards are being met. The accrediting jurisdiction can also check the compliance history of the operator and consider this when deciding whether to grant accreditation.

In South Africa, accreditation is voluntary and is seen as a means of improving both compliance with legislative requirements and other aspects of operator performance, leading to improved transport efficiency.

Box 10.4. **Road Transport Management System (RTMS) - South Africa**[3]

Heavy vehicle overloading and road safety continue to be major problems on South African roads despite efforts at more effective enforcement by the road and traffic authorities. Overloading causes premature road deterioration and, together with inadequate vehicle maintenance, driver fatigue and poor driver health, contributes significantly to South Africa's poor road safety record.

South Africa is currently developing an initiative to introduce meaningful self-regulation in the heavy vehicle transport industry through a Road Transport Management System (RTMS) with the aim of contributing to the road authorities' efforts to solve the above problems. During 2003 a heavy vehicle accreditation scheme was developed and implemented in the forestry industry in the provinces of KwaZulu-Natal and Mpumalanga. Based on an Australian accreditation model, the scheme seeks to promote compliance with standards in the areas of load control and securement, vehicle maintenance and driver wellness. In line with the Department of Transport's National Overload Control Strategy, its aim is to encourage heavy vehicle operators, consignees and consignors to take more responsibility for ensuring that their loads are transported legally.

Although the pilot project was initiated in forestry, the project has been executed keeping the broader heavy vehicle transport industry in mind. The success of the project in forestry resulted in similar initiatives commencing in other industries including pulp, paper and board, bitumen, coal, sugar and aggregate and sand. A national steering committee was established to co-ordinate the various initiatives and a strategy document developed. As part of this strategy, Standards South Africa was approached to develop national standards for transport operators, consignors and consignees using the documentation developed for the forestry industry as a starting point. This process has commenced with the creation of a standard for Road Transport Management Systems.

Although this is essentially a private sector initiative, since the commencement of the project in forestry, there has been strong support and involvement from government, including the national Department of Transport, the SA National Roads Agency, various provincial road authorities and the Department of Trade and Industry.

The RTMS includes standards on loading, driver wellness, productivity and vehicle operations and further standards are under development. The RTMS will offer additional support, including accreditation of auditors, provision of manuals, templates guidelines, information and promotion.

Pending legislation regarding the responsibilities of consignors and consignees with regards heavy vehicle road transport will no doubt have a significant impact on the nature of road transport contracts. It is anticipated that consignors and consignees will in future be required to assume a far greater responsibility for the manner in which their goods are transported on the public road network. The RTMS is a tool that can be used by consignors, consignees and transport operators as part of their quality management systems to begin to solve the current problems in road transport, thereby demonstrating their commitment to corporate governance.

10.2.4. Extension of legal liability: chain of responsibility

Prior to the development of technologies that monitor aspects of vehicle operation and allow transport operators to access this data, it could have been argued that the operator had little control of the on-road behaviour of the driver and therefore should not be held responsible for on-road breaches. From the time the driver left the depot to the time of return, the operator may have had little or no knowledge of vehicle speed or location or any aspect of driver behaviour.

However, a range of technologies now allow a truck operator to monitor and control many elements of driver behaviour. These technologies include:

- Engine management systems that provide detailed information on fuel consumption and vehicle speed.
- Electronic recording devices that provide information on driving time.
- Tracking devices that provide information on vehicle location.

Whilst these technologies are not always mandated, many are now provided as standard equipment on a new vehicle and their availability means that an operator has the ability to monitor and control driver behaviours. They can, therefore, be considered more responsible for relevant on-road breaches.

Similarly, a transport customer has the ability to seek evidence from a transport operator that systems are in place to achieve safe on-road outcomes. This could include evidence of safety ratings, evidence of accreditation or (more directly) inspection of schedules to ensure the ability to comply with hours of service requirements.

For many breaches of road transport law (*e.g.* speed, hours of service), the party immediately responsible is the driver. However, in most cases, the driver is not the only party to exercise a degree of control over on-road outcomes. In a fiercely competitive industry, each party in the transport chain is subject to pressure from those exercising higher control. For example, speeding offences and hours of service may be a response to schedules for which little or no flexibility is allowed.

Offences relating to operators, including requirements under operator licensing approaches, are a means of holding transport operators responsible for safety outcomes. Australia has recently adopted ‘chain of responsibility’ provisions which extend legal liability for compliance to all parties who exercise some degree of control over on-road outcomes.

The chain of responsibility principle is:

> *... all who have control, whether direct or indirect, over a transport operation bear responsibility for conduct which affects compliance and should be made accountable for failure to discharge that responsibility.*

According to the principle, the consigner who demands that trips be completed in unreasonable timeframes can potentially be held legally accountable for fatigue and speed-related violations, as can the operator of the poorly managed wholesale distribution centre, the person who understates the weight of an inter-modal freight container, the company director who allows short cuts to be taken with vehicle maintenance and the grain receival depot that knowingly rewards overloading by paying for weight delivered in excess of legal payloads.

To turn the principle into practice, it needs to be backed up by legislative duties and sanctions that provide effective deterrence, strategically enforced by appropriately trained officers, and well publicised so that all responsible parties in the chain understand their compliance duties.

The Australian legislation identifies relevant parties for each offence type (*e.g.* consignors, loaders, freight forwarders, customers) and holds them jointly responsible for a road transport offence. The chain of responsibility principle can be given effect either:

- By a requirement for responsible parties to put into effect processes to ensure high levels of compliance.

- Or through ‘reverse onus’, *i.e.* holding all parties in the chain responsible for any non-compliant behaviour and allowing, as a defence, the demonstration that ‘reasonable steps’ had been taken to prevent the breach. Reasonable steps are determined by a court, assisted by available codes, guidelines and best practices.

While the chain of responsibility principle has been applied in Australia in the absence of operator licensing, it could also be implemented in addition to operator licensing in order to extend responsibility and legal liability beyond transport operators.

In a recent civil litigation in the US, a freight broker was held to be negligent following a fatal crash involving two heavy vehicles (US District Court for the Western District of Virginia, Roanoke Division; documents 147 and 155, 2008). The court found that the broker had a duty to investigate the fitness of the transport operator prior to engaging it to carry a load on a public highway. It was argued that the publicly available FMCSA safety ratings could have been used to assess the fitness of the transport operator. This could be seen as a civil law equivalent of the chain of responsibility approach.

Operator licensing schemes, mandatory and non-mandatory accreditation and the 'reasonable steps' defence under chain of responsibility legislation are all means of encouraging or requiring transport operators to take a systematic approach to management systems in order to achieve high levels of road safety.

10.3. Enforcement and compliance technologies[4]

Technological developments will also enable more effective means of controlling and ensuring compliance with regulatory requirements. In some cases, technologies could be shared between transport operators and enforcement agencies, for example, positioning technologies could be used for vehicle tracking and scheduling by truck operators and for route compliance and pricing by enforcement agencies.

The use of such technologies will improve the safety of truck operations, provide assurance to the public that regulatory requirements are met and assist in enabling more flexible forms of regulation.

For technologies that must be adopted by freight operators (*e.g.* digital tachographs) governments must decide:

- Whether to mandate them or provide some other form of incentive (*e.g.* tax incentive, regulatory concession) for the operator to install them.

- The extent to which technologies, mechanisms and products should be specified; or whether broader performance standards can be set.

For technologies which are adopted by government agencies (for example, weigh in motion), the extent to which enforcement agencies directly invest in the ownership and operation of enforcement technologies or outsources operations to third parties must be determined.

An illustrative selection of potential compliance technologies are discussed in more detail below.

10.3.1. Weigh-in-motion (WIM)

Traditional methods of enforcing compliance with weight limits at roadside stations can be ineffective and/or inefficient for much of the road network, because of increasing traffic volume, increasing safety requirements, and a lack of staff. In many countries bribery and corruption at enforcement sites are common and, where the operational hours of the control site are limited by funding or human resource constraints, many operators will plan trips so as to minimise the risk of encountering law enforcement on their journey.

An additional disadvantage of traditional methods is that vehicles are usually selected for weighing either randomly or by simple visual screening. This usually results in many legal vehicles being delayed at the control area, causing unnecessary costs to compliant operators.

The use of WIM for law enforcement, as opposed to assessment of road infrastructure wear, raises issues regarding accuracy and reliability from a legal perspective and a number of projects have aimed at improving these as well as developing standards and specifications for WIM equipment (and its road approaches). The use of WIM for law enforcement has become widespread. Applications include:

- WIM monitoring on various “escape” routes in support of other strategies for overload control.
- WIM monitoring to identify the routes and hours of the most frequent offenders, thus enabling traditional enforcement efforts to be better targeted.
- The use of WIM as a screening tool to allow only vehicles that the WIM judges to be overweight to be directed to a traditional fixed enforcement site for the offence to be validated using a low tolerance device such as a weighbridge. Screening can be undertaken either at low speeds (LS-WIM at 5-15 km/h) on special enforcement lanes, or at high speed (HS-WIM at 30-100 km/h) in the traffic flow.
- On-road enforcement based solely on HS-WIM measurement with video imaging for legal identification. If the allowable tolerances, which are much higher than for LS-WIM or static weigh bridges to account for the reduced accuracy of HS-WIM, are exceeded, penalties are issued administratively via the postal system. On-going research aims to develop operational multiple sensor systems which may improve accuracy and allow the tolerances for on-road enforcement to be reduced. Bridge (B-)WIM systems may also provide an alternative solution in some cases.

10.3.2. On–board weighing

On-board weighing systems have been used in some industry sectors (*e.g.* logging) for some time. Although these will clearly help law-abiding operators to avoid unintentional overloading, they require high levels of accuracy if they are to be used as evidence in criminal court proceedings and would also need to be tamper-proof, or at least provide evidence of any tampering (tamper-evident). However, recent evidence (Transport Certification Australia, 2009) suggests that:

> *... commercial OBM systems [on-board mass monitoring systems] have sufficient accuracy for all types of regulatory applications, tampering can be addressed via the use of dynamic data and therefore it is possible to specify an evidentiary standard OBM system.*

Effective on-board weighing systems could potentially be used in any regulatory application that involves knowledge of vehicle and axle mass, for example, road pricing based on mass and distance or access limitations based on vehicle or axle mass.

10.3.3. Vehicle recognition

Vehicle recognition technologies include automated number plate recognition (ANPR) and radio frequency identification (RFID) and they enable accurate recognition of vehicles at high speed. This technology has been combined with speed cameras and data processing systems to automate speed compliance and is also used in road pricing applications. Challenges to application of automated speed enforcement for heavy vehicles include the ability to recognise a heavy vehicle where speed limits are differentiated by vehicle type and the need to recognise the number plate of the tractor for combination vehicles. Cameras which read from the rear are less effective for combination vehicles in countries where tractors and trailers are registered separately.

Use of vehicle identification technologies can also be used to make roadside enforcement more effective for the enforcement agencies and less of an imposition for transport operators. In parts of the USA it has long been common practice to voluntarily use RFID tags on heavy vehicles to help operators to identify vehicles. RFID tag readers are utilised together with WIM sensors at weighbridge/vehicle inspection sites for vehicle identification and database interrogation. Vehicles with legal weight and acceptable safety records are immediately allowed to bypass the vehicle inspection site, thus avoiding unnecessary delays.

10.3.4. Speed limiters[5]

In the European Union, vehicles with a gross mass in excess of 3.5 tonnes must be fitted with devices to limit the maximum speed to 90 km/h. Some other European countries (*e.g.* Russia) also require speed limiters. In Australia, vehicles with a gross mass of greater than 12 tonnes are required to be limited to 100 km/h. The introduction of speed limiters has recently been examined in Canada, at the request of the road freight industry, which was of the view that some operators were gaining competitive advantage by travelling at unsafe speeds. Following a comprehensive series of studies, no national requirement has been supported at this time, but two provinces (Ontario and Quebec) now require that all trucks of over 12 tonnes GVM travelling in those provinces be fitted with speed limiters set to 105 km/h. Speed limiters are not required in any other country. In countries where speed limiters are not a regulatory requirement, many operators install them voluntarily in order to reduce vehicle operating costs and improve safety.

With existing technology, speed limiters cannot be fully effective in controlling open-road speeds because they are dependent on drive train components (*e.g.* tyre size) and may be subject to tampering. However, modern speed limiters are tamper resistant and their use can be linked to auditable management systems to provide enforcement agencies with the ability to assess systematic compliance.

10.3.5. Trip/event recorders[6]

Currently, trip/event recorders are required only in the European Union, as part of the record-keeping requirements of the drivers' hours regulations. The current requirement for a digital tachograph replaces the earlier requirement for an analogue tachograph. Electronic recording devices are also permitted in the United States, Canada and Australia as an alternative to paper log books. The United States is currently developing a regulation which may mandate trip recorders in heavy vehicles. In Australia, following consideration of adoption of the European digital tachograph, it has been decided to instead develop performance standards to support electronic record keeping for the new hours of service legislation.

Electronic on-board recorders require effective driver identification and the ability of a driver to provide external data input, if non-driving work is to be included in the regulated hours of service.

The use of electronic records in preference to paper log books for the recording of hours of service has the potential to provide efficiencies for drivers and operators, provide more effective evidence of compliance, and provide management with better information for the management of driver fatigue.

Use of other forms of trip/event recorders could assist in the determination of crash causation.

10.3.6. Satellite based vehicle positioning/tracking

Satellite based vehicle positioning and tracking enables assessment of compliance with route restrictions and location-based road pricing.

Satellite-based vehicle tracking has been investigated in Europe to enable tracking and tracing of dangerous goods but has not yet been mandated (Rapp/Trans, 2008). In Australia, the Intelligent Access Program (IAP) uses third party service providers to provide satellite-based assurance to road agencies of compliance with operating conditions (see Box 10.1).

The basis of IAP is that operators will form contractual relationships with third party telematics service providers. These service providers may provide a range of services (*e.g.* scheduling) but must monitor route compliance and directly report apparent breaches to road agencies to allow action to be taken. The initial applications of IAP are for route compliance for vehicles which are subject to restrictions due to their mass and/or dimensions. But the system has the potential to be used for a wider range of applications, including speed, hours of service and road pricing.

10.3.7. Speed detection

In most countries, speed detection has largely been automated through the use of speed cameras. These devices measure speed at a point and feed into automated breach processing systems through the use of automated number plate recognition.

Increasingly, these systems are being supplemented by point-to-point systems which register vehicles at separated points on a highway and detect breaches of average speed. This makes it more difficult for a driver to evade speed enforcement by slowing down at the point at which the speed camera is known to be in operation. In New South Wales (Australia), widely dispersed Safe-T-Cam vehicle identification sites are used to assess compliance with both speed and hours of service requirements. These applications could be used in conjunction with toll points.

10.3.8. Data capture, storage, analysis and reporting

Technologies for data capture, storage, analysis and reporting are continuing to improve rapidly. These technologies will enable more effective compliance and enforcement through:

- Enabling the targeting of high-risk drivers and operators though collation of data from a wide range of sources.
- Automated enforcement of breaches, without the need for roadside intervention (*e.g.* speed cameras, weigh in motion).

In addition, transport companies now routinely accumulate large amounts of data on drivers, vehicles and many other aspects of their operations. Whilst the collection of this data is generally not a regulatory requirement, enforcement agencies, at least in some countries, could gain access to the data where breaches of compliance had been detected or suspected.

10.4. Sanctions and penalties

For every regulatory requirement, there is at least one offence for a breach. Both the offence and the degree of the penalty may vary with the degree of the breach. In some systems, offences may be aggregated and more severe sanctions applied. This applies both in operator licensing systems and in approaches which allow additional penalties for breaches which are regarded as persistent and systematic. In some cases, offences are aggregated through demerit points.

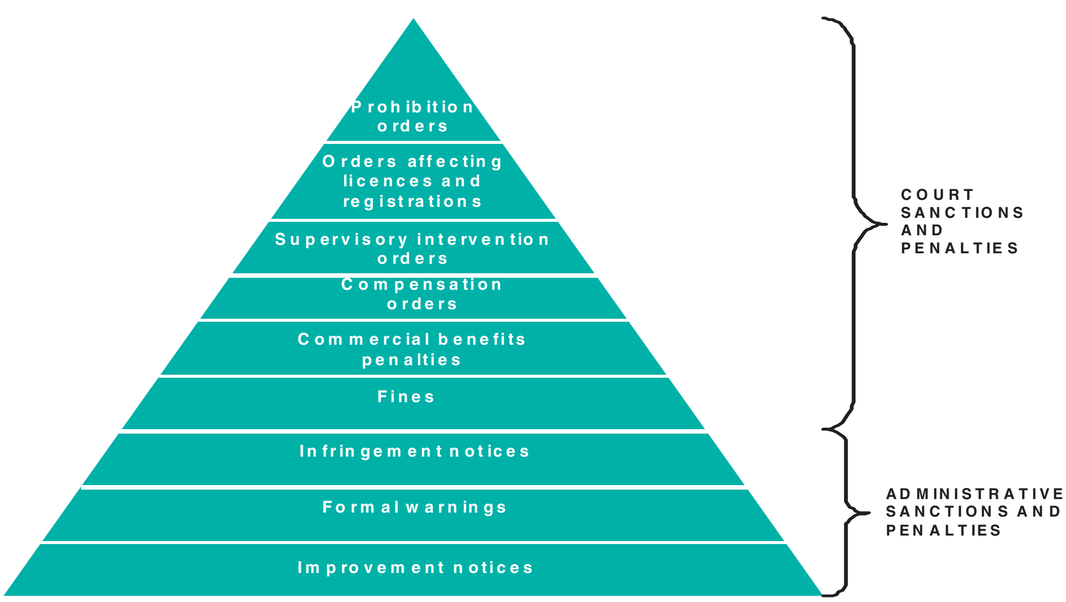
In countries without operator licensing, road transport penalties are generally restricted to fines and orders affecting licences and registrations. Operator licensing schemes can utilise a wider range of more flexible sanctions and penalties by imposing specific requirements on operators and including temporary or permanent removal of the right to operate.

Compliance and enforcement legislation can include sanctions and penalties that have been designed to target particular forms of offending. These include:

- Improvement orders (based on similar orders in occupational health and safety legislation) which aim to assist offenders improve their compliance performance.
- Formal warnings and infringement notices (both of which are administrative, rather than court-based) when leniency is appropriate for minor breaches.
- Commercial benefits orders, which are designed to target offenders who reap large profits from overloading and other road transport offences, and allow a court to impose a penalty of up to three times the amount that the offender gained, or stood to gain, from committing the violation.
- Supervisory intervention orders that require systematic or persistent offenders to do, at their own cost, such things as the court considers will improve their compliance performance.
- Prohibition orders which address those systematic and persistent offenders for whom no other sanctions are appropriate and allow a court to exclude such offenders from participating in the road transport industry.

These sanctions and penalties have been drawn from other areas of regulation (*e.g.* occupational health and safety) and extend the range of penalties available in the absence of operator licensing. An example of a hierarchy of sanctions and penalties is presented in Figure 10.1.

Figure 10.1. **Hierarchy of road freight sanctions and penalties - Australia**



Source: McIntyre and Moore (2002, p.10).

Higher level sanctions are generally imposed for serious offences or for persistent and systematic offences. These sanctions are most commonly applied through operator licensing schemes, but may also be applied in regulatory regimes that do not include operator licensing. An example of the application of a supervisory intervention order is provided in Box 10.5.

Box 10.5. **Supervisory intervention order – Australia**

Freight company fined $300k for overloading

Monday, 8 December 2008

FREIGHT and logistics company Grasten has been fined in excess of $300,000 for 47 offences involving overloaded or overwidth trucks, a move welcomed by the New South Wales Roads and Traffic Authority.

Grasten operates as Mannway Logistics and operates a number of distribution centres across Australia and a fleet of approximately 120 trucks and 211 trailers in NSW.

The offences occurred from March 2007 to October 2008 in NSW and on most occasions the trucks were carrying steel products.

"Overloaded trucks are a threat to road safety and the proper maintenance of the community's roads," said an RTA spokesperson.

"Chain of responsibility legislation for loading places the emphasis on the entire industry. 'All parties in the chain – including the consignor, packer, loader, receiver, driver and operator – must take positive steps to prevent breaches of road transport mass, dimension and road restraint laws.' As well as the fines, the magistrate issued a supervisory intervention order against Grasten, requiring it to change its management practices to ensure these offences do not reoccur and that all staff are trained and better supervised.

According to the RTA spokesperson, $112,000 of the fines was suspended. "The suspension of part of this fine is an important message from the court," the spokesperson said. "It signals the court is interested in seeing a good compliance outcome in the future. "The fact that $112,000 has been left on the table should encourage the defendant to pick up its future performance."

Source: Supply Chain Logistics Newsletter.

10.5. Measuring and monitoring

A range of mechanisms is available for measuring and monitoring compliance outcomes in the trucking industry. Examples include publication of the results of enforcement activity and collation and publication of data recorded by weigh-in-motion devices. Currently, these results are usually reported in a highly aggregated manner. However, data could be collated and results reported in a manner which would better inform the public of the compliance behaviour of the trucking industry, provide tactical information to enforcement agencies and provide the basis for policy development.

There is little data available on the performance of different sectors of the trucking industry. For example, safety data provides little differentiation between truck types. This makes it difficult to demonstrate the potential safety benefits of innovative or higher capacity trucks. The capture, analysis and reporting of more differentiated data would enable the compliance performance of different industry sectors and vehicle types to be monitored.

For example, weigh-in-motion devices measure axle mass, axle spacing and vehicle speed. Algorithms are used to translate axle spacings into vehicle classes. There is therefore the potential to closely monitor speed and mass compliance by vehicle type. This would enable monitoring of the compliance performance of higher capacity vehicles and could help to reduce public concern.

10.6. Achieving compliance in trucking

An OECD (2000) report contends that the explanations for the level of (non-) compliance fall into three categories:

- The degree to which the target group knows of and comprehends the rules.
- The degree to which the target group is willing to comply – either because of economic incentives, positive attitudes arising from a sense of good citizenship, acceptance of the policy goals, or pressure from enforcement activities.
- The degree to which the target group is able to comply with the rules.

Government actions to promote regulatory compliance must take each of these into consideration.

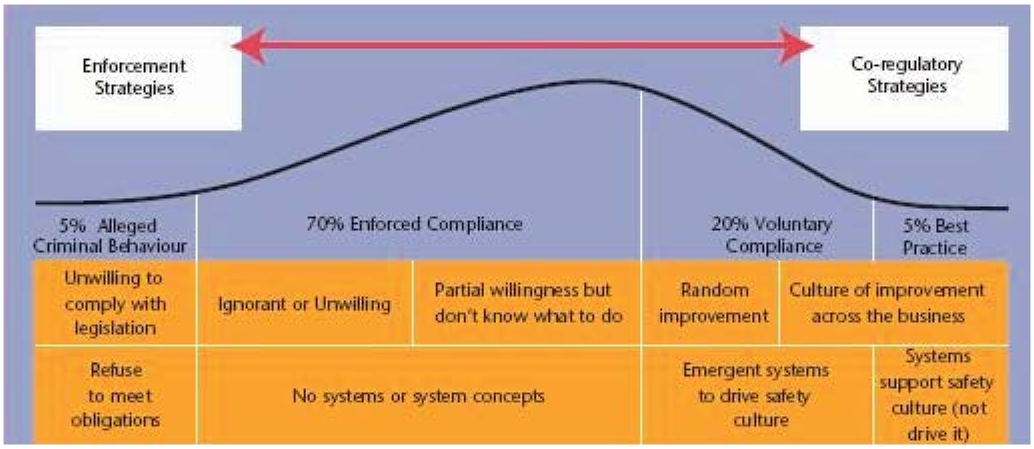
Trucking is a competitive industry, including a high proportion of small operators, so there are strong incentives to achieve competitive advantage by breaching regulatory requirements. Whilst part of the industry will choose to seek very high levels of compliance, for many operators compliance levels will depend on compliance and enforcement strategies.

Achievement of improved safety, productivity, asset and environment protection and competitive equity outcomes requires a comprehensive approach to compliance. Use of a range of complementary compliance-enhancing tools, including but not limited to enforcement, is required. This approach comprises ‘conventional’ (or sanctions-based) legislation complemented by a range of other strategies, including:

- Privileges and incentives-based strategies (including operator licensing and accreditation-based compliance), which encourage industry to take responsibility for its own performance.
- Training of enforcement officers and industry.
- Industry education and communication.
- Consistent, effective and well-targeted enforcement.
- monitoring compliance levels and the effectiveness of compliance/enforcement outcomes;
- Ongoing research to identify new challenges and compliance measures.

In using these compliance tools, it is important to understand the profile and motives of those regulated to help target the way these tools are most effectively used. Figure 10.2 shows a model of compliance behaviours. At the bottom of the compliance curve, a minority of parties do not meet the law and regulatory responses include targeting these parties and ‘hard’ penalties such as prosecution. Moving up the compliance curve, the majority of parties comply with the law but they may be ignorant or unwilling. These parties respond to enforcement. Alternatively, these parties may be partially willing but don’t know what to do. Members of this group tend to respond well to advice and information to improve their compliance. At the higher end of the compliance curve, ‘voluntary compliance’ parties willingly comply with the law. These parties have systems to improve safety and business practices and actively seek out new ways to improve their performance. At the top end of the compliance curve are those who have a 'best practice' approach to compliance, and who instil a strong culture of improvement across their businesses. Across the compliance curve, the different parties respond to different compliance strategies. Traditional enforcement practices work best at the unwilling end of the spectrum, whereas parties at the higher end of the curve actively pursue incentive-based strategies.

Figure 10.2. **Industry compliance spectrum**

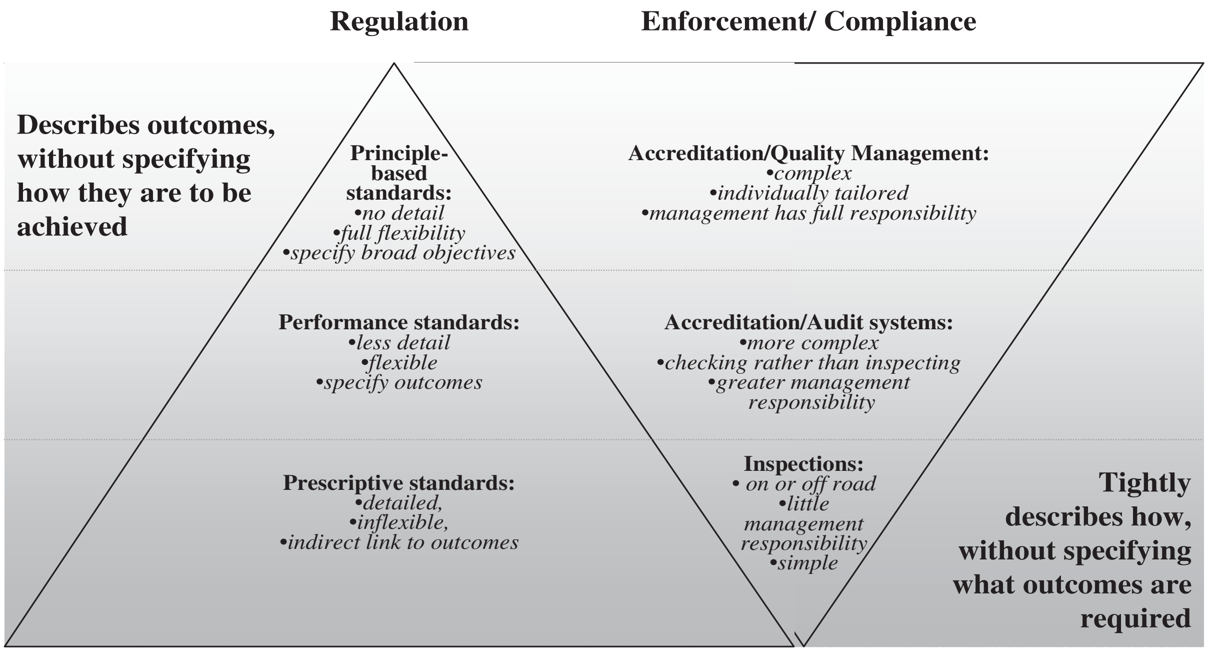


Source: Office of the Occupational Health and Safety Commissioner, Australian Capital Territory (2002).

A combination of effective targeting of systematic illegal behaviours and the provision of incentives for operators who achieve high levels of compliance will have the effect of shifting competitive advantage away from those at the lower end of the compliance spectrum and towards those at the top. Competitive advantage will shift against those who most frequently breach regulatory requirements.

Compliance and enforcement tools should relate to the type of regulation, as illustrated by Figure 10.3. In general, conventional enforcement is most suited to prescriptive standards, while accreditation and audit approaches will be more suited to achieving compliance with performance standards, for which on-road observation is more difficult.

Figure 10.3. **Matching regulation and enforcement7**



Source: OECD (2005, p.24).

Box 10.6. **Sector-wide compliance and enforcement strategy, New South Wales - Australia**[8]

In 2005 and 2007, the Roads and Traffic Authority of NSW (RTA) targeted overloading in the grain sector. The investigation brought together a number of the elements of an effective compliance and enforcement regime, including: safety management and chain of responsibility requirements (off-road parties were investigated for negligently sending and receiving overloaded vehicles carrying grain), risk-based targeted enforcement actions, and sector-wide strategies. Rather than relying solely on the past practice of intercepting and weighing trucks, the RTA used new compliance and enforcement powers to target the small number of large companies which control grain receivals. The investigation was based on an audit of company records.

As shown in Table 10.1 below, between 2005 and 2007, the level of full compliance increased by 15%, and the levels of substantial and severe non-compliance were very significantly reduced.

Table 10.1 **NSW Grain Harvest: Impact of Sector-Wide Investigations**

	Legal	Minor Overload (up to 5%)	Substantial Overload (between 5% and 20%)	Severe Overload (more than 20%)
2005 Grain Harvest	67.6%	12.0%	17.4%	3.0%
2007 Grain Harvest	82.5%	17.1%	0.3%	0.1%

10.7. Conclusion: new approaches - compliance as an enabler

Traditionally, much of the regulation of the trucking industry has been by relatively simple prescriptive standards. Efforts to ensure compliance have been heavily based on rudimentary enforcement where designated officers observe an offence and take action. Although the observation of offences has been substantially improved by technology such as speed cameras and automated penalties, enforcement tools remain relatively blunt and are not well suited to ensuring compliance with more flexible, performance-based standards because breaches are often not easy to observe. This lack of options for ensuring compliance with flexible standards is one of the factors limiting the differentiation of vehicle and road use conditions such that infrastructure asset consumption and vehicle productivity remain at less than optimum levels.

Other chapters of this report have shown that more flexible regulation can have substantial benefits in terms of vehicle productivity, infrastructure asset consumption and safety. Inspiring confidence in the wider community that the industry will comply with more flexible regulations will be one important step enabling them to be implemented.

Conventional enforcement has been best suited to on-road enforcement of prescriptive standards (especially speed, weights and dimensions) in a limited number of vehicle types and is less well suited to more flexible, performance-based, standards and a wider range of vehicle types with differential network access. The traditional approach can only be successful if breaches can easily be observed, and then only if enforcement resources are sufficient.

The availability of limited enforcement options has been one reason that there had been little or no differentiation of road use conditions, leading to an imperfect match of vehicles to infrastructure. The consequence is a combination of non-optimal rates of asset consumption and sub-optimal levels of vehicle productivity.

In many areas, regulatory standards for road freight transport are rigid because available enforcement tools are blunt. However, variations in standards can be offered to the road transport industry, as long as confidence can be provided that the associated operating conditions are met. These operating conditions could be specific to vehicle, time and location. For example, the operation of trucks in sensitive urban areas at night may be acceptable to the community if it could be demonstrated through an auditable process that noise conditions and route restrictions were complied with.

Closer linkage of vehicle characteristics, road use and asset characteristics through improved methods of monitoring compliance with conditions of road use can lead to improvements in road transport efficiency, road safety and asset utilisation.

There is a growing range of technologies and practices which give drivers greater control of their vehicles and give operators greater control over their vehicle operations. This provides the ability to aim for high levels of compliance with regulatory requirements and to demonstrate that this aim has been achieved. The development of technology and management systems will also provide the confidence in compliance that will enable variations in standards and the achievement of productivity gains.

Many countries are developing new approaches to compliance, aided by new and emerging technologies and attitudes. For example, these approaches include:

- Extending responsibility for on-road outcomes to all parties with control over those outcomes, direct or indirect (*e.g.* operator, shipper, and receiver).

- Application of more effective compliance monitoring technologies, including weigh-in-motion, speed detection and on board recording devices. Wherever possible these are used to assess compliance at traffic speed, thus reducing the imposition on compliant operators.

- Assessing compliance through the audit of data collected by systems, such as those above, maintained either by operators or by third party service providers.

- Providing compliance mechanisms which can monitor conditions for differentiated network access, for example, the Australian Intelligent Access Programme (IAP).

- Measuring and monitoring in order to provide information to the community and the industry on compliance levels and to enforcement agencies and policy makers on tactics and policy needs.

The application of improved compliance mechanisms has the potential to change the relationship between the trucking industry, regulatory authorities and the community from adjudication between competing claims to a search for joint gains for the industry and the community.

Route compliance, vehicle mass and other vehicle and operator characteristics can be monitored. The challenge is to develop the administrative and institutional arrangements to cost-effectively maintain confidence in compliance.

If the community can gain greater confidence that heavy vehicles are complying with operating conditions, it is more likely that it will tolerate a range of variations in standards that have traditionally been imposed as absolutes. This has the potential to change the nature of standards from “one size fits all” to a flexible approach based on the demands and opportunities of time and place, supported by systems to ensure that compliance with regulatory requirements is achieved. Rather than preventing variation, modern approaches to compliance can enable variations in standards and result in safety and productivity gains.

To date, methods of compliance have had the effect of preventing variations in standards which might otherwise have allowed improvements in road safety and industry productivity. There is now the potential to move from compliance as a ‘preventer’ to compliance as an ‘enabler’ of the aims of road safety, transport productivity and environmental sustainability.

There is currently the potential to move from an era of compliance provisions used to support pre-determined standards, to one where compliance mechanisms and standards will be jointly determined. Effective methods of compliance assurance will enable more flexibility in standards so that road transport applications can be tailored to circumstances and environments. The benefits will be found in improvements in safety, productivity and environmental outcomes.

The development of these new forms of compliance will be difficult. It will require the application of technology, the development of management systems and revisions to institutional arrangements. Many issues must be resolved. Implementation of new approaches will require shifts in the mindsets of regulators and industry, and change in enforcement practices.

NOTES

1. Source: US Federal Motor Carrier Safety Administration.
2. Source: National Transport Commission, Australia.
3. Source: Nordengen and Pienaar.
4. This section draws on Honefanger *et al*. (2007), McBride and Chadwick (forthcoming), Rapp/Trans (2008) and Transport Certification Australia (2009).
5. See Annex A for a more detailed discussion of speed limiters.
6. Trip/event recorders are discussed further in Annex A.
7. Source: OECD, 2005.
8. Source: Roads and Traffic Authority of New South Wales.

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Moving Freight with Better Trucks: Improving Safety, Productivity and Sustainability

ANNEX A. VEHICLE TECHNICAL STANDARDS: UNECE AGREEMENTS

The process for the international harmonisation of vehicle technical standards, including standards for heavy vehicles, is through the World Forum for Harmonization of Vehicle Regulations, known as WP.29.

WP.29 commenced in 1952 as the United Nations Economic Commission for Europe (UNECE) Working Party No. 29, with an initial membership of European governments and international roads organisations. Following the 1998 Global Agreement, which was proposed by the United States and negotiated under the leadership of Japan, the European Community and the United States, WP.29 has become the World Forum for the Harmonization of Vehicle Regulations. As a global body within the UNECE, WP.29 is unique in that it is not only concerned with European issues. The standards that it develops are international, not European.

In addition to the United States and Canada, which participated in WP.29 since its inception, Japan and Australia have attended the meetings regularly for more than 20 years. More recent participants include the European Community, the Republic of South Africa, the Republic of Korea, the People's Republic of China, India, Thailand, New Zealand and Malaysia.

WP.29 is assisted in its operation by Subsidiary Working Parties in Pollution and Energy (GRPE), General Safety Provisions (GRSG), Brakes and Running Gear (GRRF), Lighting and Light-Signalling (GRE), Passive Safety (GRSP) and Noise (GRB).

The role of WP.29 is to develop new regulations, harmonise existing regulations and amend and update current UNECE Regulations. The key agreements administered by WP.29 are the 1958 Agreement and the 1998 Global Agreement. Separate processes for developing harmonised regulations are applied under the two agreements.

1958 Agreement

Under the 1958 Agreement, each UNECE regulation is adopted by a simple majority of contracting parties present and voting at the WP 29 meeting at which the proposal is put up. The adopted regulation is then notified to all contracting parties who have a period of 6 months to decide if they wish to be bound by (*i.e.* apply) the regulation. Under the 1958 Agreement contracting parties that agree to apply a regulation must ensure that it is not in conflict with its domestic legislation, so that products complying with the applied regulation gain free access to their markets. Contracting parties applying a regulation also acquire the right to issue approvals against the applied regulation and such approvals must be accepted by all contracting parties applying the regulation. The 1998 Agreement was created because it was unclear how the obligation to recognise a type approval product would work under the self certification regimes applied in some countries.

The 1958 Agreement has 44 Contracting Parties: 33 European countries, the European Community, Japan, Australia, South Africa, Turkey, Malaysia, Thailand, Republic of Korea, Tunisia and New Zealand. Decision making is based on a two-thirds vote. At August 2009, the 1958 Agreement had 126 UNECE Regulations attached to it. These regulations include coverage of heavy trucks and trailers and have been adopted to varying degrees by the Contracting Parties.

1998 Agreement

The 1998 Global Agreement establishes a process through which countries from all regions of the world can jointly develop global technical regulations regarding the safety, emissions, energy sources and theft prevention of wheeled vehicles, equipment and parts. Global technical regulations may be established either through harmonisation of existing regulations or standards or through the establishment of a new global technical regulation where there are no existing regulations or standards. Establishment of a new global technical regulation requires a consensus vote.

A key issue which differentiates the position of the United States, and to a lesser extent Canada, from other parties is type approval. The United States and Canada operate self certification systems for safety standards (but not for emissions) whereas Europe, Japan, Australia and most of Asia (except Korea) operate type approval systems.

The 1998 Global Agreement does not require mutual recognition of approvals, thereby enabling the participation of countries with self certification approaches and countries that are ready to adopt mutual recognition obligations.

As with the 1958 Agreement, Contracting Parties are not required to implement agreed global technical regulations. However, a party which voted in favour of a regulation must initiate procedures for local adoption. The Agreement allows for global technical regulations to contain a 'global' level of stringency for most parties and 'alternative' levels of stringency for developing countries.

The 1998 Global Agreement has 31 contracting parties and affects 42 countries around the world: 17 European contracting parties plus 12 countries belonging to the European Community, Canada, United States, Japan, People's Republic of China, Republic of Korea, South Africa, Turkey, New Zealand, Azerbaijan, India, Malaysia, Tunisia and Australia.

The 1998 Agreement offers the USA, Canada and other non-type-approval countries or countries not in a position to adopt mutual recognition process, the opportunity to participate in developing international standards. As these countries cannot simply pick up the UNECE regulations, the process of developing global regulations under the 1998 Agreement offers the opportunity to develop new and harmonised regulations that take into consideration best available data and cost/benefit considerations. The objective is to see convergence over time, using the 1998 Agreement to develop standards while the 1958 Agreement covers mutual recognition issues.

Outlook

Most countries in the Asia-Pacific Economic Cooperation Region (APEC) are moving in the direction of signing both the 1958 and 1998 Agreements adopting regulations developed under either one. APEC could be important in this process as it links North, Central and South America (Canada, United States, Mexico, Chile, Peru) with Asia (including China, Japan and Indonesia) and Russia.[1] Within APEC, assistance is provided to less developed countries to build capacity to participate in the WP.29 process.

Technical standards for heavy road vehicles in the EU are based on UNECE standards. The EU also participates in the development of global technical regulations and their establishment under the 1998 Agreement. The large body of international agreements in the field of transport done under the auspices of this organization serves in similar ways as the foundation for the acts regulating transport in Europe and it is expected that the UNECE Transport's structure of Working Parties will increasingly become the forum where all preparatory work on transport regulations for the EU will be done. EU countries become contracting parties to the 1958 Agreement and the 1998 Agreement on accession to the EU. The EU votes as a block for its members.

In Australia, most Australian Design Rules for both light and heavy vehicles are closely based on UNECE regulations and ADRs are currently under review to achieve greater alignment with UNECE regulations.

Technical standards in the United States and Canada are generally aligned, with some exceptions and minor differences due in part to the Canadian use of metric units (vs. Imperial in the United States) and a Canadian requirement for bilingual labelling. Canada's priority is to harmonise with the United States FMVSS, unless it is considered that safety is compromised.

South American countries are not active in the WP.29 process. Whilst some South American countries are expressing interest, they do not yet participate in meetings.

Japan has its own system of standards: the Japan Safety Standards. Japan is also a signatory to both the 1958 Agreement and the 1998 Agreement and makes reference to regulations developed under both agreements. Most south East Asian economies have plans to develop regulatory systems based around the 1958 Agreement.

Through the WP.29 process, it is likely that heavy vehicle technical safety standards will increasingly become more harmonised under either the 1958 Agreement or the 1998 Agreement or both.

NOTE

1. APEC countries are: Australia, Brunei, Canada, Chile, Chinese Taipei, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, Peru, Peoples Republic of China, Philippines, Russia, Singapore, Thailand, United States of America, Vietnam and Peoples Republic of China.

ANNEX B. TRUCK SAFETY DATA (COMPLEMENT TO CHAPTER 6)

This annex presents detailed data on truck crashes. It completes the information included in Chapter 3.1.

B.2. Recent trends in the number of trucks crashes

Table B.1.illustrates the evolution in the number of fatal crashes in which a truck was involved between 2001 and 2007. For most countries, one can observe a decrease in the number of crashes:

Table B.1. **Trends in the number of fatal crashes in which a truck was involved 2001-2007**

	2001	2002	2003	2004	2005	2006	2007
Australia	-	289	217	229	209	215	223
Austria	109	117	128	137	115	110	86
Belgium	180	157	130	138	145	126	138
Canada	441	457	475	453	457	-	-
Denmark	67	69	54	60	73	42	62
Finland*	103	89	93	82	83	79	82
France	887	823	639	628	651	608	598
Germany	1 340	1 255	1 266	1 159	1 081	1 088	1 001
Great Britain	528	480	480	418	440	386	393
Greece*	190	182	177	152	143	145	118
Hungary*	-	-	103	225	205	212	187
Israel	-	-	71	78	57	59	-
Italy*	368	316	308	303	281	301	273
Netherlands	151	117	142	127	97	122	117
New Zealand	75	75	72	87	79	79	68
Portugal*	150	168	161	143	123	103	108
South Africa	-	-	1 005	1 031	996	1 059	1 097
Spain*	636	656	656	624	566	569	443
Sweden	102	96	84	73	62	78	85
Switzerland	59	46	44	50	44	31	33
United States	4 451	4 224	4 335	4 478	4 551	4 350	4 190

Source: Data provided by Working Group members from national datasets except * from CARE database.

Table B.2 shows comparable figures for crashes involving an articulated heavy vehicle. Again no consistent trend is apparent in the number of fatal crashes in which an articulated truck is involved. In Australia, over the period covered, the amount of freight (tonne-kilometres) carried by B-doubles increased by 43%, while the amount carried by single semi-trailers fell slightly.

Table B.2. **Trends in the number of fatal crashes in which an articulated truck was involved 2001-2007**

Year	2001	2002	2003	2004	2005	2006	2007
Australia	146	171	142	137	132	145	144
Canada	300	311	314	312	294	–	–
Great Britain	213	199	206	186	204	180	182
Israel	–	–	11	21	12	15	–
Switzerland	13	7	11	17	8	11	9
United States	3 298	3 207	3 239	3 332	3 387	3 206	3 113

Source: Data provided by Working Group members from national datasets.

B.2. Comparisons of fatality rates

Fatalities per fatal crash vary much between countries (from South Africa at 1.42 and France at 1.20 to Netherlands at 1.07 and Belgium at 1.09). It is difficult to generalise about possible contributing factors to these differences. Higher proportions of multiple vehicle crashes, large numbers of rural/remote area crashes (and hence reduced access to medical/first aid treatment) or a higher proportion of crashes on higher speed roads are all possible contributors to differences in fatalities per crash. The varying nature of the truck fleet which fits within the definition of 'heavy vehicle' in each country is also likely to be a significant factor. For those countries which provided separate information on larger articulated trucks, four out of five had a lower articulated truck crash rate than that for all truck types.

Table B.3 shows some characteristics of persons killed in crashes which involve heavy vehicles.

Table B.3. **Fatal crashes of all trucks – overall**

	Period	Fatalities	Fatal crashes	Fatalities/fatal crash	Fatal crashes per 10 000 registered trucks in 2005	Fatal crashes per 10^8 km in 2005
Australia	2002-2007	1 584	1 382	1.15	4.8	1.5
Austria	2002-2007	763	693	1.1	3.39	–
Belgium	2002-2007	905	834	1.09	9.5	1.67
Canada	2001-2005	2 688	2 283	1.18	10.63	1.64
Czech Republic	2006	215	190	1.13	–	–
Denmark	2002-2007	408	360	1.13	16.69	3.42
France	2002-2007	4 749	3 947	1.2	11.48	1.86
Germany	2002-2006	6 426	5 849	1.1	12.64	–
Great Britain	2005-2007	1 340	1 219	1.1	10.2	1.52
Israel	2003-2006	314	265	1.18	–	–
Netherlands	2002-2006	650	605	1.07	6.79	–
New Zealand	2002-2007	525	460	1.15	–	–
Poland	2004-2007	1 361	–	–	–	–
South Africa	2003-2007	7 363	5 188	1.42	38.36	9.12
Sweden	2002-2007	548	478	1.15	8.1	1.47
Switzerland	2002-2007	271	248	1.09	1.43	0.81
United States	2003-2007	25 346	21 904	1.16	5.37	1.27

Source: Data provided by Working Group members from national datasets.

Table B.4. **Summary table for all trucks – characteristics of persons killed**

	Period	Fatalities	Fatalities per 10^8 km (2005)	Fatalities per 10 000 registered trucks (2005)	Persons killed in truck crashes*	Truck occupants	All other vehicle occupants (incl. motorcyclists)	Non-occupants	Car occupants	Motorcyclists	Pedestrians	Bicyclists	Other vehicle occupants
Australia	2002-07	1 584	1.73	5.56	16%	29%							
Austria	2001-07	884		3.72	15%	11%	57%	25%	53%	4%	14%	8%	
Belgium	2002-07	905	1.85	34	13%	11%	54%	27%	49%	6%	9%	18%	
Canada	2001-05	2 688	1.96	8.8	20%	15%	73%	11.3%	68%	6%	8%	2%	1%
Czech Republic	2005-07	675	-		19%	10%	62%	20%	56%	7%	14%	7%	
Denmark	2001-07	486	3.04	18.06	18%	4%	52%	34%	49%	3%	8%	26%	7%
France	2001-07	5 407	1.96	12.13	13%	13%	67%	17%	59%	8%	9%	7%	4%
Great Britain	2001-07	3 424	1.68	11.2	15%	10%	65%	25%	48%	11%	19%	6%	6%
Germany	2002-06	6 332	-	13.62	21%	18%	63%	19%	53%	10%	10%	9%	
Israel	2003-06	314	-	-	16%	12%	57%	27%	53%	5%	24%	3%	4%
Japan	2002-06	8 261	-	-	20%	12%	55%	31%	41%	14%	19%	12%	2%
Netherlands	2001-07	948	-	7.07	16%	7%	50%	36%	45%	5%	7%	29%	
New Zealand	2002-06	451	-		25%	18%	70%	11%	63%	7%	8%	3%	1%
Poland	2004-07	1 361	-		9%	15%	47%	35%	47%	1%	23%	11%	
South Africa	2003-07	7 363	12.46	52.42	11.4% (2004)	25%	54%	21%			21%		
Sweden	2001-07	640	1.61	8.9	18%	8%	69%	16%	66%	3%	10%	6%	
Switzerland	2002-07	271	1.5	0.85	11%	5%	57%	33%	42%	12%	22%	12%	7%

* (% of all persons killed).

Source: Data provided by Working Group members from national datasets.

Table B.5. **Summary table for articulated trucks – characteristics of persons killed**

	Period	Fatalities	Fatalities per 10^8 km (2005)	Fatalities per 10 000 registered trucks (2005)	Persons killed in articulated truck crashes*	Truck occupants	All other vehicle occupants	Car occupants	Motorcyclists	Pedestrians	Bicyclists	Other vehicle occupants
Australia	2002-2007	1022	2.46	24.43	11%				5%	7%	2%	0%
Austria	2001-2007	321			5%	17%	64%	54%	2%	12%	8%	8%
Belgium	2001-2006	537			7%	17%	59%	49%	5%	6%	15%	6%
Canada	2001-2005	1841	1.97	8.42	12%	15%	72%		3%	8%	1%	1%
Denmark	2001-2007	159	2.7	18.43	6%	7%	68%	57%	3%	5%	20%	8%
France	2001-2007	2654			6%	16%	71%	61%	6%	7%	5%	4%
Great Britain	2001-2007	1529	1.64	19.5	7%	15%	67%	51%	8%	15%	3%	8%
Greece	2001-2007	183			2%	15%	73%	54%	12%	9%	2%	7%
Hungary	2004-2007	179			4%	11%	64%	52%	6%	10%	10%	5%
Israel	2003-2006	66			4%	20%	62%	62%	5%	12%	2%	0%
Italy	2001-2007	2305	1.46	17.95	5%	18%	60%	52%	5%	5%	7%	4%
Netherlands	2001-2007	350		6.62	6%	9%	65%	55%	5%	5%	20%	5%
Portugal	2004-2007	57			1%	26%	58%	42%	2%	5%	11%	14%
Spain	2001-2007	1962			6%	25%	65%	52%	3%	6%	3%	11%
Sweden	2002-2007	548	1.61	8.9		8%				9%		
Switzerland	2002-2006	76				4%		57%	11%	13%	3%	5%
United States	2003-2007	19077	1.7	18.84	9%	15%	77%	72.8%	3.3%	6.0%	1%	1.4%

* (% of all persons killed in road crashes).

Source: Data provided by Working Group members from national datasets.

Table B.6. **Characteristics of fatal crashes involving a truck**

	Australia	Canada	Denmark	France	Germany	Great Britain	Israel	Japan	Netherlands	New Zealand	South Africa	Sweden	Switzerland	United States
Period	2002-06	2001-05	2002-02	2002-06	2002-06	2005-07	2003-06	2002-06	2002-06	2002-06	2003-07	2002-07	2002-07	2002-06
Fatal crashes	1159	2283	298	3349	5849	1219	265	8505+	605	392	5188	478	248	25477
Fatal crashes per 10^8 km travelled (2005)	1.5	1.64	3.42	1.86		1.52					9.12	1.47	0.81	1.28
Articulated truck crashes (%)	63%	67%	32%	49%		46%	22%	8%	37%	n/a	-	-	25%	67%
All Single Vehicle crashes (incl. pedestrians) (%)	28%	19%	10%	18%		19%	33%	23%		12%	44%		27%	19%
Truck-only crashes (%)	17%	11%	2.70%	8%		4%	8%	5%		4%	17%		8%	12%
Truck-pedestrian crashes (%)	11%	8%	8%	9.70%		15%	25%	18%		8%	27%		19%	7%
Urban (%)	41%	22%	32%	26%		25%	31%	44%	32%	21%	28%		39%	36%
Rural (%)	59%	78%	68%	74%		75%	69%	56%	68%	79%	72%		61%	61%
Speed zone (%)														
up to 50 km/h	6%	13%	27%			21%	35%		32%	15%			35%	19%
60 km/h	8%	5%	6%			8%	7%		2.00%	1%			12%	
70-75 km/h	3%	6%	10%				5%		4.00%	5%			1%	14%
80 km/h	12%	22%	46%			4%	32%		37%	3%			39%	27%
90 km/h	2%	28%	3%				19%		1%	0.30%			0	
100 km/h	51%	25%	8%			38%	3%		10%	76%			5%	24%
>100 km/h	18%	1%	2%			29%			13%				8%	12%
At night (%)	29%		23%	24%		29%	26%	43%	14%	31%	48%		17%	33%
18:00-23:59	16%		14%	9%		15%	11%	15%	8%	16%	32%		11%	16%
00:00-05:59	12%		9%	15%		14%	14%	28%	6%	11%	17%		6%	17%
Intersection (%)	23%	30%	43%	16%		33%	26%	34.5	41%	25%			26%	34%
Divided road (%)		15%	29%	17% (13% motorway)		36%							(13% motorway)	44%
Occupant fatalities	29%	19%	4%	13%		11%	11%	12.10%		18%	25%			16%*

Note: Where some data is unknown, the percentages are calculated as "percent of known"; *2006 data only +vehicles involved ++ vehicles with unladen mass of 12 tonne or more, not necessarily articulated.

Source: Data provided by Working Group members from national datasets.

Table B.7. **Characteristics of fatal crashes involving an articulated truck**

	Australia	Switzerland	Israel	Canada	Czech Republic	Great Britain [1]
Period	2002-2006	2002-2006	2003-2006	2001-2005	2006	2005-2007
Fatal crashes	727	48	59	1531	94	564
All SV crashes (incl. peds) (%)	27.2%	21.0%	25.4%	17.5%		16.8%
Truck-only crashes (%)	17.1%	2.1%	16.9%	8.6%	27.7%	4.8%
Truck-pedestrian crashes (%)	10.2%	18.8%	8.5%	8.9%	12.8%	%
Urban (%)	24.5%	56.0%	18.6%	18.8%	33.0%	%
Rural (%)	75.5%	44.0%	81.4%	81.2%	67.0%	%
Speed zone (%)						
up to 50 km/h	2.9%	33.4%	15.3%	10.1%		13.8%
60 km/h	11.0%	10.4%	6.8%	4.9%		5.0%
70-75 km/h	4.0%		1.7%	5.6%		
80 km/h	12.9%	41.7%	45.8%	19.0%		3.4%
90 km/h	5.9%		20.3%	29.5%		
100 km/h	44.6%		5.1%	29.0%		36.2%
>100 km/h	18.7%	14.6%		1.7%		41.7%
Time of day						
18:00-23:59	19.1%		13.6%	21.5%		20.4%
00:00-05:59	22.0%		13.6%	15.3%		20.2%
06:00-17:59	58.9%		72.8%	63.2%		59.4%
Intersection (%)	22.4%	14.6%	15.3%	27.0%	24.5%	25.7%
Divided road (%)		22.90%	1.69%			46.1%
Occupant fatalities			19.7%	15.1%		7.0%

(1) Speed limits in mph have been grouped as following: (<30 mph, 30 mph into <60 km/h), (40 mph into 60 km/h), (50 mph into 80 km/h), (60 mph into 100 km/h), (70 mph and >70 mph into >100 km/h).

Source: Data provided by Working Group members from national datasets.

Table B.4 shows that for trucks the percentage of single vehicle crashes (including pedestrians) are highest for South Africa (44%), Israel (33%) and Australia (28%). In the case of South Africa and Israel, this was primarily crashes involving pedestrians (27% and 25% respectively). The percentage of single vehicle crashes that involved only the truck (not a pedestrian) was highest in South Africa and Australia (17%) followed by the United States and Canada (12% and 11% respectively). Not surprisingly, Australia, South Africa and Canada also had the highest proportions of truck occupants killed in fatal truck crashes. The lowest proportions of truck occupants killed in fatal truck crashes were in Switzerland and Denmark, where over 30% of fatal crashes involved a pedestrian or bicyclist.

The differences in single vehicle crashes may be due to such factors as the amount of travel in areas of low traffic density resulting in a lower probability of encountering other vehicles, the amount of travel on roads with safety features to reduce the risk of fatal single vehicle crashes, *e.g.* sealed shoulders and roadside barriers, or differences in driver impairment due to factors such as fatigue. These matters warrant further investigation, if relevant data can be obtained.

Similarly, without detail as to the distribution of the heavy vehicle travel undertaken on a country's road network, it is difficult to determine whether distributional differences in fatal crashes is merely a reflection of differences in the amount of travel in the various areas. Nevertheless, understanding the nature of crashes within a country or specific area can provide guidance as to which countermeasures are likely to be most beneficial in reducing those crashes.

ANNEX C. EVOLUTION IN FREIGHT TRANSPORT

This Annex presents statistics from the International Transport Forum on the evolution of freight transport between 1990 and 2008.

It includes the following tables:

- Table 1: Evolution in *total* freight transport (ton –km)
- Table 2: Evolution in *road* freight transport (ton –km)
- Table 3: Evolution in *rail* freight transport (ton –km)
- Table 4: Evolution in inland waterways freight transport
- Table 5: Evolution in freight transport by pipelines

Note: ITF Statistics do not include data on maritime freight. Other data sources were used, when required, in Chapter 1.

Table 1. **Evolution in freight transport all modes (excl. Maritime transport) (million t–km)**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Albania	1 779	2 140	2 199	3 243	4 154	134%	89%
Armenia			1 656	2 466	3 763		127%
Australia	169 548	212 469	265 848	344 702	379 083	124%	43%
Austria	29 730	37 406	43 763	44 493	49 955	68%	14%
Azerbaijan	43 716	5 271	10 822	26 558	88 851	103%	721%
Belarus	99 596	35 182	41 196	58 694	71 893	-28%	75%
Belgium	46 875	61 528	67 634	62 124	57 021	22%	-16%
Bosnia-Herzegovina	7 075	71	458	819	870	-88%	90%
Bulgaria	30 143	28 300	9 374	12 092	14 171	-53%	51%
Canada		425 100	467 800	579 200	578 478		24%
Croatia	13 489	3 741	5 336	14 056	16 110	19%	202%
Czech Republic	–	60 321	58 917	61 351	69 492		18%
Denmark	13 155	14 420	17 715	18 150	16 790	28%	-5%
Estonia	11 489	5 395	12 118	18 280	14 222	24%	17%
Finland	33 827	31 708	37 941	37 594	38 493	14%	1%
France	191 660	233 568	270 351	262 573	260 687	36%	-4%
FYROM	2 958	1 343	1 303	6 255	4 885	65%	275%
Georgia	13 411	1 376	6 234	9 313	7 115	-47%	14%
Germany	339 540	386 754	439 698	486 372	537 198	58%	22%
Greece	13 095	12 662	14 717	16 474	17 746	36%	21%
Hungary	39 265	26 777	25 156	28 191	30 771	-22%	22%
Iceland							
Ireland	5 719	6 095	12 839	18 455	19 061	233%	48%
Italy	210 745	229 162	194 888	205 827	225 328	7%	16%
Japan	301 440	319 749	335 254	357 792	374 213	24%	12%
Korea	13 663	13 838	10 803	110 977	116 788	755%	981%
Latvia	24 683	16 907	24 565	31 706	34 022	38%	38%
Liechtenstein				390	330		
Lithuania	26 758	14 404	20 145	32 772	35 707	33%	77%
Luxembourg	1 428	1 390	1 454	1 262	1 270	-11%	-13%
Malta							
Mexico	145 301	200 440	242 386	276 402	301 872	108%	25%
Moldova	21 405	4 125	2 539	5 385	5 840	-73%	130%
Montenegro				132	186		
Netherlands	66 496	70 479	83 222	88 032	91 034	37%	9%
New Zealand		11 205	18 423	22 231	23 391		27%
Norway	11 919	16 562	18 277	22 669	23 221	95%	27%
Poland	138 744	133 775	150 565	196 377	248 787	79%	65%
Portugal	12 510	13 138	17 135	19 847	19 317	54%	13%

Table 1. **Evolution in freight transport all modes (excl. Maritime transport) (million t–km) contd.**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Romania	69 613	37 408	31 887	43 337	45 067	-35%	41%
Russia	4 276 002	2 129 557	2 341 894	3 295 161	3 509 073	-18%	50%
Serbia	19 102	6 299	3 581	6 241	7 284	-62%	103%
Slovakia	–	41 678	26 958	32 693	39 494		47%
Slovenia	9 096	4 778	4 794	5 606	6 155	-32%	28%
Spain	106 358	118 180	168 350	248 250	258 084	143%	53%
Sweden	36 091	38 684	43 775	48 807	53 908	49%	23%
Switzerland	21 213	24 522	33 075	36 237	39 677	87%	20%
Turkey	136 153	124 128	224 581	181 719	229 072	68%	2%
Ukraine	551 283	242 576	217 829	271 581	316 217	-43%	45%
United Kingdom	159 269	171 313	183 438	197 815	205 333	29%	12%
United States	4 028 395	4 740 759	5 165 881	5 649 810	5 726 705	42%	11%
Total	**11 493 737**	**10 316 683**	**11 378 774**	**13 500 513**	**14 218 184**		

Table 2. **Evolution in road freight transport (million t–km)**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Albania	1 195	2 077	2 164	3 210	4 098	243%	89%
Armenia				231	1 034		
Australia	81 628	106 279	132 278	161 722			
Austria	9 015	14 879	17 154	16 889	18 160	101%	6%
Azerbaijan	3 287	1 849	3 774	7 870	10 317	214%	173%
Belarus	22 361	9 539	9 745	15 045	22 767	2%	134%
Belgium	32 049	47 136	51 023	43 846	38 356	20%	-25%
Bosnia-Herzegovina	3 066	55	318	440			
Bulgaria	13 770	18 562	3 060	5 045	7 122	-48%	133%
Canada		65 800	84 700	131 500	134 400		59%
Croatia	2 852	1 251	2 816	9 328	11 042	287%	292%
Czech Republic	–	31 267	39 036	43 447	50 877		30%
Denmark	9 352	9 326	11 000	11 058	10 718	15%	-3%
Estonia	4 510	1 549	3 932	7 641	8 279	84%	111%
Finland	25 400	22 338	27 716	27 813	27 614	9%	0%
France	114 800	157 084	184 222	193 153	195 515	70%	6%
FYROM	2 189	1 174	776	5 576	3 978	82%	413%
Georgia	2 577	130	475	578	600	-77%	26%
Germany	169 900	237 515	280 699	310 114	341 550	101%	22%
Greece	12 486	12 356	14 291	15 861	16 960	36%	19%
Hungary	15 159	13 040	12 146	11 400	13 010	-14%	7%

Table 2. **Evolution in road freight transport (million t–km) contd.**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Iceland							
Ireland	5 130	5 493	12 348	18 152	18 958	270%	54%
Italy	177 945	195 327	158 562	171 554	189 779	7%	20%
Japan	274 244	294 648	313 118	334 979	351 957	28%	12%
Korea				100 869			
Latvia	5 853	1 834	4 788	8 547	12 344	111%	158%
Liechtenstein				390	330		
Lithuania	7 336	5 160	7 769	15 908	20 419	178%	163%
Luxembourg	383	530	448	533	624	63%	39%
Malta							
Mexico	108 884	162 827	194 053	204 217	227 290	109%	17%
Moldova	6 305	1 121	1 001	2 405	2 966	-53%	196%
Montenegro							
Netherlands	22 891	27 006	31 560	34 003	32 552	42%	3%
New Zealand		11 205	14 345	18 378	19 538		36%
Norway	8 231	9 654	13 017	15 871	16 728	103%	29%
Poland	40 293	51 200	75 023	119 740	174 223	332%	132%
Portugal	10 922	11 119	14 952	17 425	16 768	54%	12%
Romania	5 208	4 186	9 879	19 399	23 183	345%	135%
Russia	299 362	156 483	152 735	193 597	216 276	-28%	42%
Serbia	8 567	4 534	582	680	1 112	-87%	91%
Slovakia	–	26 536	14 341	22 550	29 094		103%
Slovenia	4 887	1 702	1 937	2 361	2 635	-46%	36%
Spain	90 530	101 874	148 714	227 381	238 656	164%	60%
Sweden	25 649	28 247	31 355	34 682	37 933	48%	21%
Switzerland	11 548	14 956	21 949	24 360	26 793	132%	22%
Turkey	65 710	112 515	161 552	166 831	181 935	177%	13%
Ukraine	14 794	3 567	2 490	9 180	18 168	23%	630%
United Kingdom	132 900	146 714	153 704	165 468	174 148	31%	13%
United States	1 239 194	1509 671	1 741 491	1 885 576			
Total	**3 115 671**	**3 641 315**	**4 163 038**	**4 836 803**	**2 950 806**		

Table 3. **Evolution in rail freight transport (million t–km)**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Albania	584	53	28	26	52	-91%	86%
Armenia			354	654			
Australia	87 920	106 190	133 570	182 980	201 590	129%	51%
Austria	12 682	13 715	16 602	17 064	21 915	73%	32%
Azerbaijan	37 076	2 409	5 677	9 628	10 021	-73%	77%
Belarus	75 430	25 510	31 425	43 559	48 994	-35%	56%
Belgium	8 354	7 287	7 674	8 042	8 469	1%	10%
Bosnia-Herzegovina	4 009	16	140	379	343	-91%	145%
Bulgaria	14 132	8 595	5 538	5 163	4 693	-67%	-15%
Canada		226 000	267 200	306 300	290 678		9%
Croatia	6 535	1 974	1 788	2 835	3 312	-49%	85%
Czech Republic	–	25 459	17 496	14 866	15 437		-12%
Denmark	1 787	1 985	2 025	1 967	1 863	4%	-8%
Estonia	6 977	3 846	8 185	10 639	5 943	-15%	-27%
Finland	8 357	9 293	10 107	9 706	10 777	29%	7%
France	49 670	46 560	55 350	39 659	35 697	-28%	-36%
FYROM	769	169	527	530	743	-3%	41%
Georgia	10 834	1 246	3 913	6 145	6 515	-40%	66%
Germany	103 100	70 500	77 500	95 421	115 652	12%	49%
Greece	609	306	426	613	786	29%	85%
Hungary	16 781	8 337	8 095	9 090	9 874	-41%	22%
Iceland	–	–	–	–	–		
Ireland	589	602	491	303	103	-83%	-79%
Italy	21 170	24 050	25 839	22 761	23 831	13%	-8%
Japan	27 196	25 101	22 136	22 813	22 256	-18%	1%
Korea	13 663	13 838	10 803	10 108	11 566	-15%	7%
Latvia	18 538	9 757	13 310	19 779	19 581	6%	47%
Liechtenstein	–	–	–	–	–		
Lithuania	19 258	7 220	8 918	12 457	14 748	-23%	65%
Luxembourg	709	529	633	392	280	-61%	-56%
Malta	–	–	–	–	–		
Mexico	36 417	37 613	48 333	72 185	74 582	105%	54%
Moldova	14 783	3 004	1 538	2 980	2 873	-81%	87%
Montenegro				132	186		
Netherlands	3 070	3 097	4 522	5 865	7 041	129%	56%
New Zealand			4 078	3 853			
Norway	1 633	1 647	1 775	2 208	2 666	63%	50%

Table 3. **Evolution in rail freight transport (million t–km) contd.**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Poland	83 530	68 206	54 015	49 972	52 043	-38%	-4%
Portugal	1 588	2 019	2 183	2 422	2 549	61%	17%
Romania	57 253	27 179	17 982	16 582	15 236	-73%	-15%
Russia	2 522 915	1 213 711	1 373 178	1 858 093	2 116 240	-16%	54%
Serbia	7 222	1 364	1 917	3 481	4 341	-40%	126%
Slovakia	–	13 674	11 234	9 463	9 299		-17%
Slovenia	4 209	3 076	2 857	3 245	3 520	-16%	23%
Spain	11 613	10 419	12 171	11 641	10 287	-11%	-15%
Sweden	10 442	10 437	12 420	14 125	15 975	53%	29%
Switzerland	8 303	8 157	10 786	11 527	12 516	51%	16%
Turkey	8 030	8 632	9 895	9 152	10 739	34%	9%
Ukraine	473 953	195 762	172 840	223 980	257 007	-46%	49%
United Kingdom	16 000	13 272	18 100	21 400	21 100	32%	17%
United States	1 509 565	1 906 267	2140 260	2476 733	2 593 052	72%	21%
Total	**5 376 745**	**4 168 083**	**4 635 834**	**5 652 918**	**6 096 971**		

Table 4. **Evolution in freight transport by inland waterways (million t–km)**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Albania	–	–	–	–	–		
Armenia	–	–	–	–	–		
Australia	–	–	–	–	–		
Austria	1 663	2 046	2 444	2 760	2 359	42%	-3%
Azerbaijan				7 521	6 079		
Belarus	1 805	133	26	90	132	-93%	408%
Belgium	5 448	5 807	7 313	8 719	8 746	61%	20%
Bosnia-Herzegovina	–	–	–	–	–		
Bulgaria	1 606	733	397	1 532	1 936	21%	388%
Canada		31 800	25 400	27 400			
Croatia	527	33	63	119	79	-85%	25%
Czech Republic	–	1 319	773	779	863		12%
Denmark	–	–	–	–	–		
Estonia	2		1				
Finland	70	77	118	75	102	46%	-14%
France	7 581	7 649	9 110	8 905	8 557	13%	-6%
FYROM	–	–	–	–	–		
Georgia	–	–	–	–	–		

Table 4. **Evolution in freight transport by inland waterways (million t–km) contd.**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Germany	54 803	63 982	66 466	64 096	64 061	17%	-4%
Greece	–	–	–	–	–		
Hungary	2 038	1 260	891	2 110	2 250	10%	153%
Iceland	–	–	–	–	–		
Ireland	–	–	–	–	–		
Italy	118	135	170	89			
Japan	–	–	–	–	–		
Korea	–	–	–	–	–		
Latvia	292						
Liechtenstein	–	–	–	–	–		
Lithuania	164	18	1	1	13	-92%	1200%
Luxembourg	336	331	373	337	366	9%	-2%
Malta	–	–	–	–	–		
Mexico	–	–	–	–	–		
Moldova	317				1		
Montenegro	–	–	–	–	–		
Netherlands	35 662	35 098	41 271	42 225	46 024	29%	12%
New Zealand	–	–	–	–	–		
Norway	–	–	–	–	–		
Poland	1 034	876	1 173	1 277	1 274	23%	9%
Portugal							
Romania	2 090	3 107	2 634	5 146	4 928	136%	87%
Russia	213 949	90 872	70 988	87 173	63 705	-70%	-10%
Serbia	3 232	336	980	1 622	1 369	-58%	40%
Slovakia	–	1 468	1 383	680	1 101		-20%
Slovenia	–	–	–	–	–		
Spain	–	–	–	–	–		
Sweden	–	–	–	–	–		
Switzerland	196	160	124	124			
Turkey	–	–	–	–	–		
Ukraine	11 925	5 680	5 898	6 315			
United Kingdom	200	200	210	170	160	-20%	-24%
United States	426 866	447 232	441 726	400 568			
Total	**776 346**	**700 352**	**679 933**	**669 833**	**214 105**		

Table 5. **Evolution in freight transport by pipelines (million t–km)**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Albania		10	7	7	4		-43%
Armenia			1 302	1 581			-100%
Australia	–	–	–	–	–		
Austria	6 370	6 766	7 563	7 780	7 521	18%	-1%
Azerbaijan	3 353	1 013	1 371	1 539	62 434	1762%	4454%
Belarus	–	–	–	–	–		
Belgium	1 024	1 298	1 624	1 517	1 450	42%	-11%
Bosnia-Herzegovina	–	–	–	–	–		
Bulgaria	635	410	379	352	420	-34%	11%
Canada		101 500	90 500	114 000	124 000		37%
Croatia	3 575	483	669	1 774	1 677	-53%	151%
Czech Republic	–	2 276	1 612	2 259	2 315		44%
Denmark	2 016	3 109	4 690	5 125	4 209	109%	-10%
Estonia	–	–	–	–	–		
Finland	–	–	–	–	–		
France	19 609	22 275	21 669	20 856	20 918	7%	-3%
FYROM				149	164		
Georgia			1 846	2 590			
Germany	11 737	14 757	15 033	16 741	15 935	36%	6%
Greece	–	–	–	–	–		
Hungary	5 287	4 140	4 024	5 591	5 637	7%	40%
Iceland	–	–	–	–	–		
Ireland	–	–	–	–	–		
Italy	11 512	9 650	10 317	11 423	11 624	1%	13%
Japan	–	–	–	–	–		
Korea	–	–	–	–	–		
Latvia		5 316	6 467	3 380	2 097		-68%
Liechtenstein	–	–	–	–	–		
Lithuania		2 006	3 457	4 406	527		-85%
Luxembourg	–	–	–	–	–		
Malta	–	–	–	–	–		
Mexico							
Moldova	–	–	–	–	–		
Montenegro	–	–	–	–	–		
Netherlands	4 873	5 278	5 869	5 939	5 417	11%	-8%
New Zealand	–	–	–	–	–		
Norway	2 055	5 261	3 485	4 590	3 827	86%	10%

Table 5. **Evolution in freight transport by pipelines (million t–km) contd.**

Countries	1990	1995	2000	2005	2008	Evolution 1990-2008	Evolution 2000-2008
Poland	13 887	13 493	20 354	25 388	21 247	53%	4%
Portugal	–	–	–	–	–		
Romania	5 062	2 936	1 392	2 210	1 720	-66%	24%
Russia	1 239 776	668 491	744 993	1 156 298	1 112 852	-10%	49%
Serbia	81	65	102	458	462	470%	353%
Slovakia	–	–	–	–	–		
Slovenia	–	–	–	–	–		
Spain	4 215	5 887	7 465	9 228	9 141	117%	22%
Sweden	–	–	–	–	–		
Switzerland	1 166	1 249	216	226	240	-79%	11%
Turkey	62 413	2 981	53 134	5 736	36 398	-42%	-31%
Ukraine	50 611	37 567	36 601	32 106	35 372	-30%	-3%
United Kingdom	10 169	11 127	11 424	10 777	9 925	-2%	-13%
United States	852 770	877 589	842 404	886 933			
Total	**2 319 703**	**1 806 933**	**1 899 969**	**2 340 959**	**1 497 533**		

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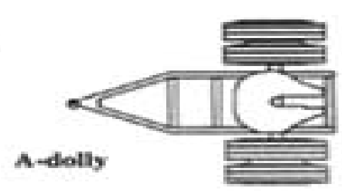
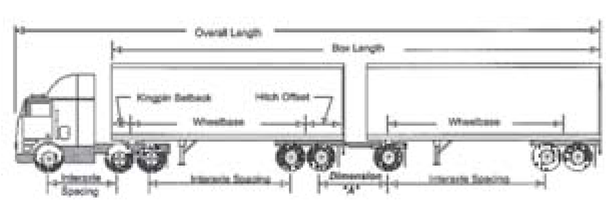
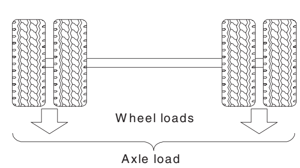
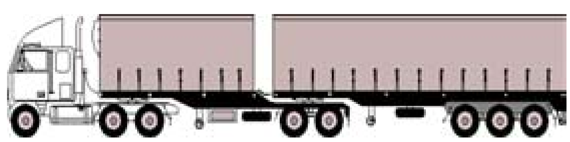
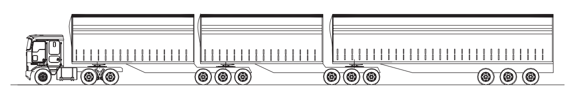
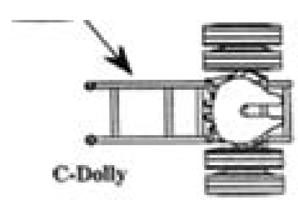
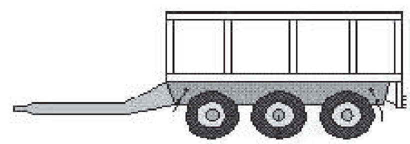
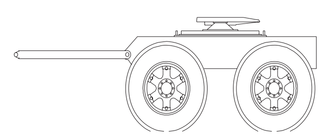
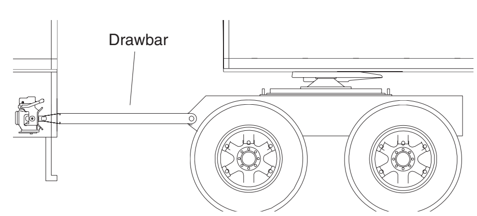
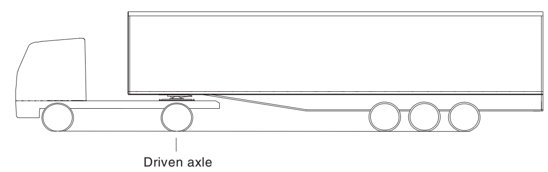
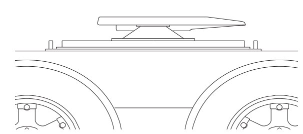
TECHNICAL GLOSSARY

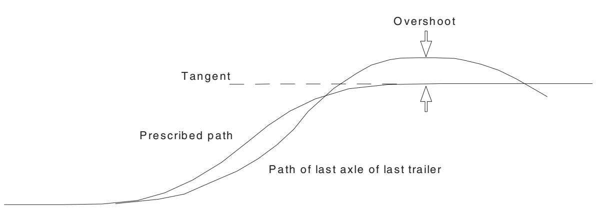
Terms	Definition	Illustration
3 PL - 3rd Party Logistics	Providers of individually tailored logistics products integrated in the processes of companies in trade and industry.	
4PL - 4th Party Logistics	Multi-tier vertical collaborative structure between logistics service companies. Those at the top of the structures view themselves as “supply-chain architects” or “navigators,” also known as “4PLs” or “Lead Logistics Service Providers".	
‘A’ coupling	A drawbar-based coupling type (see A dolly). This coupling type does not transfer roll between the vehicle units.	
‘A’ dolly	Trailer converter dolly that is towed from a single hitch located on the centreline of the towing unit.	
‘A’ train double or double road train	Combination of vehicles composed of a tractor, a semitrailer and either an ‘A’ Dolly and a semitrailer or a full trailer attached to the lead semitrailer in the same manner as if an ‘A’ Dolly was used.	
A train triple (also triple road train)	Similar to an ‘A’ train double, but with three trailers.	

Active steer system	A command steer system where the steering angle is not controlled in proportion with the steering angle applied by the driver but using a sophisticated control algorithm to apply the degree of steering required to achieve the system objectives such as minimising cut-in and/or tail swing	
Articulated vehicle (also combination vehicle or vehicle combination)	A combination of vehicle units, including a motorised unit, with one or more pivoting joints. In this report, the term generally refers to vehicles with a gross mass in excess of 30 tonnes.	
Articulation point	Point about which a vehicle, or vehicle combination, will bend during a turn.	
Axle	Two or more wheel assemblies on a common axis oriented transversely to the nominal direction of motion of the vehicle.	
Axle group load (also axle unit load)	Sum of all the axle loads of the axles which belong to a group of axles.	
Axle group spread (also axle unit spread)	Longitudinal distance between the centres of the extreme axles of an axle group.	
Axle group, axle unit	A set of closely spaced load sharing axles acting as a unit.	
Axle load	The sum of all the wheel loads of an axle.	
Axle load scale	Scale having a load-receiving element specially adapted to determine the combined load of all wheels on a single axle or axle group of a vehicle.	

Axle spacing	Longitudinal distance between two successive axles.	
Axle wear factor	Dimensionless factor relating the damage contribution of a specific axle at a given axle load and axle configuration to the damage contribution of a single passage of a reference axle with a reference axle load (10 tonnes or 100 kN).	
B coupling	A fifth-wheel connection. This coupling type transfers roll between the vehicle units.	
B train (also B double)	Tractor towing two semitrailers. The first trailer includes a 5th wheel or turntable which links to the second trailer, rather than using a dolly to link the trailers as in road train configurations.	
B Triple	Tractor towing three semitrailers. The first and second trailers are connected to the following trailer by a fifth wheel or turntable.	
Base length	Distance between the centres of the first and last axles of a vehicle or combination of vehicles.	
Bobtail	Tractor travelling without a trailer attached.	
Bridge WIM (B-WIM)	WIM using an instrumented bridge as a large scale; the strains measured in some of the bridge elements are used to estimate through software the gross weight and axle loads of a vehicle crossing the bridge.	
C dolly	Trailer converter dolly, with a frame that is rigid in the horizontal plane and is towed from two hitches located in a horizontal transverse line on the towing unit. This precludes any rotation in the horizontal plane about the hitch points, and provides roll coupling between the trailers.	

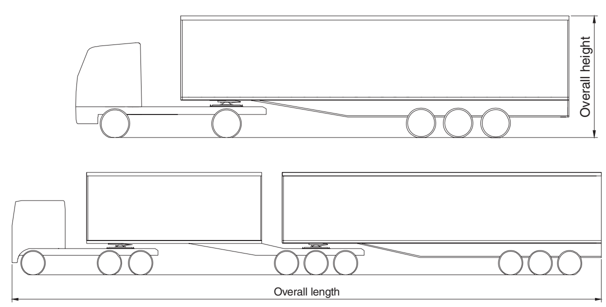
C train double	Combination of vehicles composed of a tractor and two semitrailers, whereby the two semitrailers are coupled by means of a C Dolly.	
Centre Axle Trailer	Trailer with a rigid drawbar and with axles positioned in the middle of the trailer body, designed and used so that most of its weight is carried on its own axles. Called a pig trailer in Australia and a pony trailer in North America.	
Combination mass	Total mass of a combination of vehicles.	
Command steer system	A method for controlling rear steering axles in proportion to the steering angle applied by the driver. Commonly used to describe a steerable axle or a group of axles fitted to a semi-trailer, that is steered by a mechanical link to the turntable of the prime mover.	
Co-modality	Term used by the European Commission to describe the concept of all transport modes operating as efficiently as possible both when used on their own and when used in a combined transport chain.	
Consignee	The party which receives the goods, cargo or containers.	
Cornering force	The sideways force produced by a tyre when cornering.	
Dolly (converter dolly)	Short trailer containing a fifth wheel intended to couple a semi trailer, and converting it to a full trailer.	
Drawbar	Bar that connects a trailer to another vehicle unit. Sometimes referred to as the tongue of the trailer.	

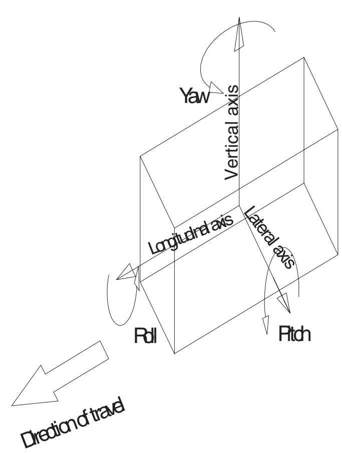
Drive(n) axle	An axle through which the tyres are driven by the vehicle's engine. A driven axle transmits the power of the engine to the pavement.	
Dual tyres (also dual wheels)	Two wheels mounted together on an axle hub.	
Dynamic load	Force applied to the pavement by a wheel/axle while the vehicle is travelling at speed; by extension, sum of the forces applied by all the axles of a vehicle.	
Equivalent axle load	The number of standard axles that would produce an effect on the pavement equivalent to that of any combination of axle loads of varying magnitude.	
Equivalent Standard Axle Load (ESAL)	The number of passes of a standard design axle (usually 100 kN) that would produce an equivalent effect on the pavement as a given combination of axle loads of varying magnitude.	
European Modular System (EMS)	The coupling of vehicle units which individually comply with EU Directive 96/53/EC into combinations that exceed the maximum combination length and mass permitted by 96/53. Typically, EMS combinations operate at 25.25 m in length and 60 t in gross mass.	
Fifth wheel	Component of the hinging connection which provides roll coupling and vertical and horizontal load transfer between two vehicle units.	
Forwarder	A carrier that collects small shipments from shippers, consolidates the small shipments, and uses a basic mode to transport these consolidated shipments to a destination where the freight forwarder delivers the shipment to the consignee.	

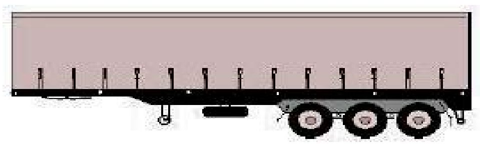
Front overhang	*Unladen vehicle*: Longitudinal distance from the centre of the steer axle to the front bumper. *Laden vehicle*: Longitudinal distance from the centre of the steer axle to the foremost point of the vehicle or cargo, whichever is greater.	
Gross Combination Mass (GCM)	The maximum allowable mass of a combination of vehicles as specified by the vehicle manufacturer and indicated on the manufacturer's plate on the motorised unit (rigid truck or tractor). In some countries, this term is also used to refer to the maximum allowable mass of a combination of vehicles as specified by the applicable regulations.	
Gross Combination Weight	This is the term used in some countries to refer to Gross Combination Mass.	
Gross Vehicle Mass (GVM)	The maximum allowable mass of a vehicle unit (motorised or non-motorised) as specified by the vehicle manufacturer and indicated on the manufacturer's plate. In some countries, this term is also used to refer to the maximum allowable mass of a vehicle as specified by the applicable regulations.	
Gross Vehicle Weight (GVW)	This is the term used in some countries to refer to Gross Vehicle Mass.	
Heavy truck	In this report, a truck with a gross vehicle mass greater than 12 tonnes.	
High Speed Transient Offtracking	The lateral distance that the last axle on the rearmost trailer or semitrailer tracks outside the path of the steer axle when undergoing an ISO single lane change.	

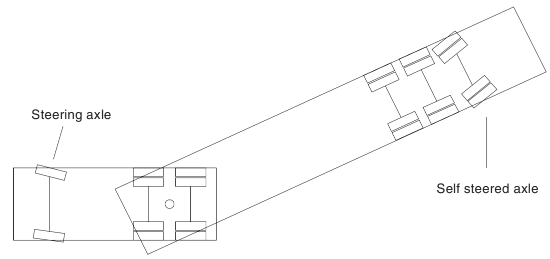
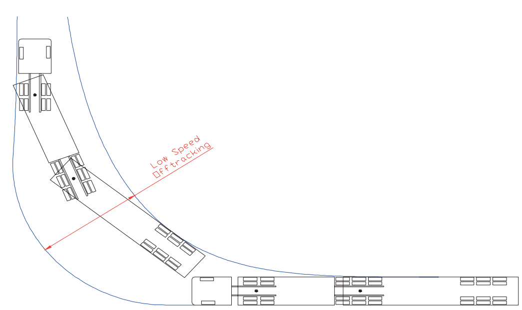
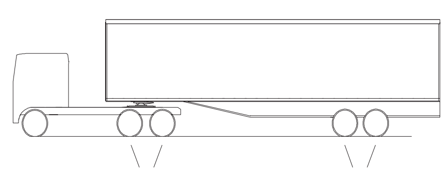
High Speed WIM (HS-WIM)	A device that can Weigh a vehicle in motion in the traffic flow, at its actual traffic speed.	
Higher capacity vehicle	Vehicle combination with greater weight and/or dimension than a workhorse vehicle.	
Higher productivity vehicle (HPV)	Term used in Australia to describe a higher capacity vehicle with a mass and/or dimension exceeding a B-double, *i.e.* with a GCM greater than 68 tonnes and/or a length greater than 26 metres.	
Hire and reward	The carriage for remuneration of freight on behalf of third parties.	
Hitch	Device attached to a vehicle or converter dolly for towing another vehicle or converter dolly.	
Intermodal freight terminal	Location for the transfer of freight from one transport mode to another, for example between road and rail. It connects a freight service user or exporter/importer and a destination and offers customers road and rail transport access and short term storage.	
Intermodality	Use of more than one transport mode for a given freight transport operation. It involves the transportation of freight in a container or vehicle, without any handling of the freight itself when changing modes.	
Jacknife	A loss of control incident involving a tractor semitrailer (vehicle combination) where the tractor rotates in yaw to the interference limit with respect to the semitrailer as the blade of a jackknife folds into its casing.	
Just-in-time delivery	Just-in-time refers to the concept of delivering goods to their destination at the point in time that they need to be used, thus avoiding holding stock in warehouses. Very closely synchronised and reliable deliveries are required to achieve this.	

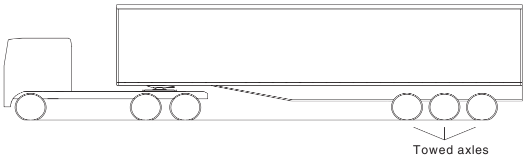
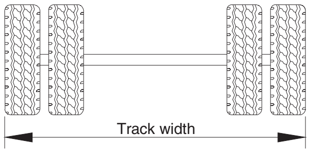
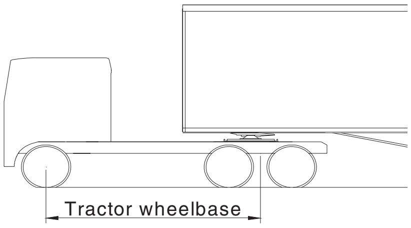
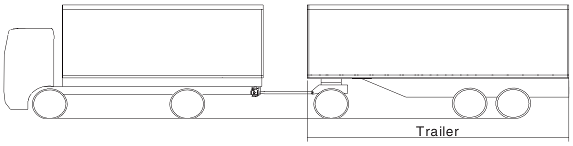
Kingpin	A vertically aligned coupling pin, located under the front of a semitrailer, that engages in the fifth wheel of a tractor, forming a roll coupled joint between the two vehicle units.	
Lateral wander	Transversal distribution of the positions of wheel paths over a carriageway or traffic lane.	
Lift (liftable) axle	An axle that is equipped with a device for altering the weight transmitted to the highway surface and that may be able to lift its tyres from contact with that surface.	
Light commercial vehicle	Motor vehicle constructed for the carriage of freight and which is not greater than 3.5 tonnes gross vehicle mass (or 4.5 tonnes in some countries).	
Load	Force that acts on a structure (*e.g.* on pavements or bridges).	
Load factor	The quotient of the actual load a vehicle carries and the available capacity.	
Load Transfer Ratio	Proportion of load on one side of a vehicle unit transferred to the other side of the vehicle in a transient manœuvre.	LTR=(Wl- Wr)/(Wl+Wr) Wl = sum of the left wheel loads Wr = sum of the right wheel loads
Logistics service provider	Logistics service provider (LSP), or asset-based logistics (2PL): means the management of traditional logistics functions, such as transport and warehouse.	
Long combination vehicle	Term used in the United States to describe a higher capacity vehicle -- with two or more trailers -- with a total length exceeding 65 feet (19.8 metres).	
Long and heavy vehicle (LHV)	Term used in Europe to describe a higher capacity vehicle which exceeds EU weight and/or dimension legislation, *i.e.* is greater than 18.75 m in length and 40 tonnes in weight.	

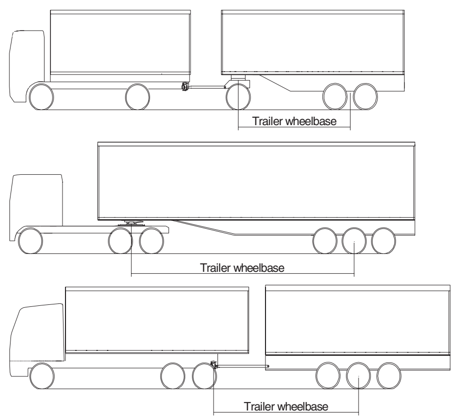
Low Speed WIM (LS-WIM)	A device for weighing a slowly moving vehicle, on a specific area usually outside the traffic flow, on a horizontal, straight, and even pavement surface under controlled conditions, such as constant and limited speed (*e.g.*5 or 15 km/h) in order to minimise dynamic effects.	
Multimodality	Carriage of freight by two or more modes of transport within a single transport chain.	
Non-roll coupled connection	A connection which does not transfer the roll experienced by one vehicle unit to another unit. A drawbar is an example of a non-roll coupled connection.	
Off-tracking	Off-tracking is the lateral deviation between the path of the centreline point of the front axle of the vehicle and the path of a centreline point of the rearmost axle group. If a single number is given, it refers to the maximum off-tracking.	
Overall height	Maximum overall vertical distance from the highest point on the vehicle or load to the ground.	
Overall length	Overall longitudinal dimension of a vehicle or combination of vehicles including load.	
Own account transport	Transport which is not for hire or reward.	
Owner-driver	Any person with the skills, licence and vehicle to undertake hire or reward work in road transport, usually operating as a sole trader.	
Pavement distress / wear	Reduction of pavement quality due to loading by traffic and/or climate. Several types of distress exist, of which the main types are: primary rutting, secondary rutting, fatigue cracking, surface cracking, thermal cracking, reflective cracking and ravelling.	
Payload	Amount of freight (in volume or mass) carried by a particular vehicle.	

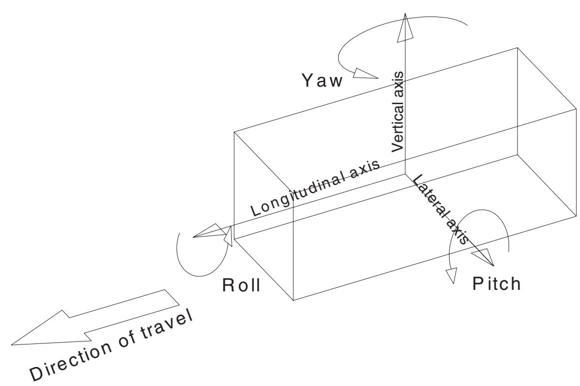
Payload capacity	The amount of freight (volume or mass) that a vehicle can legally carry.	
Pre- and End-Haulage	Pre-haulage is normally referred to as the first leg of an intermodal transport chain by road from the customer's site to the intermodal terminal. At the intermodal terminal the cargo is shifted onto an alternative transport mode (other than road). End-haulage is normally referred to as the last leg of an intermodal transport chain by road from the terminal to the consignee.	
Rear overhang	Unladen vehicle: Longitudinal distance from the centre of the last axle to the rearmost point of the vehicle. Laden vehicle: Longitudinal distance from the centre of the last axle to the rearmost point of the vehicle or cargo, whichever is greater.	
Rearward Amplification	The degree to which the trailing units amplify the lateral acceleration of the hauling unit when undergoing an ISO single lane change.	
Rigid truck	Motorised vehicle unit for the transport of freight.	
Road tractor	*See tractor.*	
Road train	A combination of vehicle units consisting of a tractor towing at least two trailers. (The terminology does not include the Australian B - double).	
Roll	Rotation about the longitudinal axis of the vehicle (see also pitch, yaw).	

Roll-coupled connection	A connection which transfers the roll experienced by one vehicle unit to a vehicle unit to which it is connected. A fifth wheel is an example of a roll-coupled connection.	
Self steering axle	A method for steering axles that is dependent on the cornering forces experienced by the tyre. A self-steering axle will only steer when the tyres develop a sufficient cornering force to overcome friction or pre-loads in the pivoting mechanism.	
Semitrailer	Vehicle unit supported by another vehicle unit by means of a fifth wheel. Trailer where a significant proportion of its mass is carried by the tow vehicle rather than its own axles.	
Shipper (also consignor)	An individual or organisation that prepares a bill of lading by which a motor carrier is directed to transport freight from one location to another.	
Single axle	Axle which does not belong to a group of axles, *i.e.* is not linked to another axle by a common suspension. In absence of a standardised definition based on axle spacing, the geometrical criterion to identify a single axle by road sensor(s) is that it is spaced from the nearest neighbouring axles of the same vehicle, by more than 2.2 m by default.	
Static load	Load (of a vehicle or on an axle, tyre assembly or tyre) which is caused by gravity acting on the mass of the vehicle and its payload when the vehicle does not move.	
Static Rollover Threshold	The steady state level of lateral acceleration that a vehicle can sustain - on a constant radius - without rolling over during turning.	
Steer Tyre Friction Demand	The maximum friction level demanded of the steer tyres of the hauling unit in a prescribed 90º low speed turn.	

Steering axle	Axle on which the wheels can be steered for manoeuvring the vehicle.	
Strip sensor	Sensor installed perpendicular to the direction of travel of a road, with an extent equal either to the lane width or half the lane width, and a longitudinal extent (in the traffic direction) of a few centimetres, but smaller than a tyre imprint length. Therefore if used as a weighing sensor, the signal must be integrated during the time during which the tyre applies a pressure to it.	
Super single tyre	Wide-based single tyre	
Supply chain	Sequence of events, which may include conversion, assembly/disassembly, movement or placement, which creates value.	
Suspension configuration factor	Factor expressing the relative pavement wear of an axle load with a certain suspension type, relative to an axle with a reference suspension.	
Swept path	The total swept width while travelling on a curved path, including the influence of prescribed variations in crossfall and road surface unevenness, and driver steering activity.	
Tandem axle (also double axle, bogie group)	A group of two load sharing axles supporting a vehicle unit.	

Tare mass	The mass of a vehicle in running order, equipped with all standard equipment and with all fuel and other fluid reservoirs filled to nominal capacity, but unoccupied and without any other load.	
Towed axle (also non driven axle, pusher axle or trailing axle)	Axle on which the wheels are not driven.	
Track width	Overall width of an axle across the outside edges of the outermost tyres.	
Tracked width (see swept path)		
Tracking ability on a straight path (TASP)	The total swept width of a vehicle or combination of vehicles while travelling on a straight path, including the influence of prescribed variations in crossfall and road surface unevenness, and driver steering activity.	
Tractor	Powered unit containing a fifth wheel for the purpose of hauling a semitrailer. Also referred to as a prime mover, road tractor or truck tractor.	
Tractor wheelbase	Longitudinal distance from the centre of the steering axle to the geometric centre of the drive axle unit of a truck tractor.	
Trailer	A non-powered vehicle with a drawbar designed to be coupled to a rigid truck, semitrailer or another trailer. Unlike a semitrailer, a trailer is balanced on its own, and does not require a tractor or dolly for vertical support.	

Trailer wheelbase	Longitudinal distance from the centre of the kingpin of a semitrailer, or the centre of the turntable of a full trailer, or the centre of the hitching device on a centre axle trailer, to the trailer turn centre.	
Tridem (also tridem axle unit)	Group of three equally spaced load sharing axles supporting a vehicle unit.	
Triples	Set of three trailers pulled by a tractor.	
Truck	Motorised heavy vehicle for the transport of freight with a mass greater than 3.5 tonnes. (In some countries a limit of 4.5 tonnes is used). Also used in this report as a generic term to cover any form of motorised freight vehicle or vehicle combination.	
Turn centre	Geometric centre of the axle group on a semitrailer or centre axle trailer or the centre of the rear axle group on a truck, tractor or trailer.	
Twenty Foot Equivalent Unit (TEU)	Standard unit based on a container of 20 feet length (6.10 m), used as a statistical measure of freight transport flows or capacities.	
Tyre load	Vertical force applied by a tyre to the pavement.	
Tyre width	Tread width of the tyre.	
Vehicle	Mechanical means of transport.	
Vehicle mass	Actual mass of a vehicle, including freight.	
Very high capacity vehicle	Exceptional vehicle that exceeds the weight or length of a higher capacity vehicle and is operated under special permit.	

Weigh-bridge	A weighing device which measures the complete stationary vehicle weight at once (generally approved for legal weighing and thus suitable for generating gross weight reference values).	
Wheel assembly	Half axle with one or more tyres.	
Wheel load	The sum of the tyre loads on all tyres included in the wheel assembly.	
Wheelbase	Distance measured centre to centre from the front axle group or 5th wheel to the rear axle group of a vehicle unit.	
WIM - Weigh in Motion	Process of estimating the gross weight of a moving vehicle, and the portion of that weight that is carried by each of its wheels or axles, by measurement and analysis of dynamic vehicle tyre forces.	
Workhorse vehicle	In a specific country, the truck configurations that are most commonly used for long distance hauling of freight For example, in the US this is the 5-axle (1+2+2) tractor semitrailer; in Europe, it is the 5-axle tractor semitrailer (1+1+3) or the truck-trailer; in Australia, it is the 6-axle (1+2+3) tractor semitrailer.	
Yaw	Rotation about the vertical axis of the vehicle (see also roll, pitch).	
Yaw Damping	The rate at which “sway” or yaw oscillations decay after a short duration pulse steer input (typically a steer input at the hauling unit).	

LIST OF ACRONYMS

AADT	annual average daily traffic
ABS	Antilock Braking System
ACC	Adaptive Cruise Control
ADAS	advanced driver assistance systems
ADT	Average daily traffic
CSW	Curve Speed Warning System
EBS	Electronically controlled braking system
ESAL	Equivalent Standard Axle Load
ESC	Electronic Stabilty Control
FCWS	Forward Collision Warning Systems
GCM	Gross Combination Mass
GVM	Gross Vehicle Mass
ISA	Intelligent Speed Adaptation
ITF	International Transport Forum
JTRC	Joint Transport Research Centre of the OECD and the International Transport Forum
LCV	Longer Combination Vehicles
LDWS	Lane Departure Warning Systems
LHV	Longer and Heavier Vehicles
NTC	National Transport Commission (Australia)
OECD	Organisation for Economic Co-operation and Development
PBS	Performance Based Standards
RSC	Roll Stability Control
TEU	Twenty Foot Equivalent Unit

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