

Christensen, Jorgen; Glaeser, Klaus Peter; Shelton, Terry; Moore, Barry; Aarts, Loes

Working Paper

Innovation in truck technologies

OECD/ITF Joint Transport Research Centre Discussion Paper, No. 2010-10

Provided in Cooperation with:

International Transport Forum (ITF), OECD

Suggested Citation: Christensen, Jorgen; Glaeser, Klaus Peter; Shelton, Terry; Moore, Barry; Aarts, Loes (2010) : Innovation in truck technologies, OECD/ITF Joint Transport Research Centre Discussion Paper, No. 2010-10, Organisation for Economic Co-operation and Development (OECD), Joint Transport Research Centre (JTRC), Paris,
<https://doi.org/10.1787/5kmjp66069s4-en>

This Version is available at:

<https://hdl.handle.net/10419/68754>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

2010

Joint Transport Research Centre

10

DISCUSSION PAPERS



International
Transport
Forum

INNOVATION IN TRUCK TECHNOLOGIES



Discussion Paper No. 2010-10

INNOVATION IN TRUCK TECHNOLOGIES

Paper extracted from the JTRC report

*MOVING FREIGHT WITH BETTER TRUCKS: IMPROVING SAFETY, PRODUCTIVITY AND
SUSTAINABILITY*

JORGEN CHRISTENSEN

KLAUS PETER GLAESER

TERRY SHELTON

BARRY MOORE

LOES AARTS

March 2010

INTERNATIONAL TRANSPORT FORUM

The International Transport Forum is an inter-governmental body within the OECD family. The Forum is a global platform for transport policy makers and stakeholders. Its objective is to serve political leaders and a larger public in developing a better understanding of the role of transport in economic growth and the role of transport policy in addressing the social and environmental dimensions of sustainable development. The Forum organises a Conference for Ministers and leading figures from civil society each May in Leipzig, Germany.

The members of the Forum are: Albania, Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Canada, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, FYROM, Georgia, Germany, Greece, Hungary, Iceland, India, Ireland, Italy, Japan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Moldova, Montenegro, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom and the United States. The Forum's Secretariat is located in Paris.

Joint Transport Research Centre

The OECD and the International Transport Forum established a Joint Transport Research Centre (JTRC) in 2004. The Centre conducts co-operative research programmes addressing all modes of transport to support policy making in Member countries and contribute to the Ministerial sessions of the International Transport Forum.

JTRC Discussion Papers

The JTRC Discussion Paper Series makes economic research commissioned or carried out at the Joint Transport Research Centre available to researchers and practitioners. The aim is to contribute to the understanding of the transport sector and to provide inputs to transport policy design. The Discussion Papers are not edited by the JTRC and they reflect the author's opinions alone.

The Discussion Papers can be downloaded from:

<http://www.internationaltransportforum.org/jtrc/DiscussionPapers/jtrcpapers.html>

The International Transport Forum's website is at:

<http://www.internationaltransportforum.org/>

For further information on the Discussion Papers and other JTRC activities, please email: itf.contact@oecd.org

INNOVATION IN TRUCK TECHNOLOGIES

This paper, extracted from the forthcoming report on “*Moving Freight with Better Trucks*” describes the innovations in truck engine and vehicle technology which aim to:

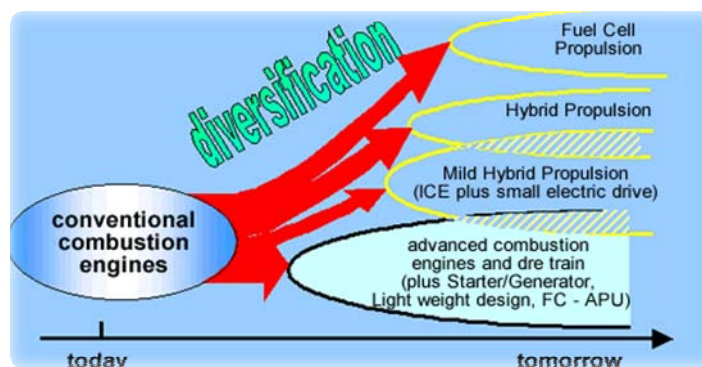
- Improve fuel efficiency and reduce emissions of CO₂;
- Improve truck efficiency by increasing payload capacity;
- Improve compliance with regulations;
- Improve safety and truck operation through the adoption of driver support and communication systems.

1. Improving fuel efficiency

1.1. Energy Sources

The automotive industry is preparing the passenger car and small van market for a diversification of its' energy source as part of a transition from fossil fuel powered engines to hybrid, battery electric or fuel cell electric technology (see figure 1). 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 are now on the market (e.g. in the United States).

Figure 1. Future diversification of engines]



Source: CARS21

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 limits¹.

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 limits².

1.2. Engines

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 liters/100 km to 30-35 liters/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 liters/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.

1.3. 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 power train losses and auxiliaries.

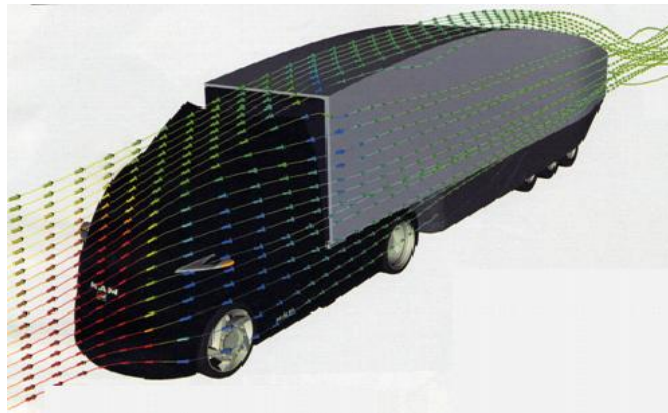
Aerodynamics

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).

¹. 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.

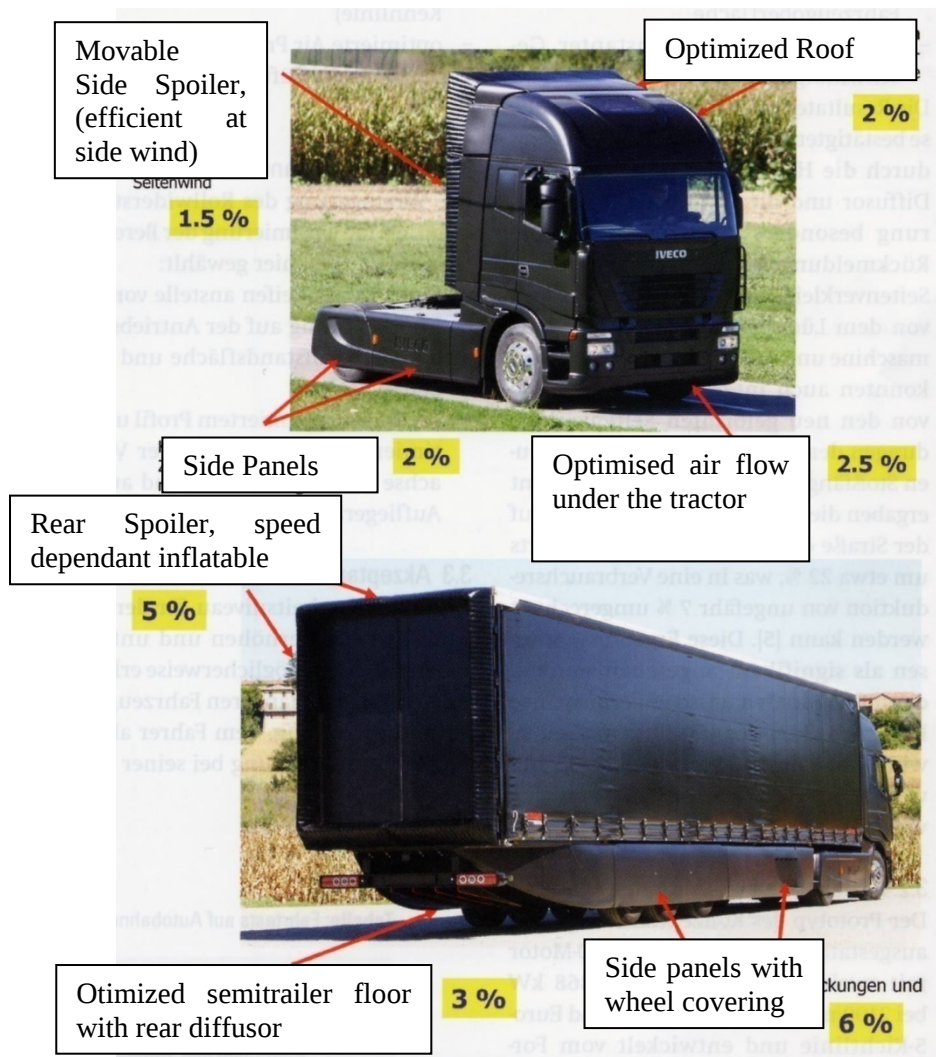
². The United Parcel Service runs a fleet of liquefied natural gas trucks hauling parcels from its hub on the east Coast of the U.S. through the Mojave Desert to Las Vegas, Nevada. Propane and compressed natural gas buses are being deployed in the Bryce, Zion, and Grand Canyon National Parks in the U.S. to help preserve environmental quality.

Figure 2. Aerodynamic model of a tractor semitrailer combination with extreme low air drag.



Source: Schnittig und sparsam in Wirtschaftswoche Nr 36 9/2008

Figure 3. Example of aerodynamic optimization and share of cw decrease [%] (total 22%)

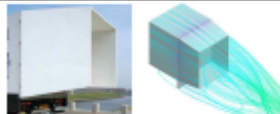


Source: Optimiertes Transportkonzept für Sattelzüge ATZ 2/2008 S.154ff

Aerodynamically most trucks and articulated vehicles of today can still be described as “wheeled bricks” [CEO of MAN in *Wirtschaftswoche* Nr 36 Sept.2008]. The drag coefficient (c_w) 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 3. 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 the potential of 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 aerodynamic devices certified to be safe.

Figure 4. Devices to Reduce Aerodynamic Drag at the Rear of Trucks

Device	approx. additional dimension required	best suiting trailer type	approximate CO ₂ reduction long haul	Image / working principle
Open cavity tails	1.0 - 1.5 m	box, curtain, reefer, refrigerated box (reefer)	6%	
Inset open cavity tails	0.6 m - 0.8m	box, curtain, reefer, refrigerated box (reefer)	5-8%	
Inflatable open cavity tails	0.4 - 0.6 m	box, curtain, reefer, refrigerated box (reefer)	3-4%	
Inflatable closed cavity tails	1.0 - 1.5 m	box, curtain, reefer, refrigerated box (reefer), chassis	5%	
Active Flow Control / Difusors	0.3 m	box, curtain, reefer, refrigerated 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 3 lead to an experimentally confirmed fuel consumption decrease of 7%.

Since 2007, the US Environmental Protection Agency's "SmartWay" program 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 tires 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 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 program 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 tonne of GHG, corresponding to taking 750 000 cars or 19 200 trucks off the road.

Figure 5. The Canadian "EnviroTruck" concept (2007) with fuel-reducing improvements.



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.³ The smaller the tyre

³. What might be surprising is that rolling resistance changes with tire wear. In general, tire fuel economy is worst when tires are new, gets better as they wear, and is best right before removing them.

diameter the higher the rolling resistance coefficient and drive axle tyres have higher rolling resistance coefficients than steering axle tyres, see Table 1.

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 ($0.022 \times 0.45 = 0.01$). Today's trailer tyres (towed axle tyres, 385 mm size) have a rolling resistance at about 0.6%.

Table 1. 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

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 optimization 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.⁴

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. There has to-date, been little research in this area.

Vehicle components: Power train and auxiliaries

The power train (gearbox and transmission) and the additional auxiliary equipments (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 US the 21st Century Truck Partnership aims for an aggressive target of a 30% reduction in the remaining driveline losses,

⁴. Michelin Press Release 2006.

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-synchronized transmissions.

Automated gearboxes are weight optimized and non-synchronized 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 1400 rpm -1600 rpm). However, a manual intervention by the truck driver at any time can override the automatic shifting strategy (ATZ, 2008). A sensor controlled topography dependant gear shifting program 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, utilizing 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 US 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 as 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.

1.4. 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 CO₂ 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 does not require substantial changes to the fuelling infrastructure.

The net CO₂ 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 directive⁵ 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

⁵. 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.

US Environmental Protection Agency (EPA) has proposed new regulations for renewable fuels⁶, 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.

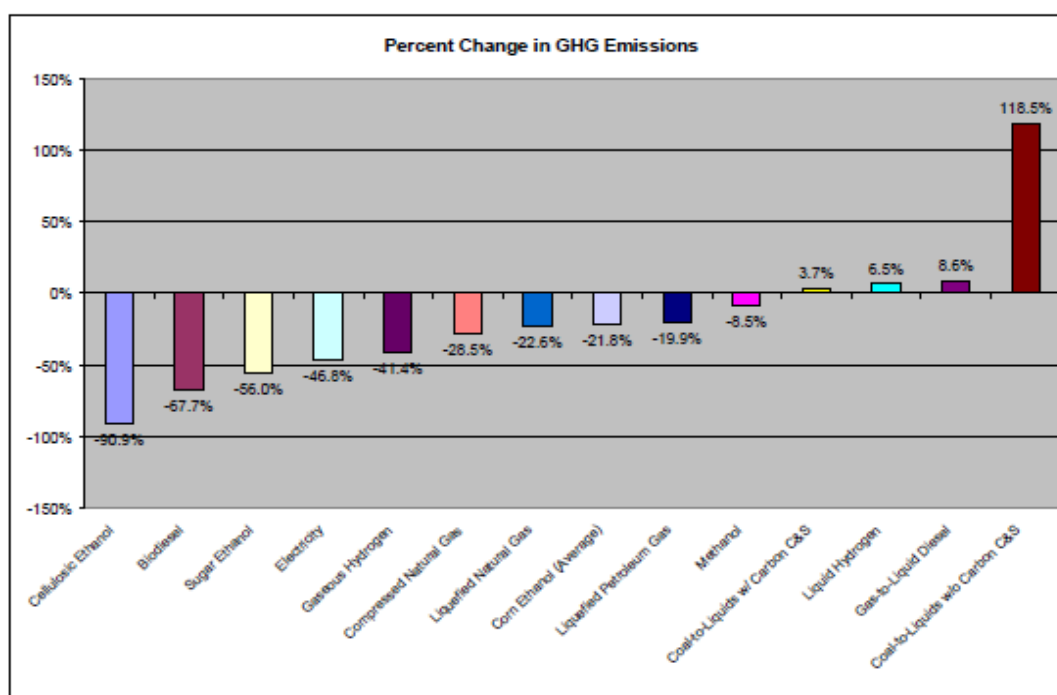
Fischer-Tropsch fuel is another alternative for heavy duty vehicles. It is synthesised from coal gas, natural gas, biomass, or any other carbonaceous material and can replace petroleum diesel fuel without any modification to a conventional diesel engine. It biodegrades more easily than conventional diesel 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 2007⁷. 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 6 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.

⁶. EPA Proposes New Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond, 26 May 2009.

⁷. 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.

Figure 6. Percent change in GHG emissions



Source: US Environmental Protection Agency EPA420-F-07-035, April 2007

1.5. 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 per cent were recorded for cars, busses and trucks. The best results for individual drivers showed 20-50 per cent 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.

2. *Techologies to increase loading capacity*

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 shows examples of the density of a range of different goods.

Table 2. The density of common commodities (kg/dm³ = t/m³)

Commodity	Density (tonne/m ³)
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 100m ³ transporter	0,135
Single dispatched items (parcels)	0,15
Plastic foam	0,04

2.1. *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 3 illustrates the variation between countries for vehicles with general road access.

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” trailers⁸ to reduce the space between truck and trailer. Another way to increase volume capacity is to

⁸. The hitch is (low) located behind the rear axle of the truck instead of standard (high) hitch location at the rear cross beam of the truck.

replace standard rigid semi-trailer axles by independent suspension at each wheel of the semitrailer. A European example is shown in Figure 7 (two floor semitrailer). The volume for cargo is increased by 63% from standard 33 Euro pallets to 54 Euro 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.

Table 3. Typical load unit lengths and volumes for freight vehicles with general road access⁹

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 ⁶	16,15 m	113 m ³	8,69 m + 8,69 m	123m ³
Australia ¹	14,60 m	103 m ³	8,3 + 7,3 m	110 m ³
Canada ²	16,20 m	113 m ³	9,1 + 12,5 m	136-148 m ³
South Africa ³	15,50 m	110 m ³	6,2 m + 12,2 m	125-140 m ³
Mexico ⁴	15,30 m	105 m ³	7,01 + 7,01 m	80-90 m ³
Russia ⁵	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 table2 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/m³, 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.

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

⁹ 1.: Recent statistics (2007) had 74.343 articulated trucks, 392.837 rigid trucks and 2.2 mill 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 %.

2. Figures are based on the most common tractor-semi-trailer combination with a 16,2 m. semi-trailer 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).

3. B-doubles are far more common than truck-trailers on the roads of SA, but they have similar volume capacities.

4. Tractor-semi-trailer 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.

5. 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.

6. In the U.S., some states are limited to 14.63 m in semi-trailer length; some states are limited to 8.53 in trailer lengths.

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 37 Euro pallets runs under special permit in Germany.

Figure 7. Two floor semitrailer with lift, 40 cm ground clearance and 4m box height, length 16.50 m, single wheel suspension on semitrailer for volume transports.



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 categorized 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 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.

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 and 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.

2.2. Payload capacity

Trailers or semitrailers for transport of fluids, bulk goods, wood, building materials with a density (tonnes/m³) 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 fiber reinforced plastics (CFK) instead of steel. The potential of these materials is shown by the vehicles in Figure 8, 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 fiber reinforced plastics (for the cabin) can also be seen in future tractor construction. [Marwitz: 7.CTI Forum Nutzfahrzeuge 2/2008]

Figure 8. 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 with the 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 combinations¹⁰ 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.

3. Enforcement and compliance technologies¹¹

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

¹⁰. The UK allows 44 tonnes on 6 axles with semitrailer length of 13.6m.

¹¹. This section draws on Honefanger et al (2007), McBride and Chadwick (forthcoming), Rapp/Trans (2008) and Transport Certification Australia (2009).

- 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 outsource operations to third parties must be determined.

An illustrative selection of potential compliance technologies are discussed in more detail below.

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 minimize 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.

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.

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 utilized 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.

3.4. Speed limiters

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.

3.5. *Trip/event recorders*

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.

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. 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 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.

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.

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 through 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.

4. Driver support and communication systems to improve safety and trucking operation

4.1 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 4).

Table 4. 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 (including adaptive cruise control and automatic emergency braking system)	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.

4.2. 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 Regulation¹² 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 box5.1.

Forward collision warning, 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. $>3\text{m/s}^2$) 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

¹². 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 therefore.

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.*

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 \$ 380 – 544. The technology and deployment cost estimates ranged from approximately \$440 to \$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 \$1.66 to \$ 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 \$ 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 \$1.37 to \$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 \$ 652 –1367 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 \$1.33 to \$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.

4.3. *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 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 countries¹³. Future ISA developments are expected to be capable of adapting speeds to an increasing number of features of the traffic and infrastructure situation.

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.

4.4. Vehicle component condition warning systems

Onboard Brake Stroke Monitoring Systems

Onboard brake stroke monitoring systems utilize 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 equalizer 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 tire 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.

¹³. 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.

4.5. 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 characterize 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 are indicators of unsafe driving behaviour in addition to eye movements. 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.

4.6. Vehicle tracking and communication systems

Many of the potential users (for example, 35 % in the US) 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 programs 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 utilization 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 data, 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 1000 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 2500 lives every year and reduce the severity by 15 % of all injuries.¹⁴

4.7. 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. Seat belts 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.

¹⁴. See <http://www.esafety-effects-database.org/index.html> with reference to several studies.

- 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 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 for 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.

5. Conclusions

Vehicles

Truck fuel economy has improved in the past 30 years from about 50 liters/100 km to 30-35 liters/100 km, while engine power has doubled from 180 kW to 360 kW. As the fuel saving potentials from reduced drag and rolling resistance become realised along with more efficient auxiliary systems and engine downsizing, future overall fuel economy is expected to improve to about 25 liters/100 km. These savings from technical measures may be complemented by the use of speed limiters, storing and reuse of braking energy and eco-driving.

Volume capacity limits (which are reached more often than the mass capacity because the market for high-value low-density freight is growing), may be increased through design within existing limits, depending on the specific gravity of freight. Mass load capacity can be increased within regulatory limits through the use of lightweight construction materials, and additional axles could allow for higher mass maxima without exceeding current axle load and dimension limits, but might present a problem to certain bridge designs.

Low-speed manoeuvrability can be sustained with longer semitrailer lengths by self-steering systems that have been found able to improve swept path performance dramatically with no adverse affects on dynamic performance, if certain requirements are followed. More advanced active steering systems can result in longer vehicles with better manoeuvrability than existing vehicles.

Compliance technologies

Technological developments will continue to provide still more effective means of ensuring compliance with regulatory requirements. In some cases, technologies will be shared between transport operators and enforcement agencies.

Enforcement of axle load and weight limits with Weigh-in-Motion (WIM) systems embedded in the road has become widespread in various applications. Effective, accurate and tamper proof on-board weighing systems can soon be used in any regulatory application where knowledge of vehicle and axle mass is required.

Satellite based vehicle tracking has been investigated in Europe to enable tracking and tracing of dangerous goods and is used in Australia, to assess compliance with route restrictions for some vehicle types.

Systems for data capture, storage, analysis and reporting are improving rapidly and will enable the targeting of high-risk drivers and operators through collation of data from many sources as well as automated enforcement of breaches, without the need for roadside intervention.

Driver Assistance and Communication Systems

Trucks are now offered a great and increasing variety of IT-based systems designed to assist drivers in the safe and efficient operation of the vehicles in traffic. This chapter has presented a selection of such systems which are on the market, or about to enter the market in the near-term future.

At the core are systems that serve to detect imminent risks, alert the driver appropriately and assist in the avoidance of the dangers posed by these risks by reducing the perils of loss of control (roll or yaw), unintended deviation from the lane, and collision with vehicles ahead of and alongside of the truck. Related to these are systems that anticipate and prevent risk by maintaining the 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. The very real crash causation factors of erratic driver behaviour, as well as fatigue and drowsiness, can be mitigated by driver condition warning systems to detect and alert against the onset of such conditions. Other on-board systems are available for alerting the driver to intervene in time against potentially dangerous failures of brakes and loss of tyre pressure.

Various vehicle tracking and communication systems offer important services to the driver, the haulier and the customer by enabling better planning and execution of the freight task.

Cost can be a significant barrier to the adoption of a new system, in particular when the beneficiary of the feature is not the operator or occupant of the vehicle. Approaches to overcoming this barrier include targeted 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. A multi-faceted approach is often most successful.

References

ATZ (2008), *Off Highway*, June 2008, Automobiltechnische Zeitschrift

- Aprosys (2008). *A holistic approach to improve heavy goods vehicle safety*.
<http://www.underridenetwork.org/Portals/0/APROSYS%20Truck%20Safety%20Implementation%20RoadMap%202020.pdf>.
- T&E (2010), *The case for the exemption of aerodynamic devices in future type-approval legislation for heavy good vehicles*, T&E 2010, Brussels.
- ITF (2008) Biofuels: Linking Support to Performance, Round Table 138, ITF/OECD 2008.
- Searchinger, R. et al. (2008), Use of U.S. Croplands for Biofuels Increased Greenhouse Gases Through Land-use Change, Science Express, Feb. 7, 2008.
- Gallagher, E (2008), *The Gallagher Review of the indirect effects of biofuels production*, Renewable Fuels Agency, London.
- ITF / IEA (2007b). International Workshop on Ecodriving, 22-23 November 2007, Conclusions and Messages for Policy Makers.
- Hata, N., Hasegawa, S., Takahashi, S., Ito, K., and Fujishiro, T (1989). *A control method for 4WS truck to suppress excursion of a body rear overhang*. SAE, 1989(892521): p. 754-760.
- Cheng & Cebon (2007). *Improving roll stability of articulated heavy vehicles using active semi-trailer steering*. 20th IAVSD symposium, August 2007, Berkeley, California.
- Jujnovich & Cebon (2008). Path following steering control for articulated vehicles. University Engineering Department, Trumpington St, Cambridge, CB2 1PZ, UK. Submitted to ASME J Dynamic Systems Measurement and Control August 14, 2008
- Honefanger, J, J Strawhorn, R Athey, J Carson, G Conner, D Jones, T Kearney, J Nichols, P Thurber, R Woolley, Commercial Motor Vehicle Size and Weight Enforcement in Europe, Federal Highway Administration, US Department of Transportation, July 2007
- McBride, C and D Chadwick, Compliance and Enforcement – Intelligent Freight Compliance Technologies, Austroads Strategic Research Report, forthcoming
- Rapp/Trans, Transport Regulatory Uses of Telematics in Europe, Transport Certification Australia, 2008.
- Transport Certification Australia, On-Board Mass Monitoring Test Report (Final), May 2009
- Murray D, Schackelford S and A. Hauser (2009A). *Analysis of benefits and costs of lane departure warning systems for the trucking industry*; FMCSA-RRT-09-020, US Department of Transportation.
- Murray D, Schackelford S and A. Hauser (2009B). *Analysis of benefits and costs of roll stability control systems for the trucking industry*; FMCSA-RRT-09-022. US Department of Transportation.
- Murray D, Schackelford S and A. Hauser (2009C). *Analysis of benefits and costs of forward collision warning systems for the trucking industry*; FMCSA-RRT-09-021, US Department of Transportation.