Longer and Heavier Vehicles

An overview of technical aspects

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1   INTRODUCTION

The Freight Transport Logistics Action Plan[a] discusses the possibility of changes in weights and dimensions of vehicles. Within this frame, the European Commission is analysing the impacts of a potential introduction across the EU of Longer and Heavier Vehicles[b], i.e. vehicles measuring up to 25.25 m and weighting up to 60 tons. Such vehicles are expected to improve the efficiency of the road freight sector, but their impacts on the environment, infrastructure and safety need to be analysed in more depth.

This report is a preliminary desk-based study focusing on <u>technical aspects</u> of LHVs, with the main following objectives:

- To provide a concise and pragmatic analysis of the impacts of LHVs with regard to energy efficiency, infrastructure and safety issues. This is carried out at vehicle level based on a comparison with standard 40t heavy duty vehicles (HDVs). Most of the information gathered in this report derives from recent literature results.

- To highlight technologies that can potentially improve the performance of and reduce the damage caused by LHVs. Issues that require further and detailed research are also identified.

The present study does not constitute a comprehensive technical analysis of LHVs, and it is not meant to draw any positive/negative conclusions about their potential introduction across Europe. The connection between the aspects of LHVs analysed in this report is described in Figure 1 below.
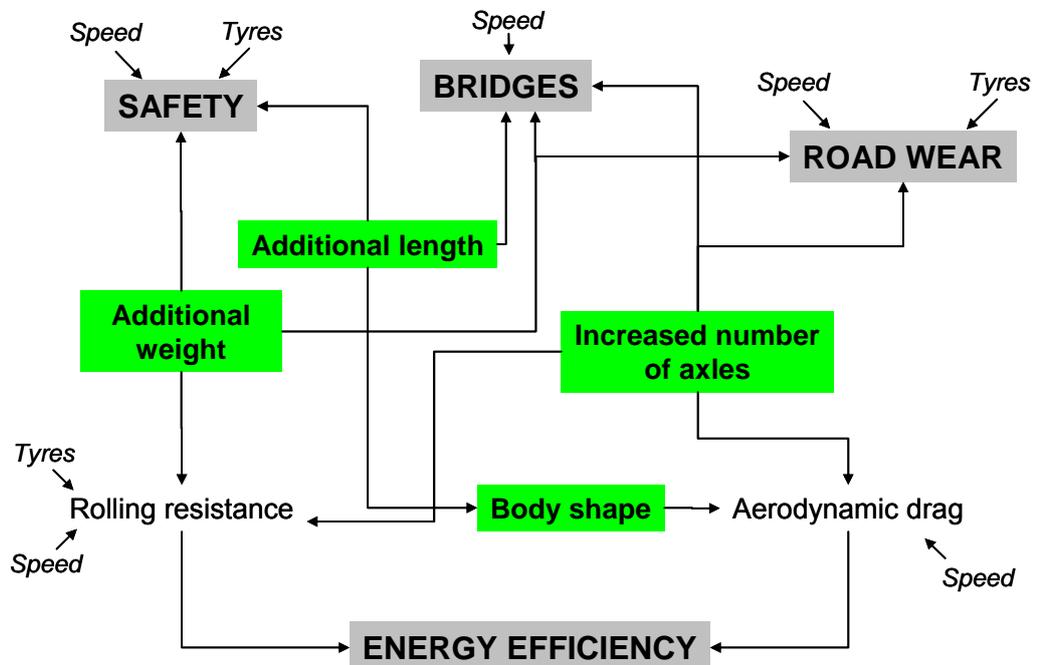
Figure 1: Schematic overview of effects associated with LHVs on energy, infrastructure and safety
In green: additional (obvious) factors due to LHVs compared to conventional HDVs
Note that only the most influencing factors are highlighted

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[a] COM(2007) 607 final.
[b] Abbreviated as LHVs in the following.

2   ENERGY EFFICIENCY

The objective of this chapter is first to review the source of the differences in energy efficiency between LHVs and standard HDVs; and second to discuss the effects of different technologies that could be implemented on such vehicles to reduce their fuel consumption, at vehicle level. Because of the different LHV configurations available, it is not possible to make a detailed technical analysis of each of them. Nevertheless, based on some (but still limited) technical studies carried out in Europe and outside, general trends can be underlined. With regard to energy efficiency, the basic changes between LHVs and standard HDVs stem from:

1- Additional weight: greater tare weight (engine size and additional trailer) and loading capacity.

2- Increase of drag resistances due to:

- additional friction zones: higher number of axles and an additional trailer;

- modifications of the body shape: increased vehicle length and possible change in frontal area.

As shown in Figure 2, the drag resistances (i.e. rolling and aerodynamic resistances) of a semi-trailer combination can account for more than 80% of the mechanical energy (or tractive load), the rest being dissipated through auxiliaries and driveline. With respect to the total energy, the figures are much lower seeing as around 60% of the energy input is lost in the engine (heat transfer).
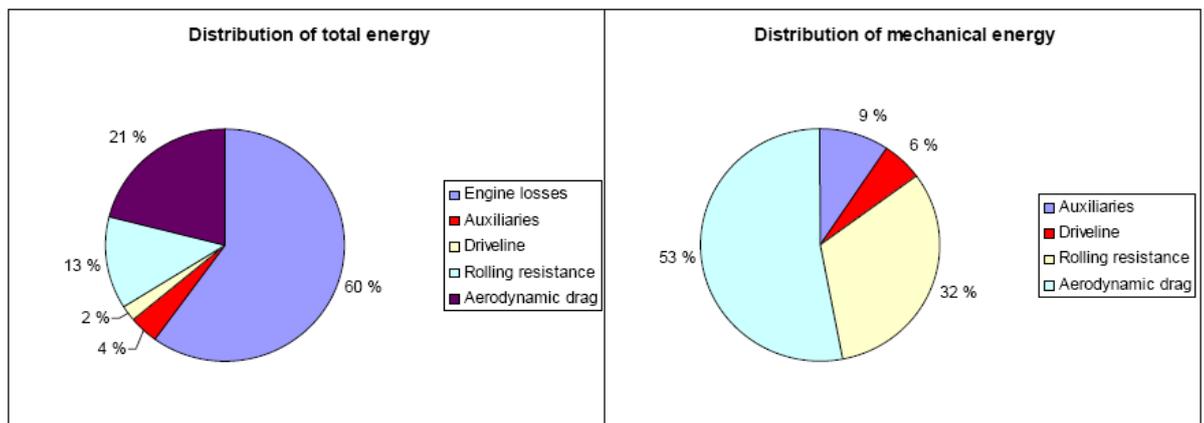

Figure 2: Relative distribution of energy for a semi-trailer combination (at constant speed of 104 km/h)
Source: [VTT, 2006]

In the following, the emphasis will be put on the influence of weight and drag resistances on energy consumption.

2.1   The importance of payload

As illustrated in Figure 3, the total weight of LHVs depends on its tare weight and loading factor such as:

$M(\alpha) = M_0 + \alpha(M_{max} - M_0)$ where:

M is the vehicle weight (tons);

α is the loading rate (ranging from 0 to 1);

M_o is the tare weight (tons);

M_{max} is the vehicle weight when fully loaded (tons).
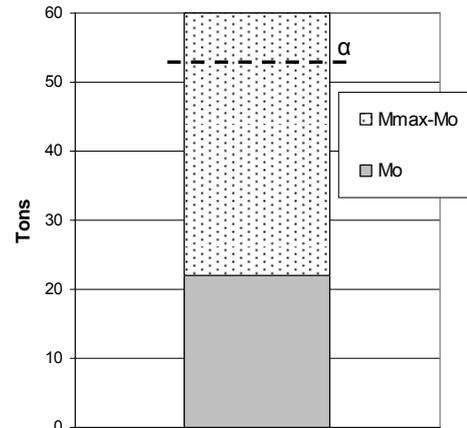

Figure 3: Example of LHV weight decomposition

The loading factor is defined as the ratio of the average load to the total load capacity (i.e. the percentage utilisation of the capacity)[3]. Alongside other contributing elements affecting fuel consumption such as body shape, power train, tyres, etc. the loading factor is without a doubt the most important parameter to be taken into account in the comparison between conventional HDVs and LHVs. Based on Figure 3, one can highlight two important aspects regarding the energy efficiency of LHVs:

<u>If the problem is analysed in terms of fuel consumed per distance travelled</u> (e.g. litre per 100 km), the lower the tare weight and payload, the lower the fuel consumption and emissions will be. In this case, LHVs will be less efficient than conventional HDVs, assuming they both carry the same load.

On average, an additional 1000 kg in weight can lead to more than 0.7 l/100km in fuel consumption for a truck-trailer combination on highway cycle. Differences in fuel consumption between 60t vehicles were analysed by the VTT Technical Research Centre of Finland [VTT, 2008] on highway cycle for different load rates. Fuel consumption was found to be around 30, 40 and 50 l/100km respectively for 0-load, 1/2 load and 2/2 load (see Figure 4). Under the same conditions, a 42t semi-trailer would consume respectively 22, 30 and 35 l/100 km. On average, the energy consumption increases linearly with the load weight [IFEU, 2008].

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[3] Statistically, the loading factor is defined as the ratio of the number of tonne-km to the number of vehicle-km.
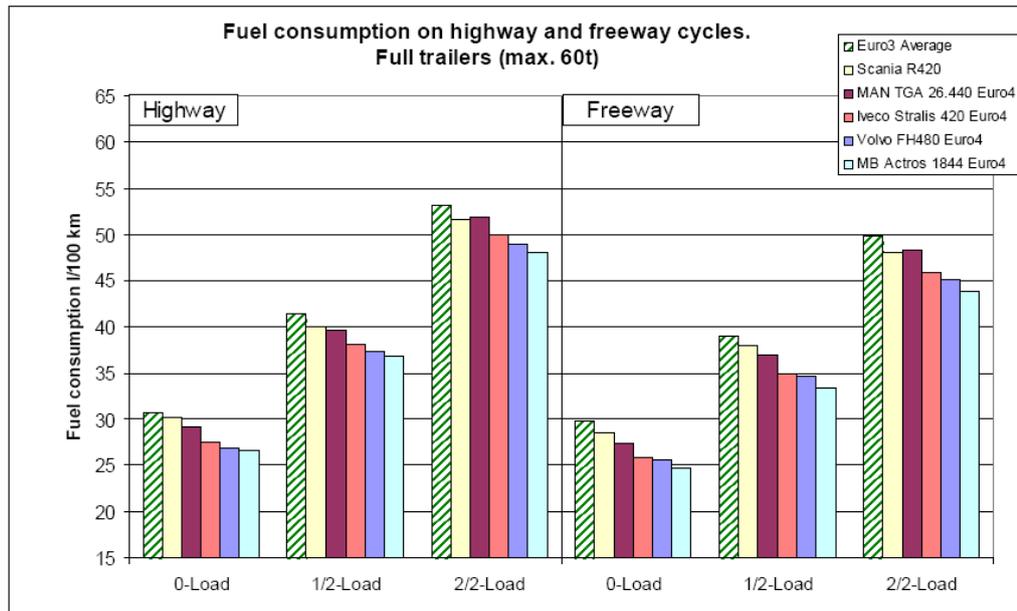
Figure 4: Influence of payload on fuel consumption for 60t LHVs (type approval measurements)
Source: [VTT, 2008]

If the problem is analysed in terms of fuel consumed per tonne transported (e.g. litre per tonne-km), the lower the tare weight and the higher the load weight, the lower the fuel consumption and emissions will be. In this case, the objective is therefore to minimise the tare weight and maximise the load weight, taking into account the engine size needed to power the vehicle at optimum efficiency. Since one LHV can provide up to half extra payload capacity compared to a conventional HDV[4], they can be more energy efficient.

Figure 5 shows the overall trend decrease in specific energy consumption with respect to the total vehicle weight. It is reported that a 60t LHV would reduce the specific fuel consumption by around 15% compared to a standard 40t HDV. In the framework of a pilot study allowing LHVs to be used by four companies in the Netherlands (2000-2003), it was concluded that fully-loaded LHVs can lead to a decrease in fuel consumed per ton-km by up to 30% [Delft, 2000]. Note that the same type of conclusions can be obtained from a volume-based analysis.

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[4] Typically up to 50% greater loading capacity (e.g. from 25.5t to 38t) and up to 60% increase on a volume basis (e.g. from 100 m^3 to 160 m^3).
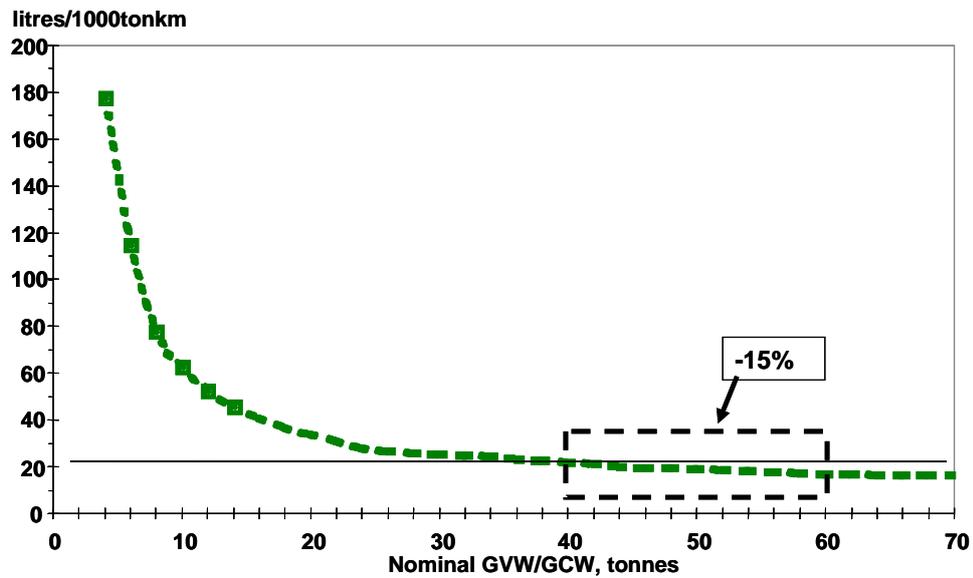
Figure 5: Specific fuel consumption vs. Gross Combination Weight (i.e. total vehicle weight)
Source: Swedish Road Administration [Hedberg, 2008]

A detailed analysis is however required to better estimate this difference. For this purpose, it would be relevant for instance to extend the results presented by Leonardi and Baumgartner [Leonardi and Baumgartner, 2004] to vehicle load class greater than 44t (i.e. 44-60t), as displayed in Figure 6.
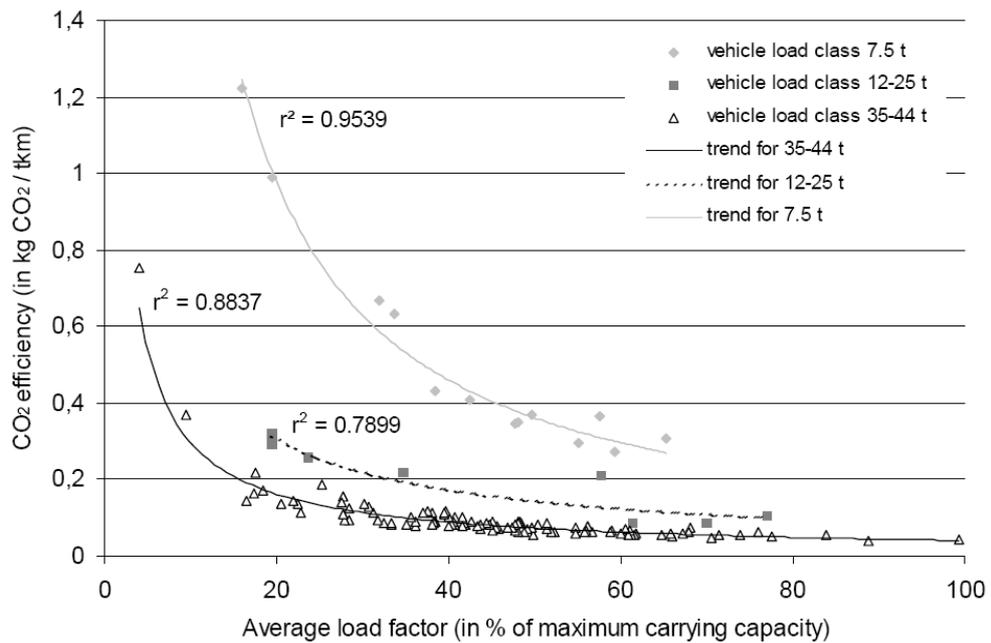
Figure 6: CO_2 efficiency in relation to load capacity utilisation and vehicle size class
Source: [Leonardi and Baumgartner, 2004]

Such a comparison implies however to know the loading rate of the LHV, whether it is fully or at least 'sufficiently' loaded. An interesting question then arises as to assess the payload rate from which a 60t LHV would be systematically more energy efficient, at vehicle level, than a fully-loaded 40t HDV. This will be discussed at the end of this chapter.

In literature, there are many studies focusing on the environmental performance of HDVs but only a few of them provide a detailed analysis of the effect of weight and size of trucks on fuel consumption and emissions. In the following, two examples of results are presented based on experimental and modelling-based studies.

Some experimental measurements were carried out by VTT [Nylund and Erkkila, 2005] comparing the energy efficiency of 42t semi-trailers to 60t trucks with full trailers on highway cycle. The results show the influence of load on energy consumption reduction with respect to the payload for both trucks (Figure 7). As reported by VTT, *"it shows clearly that fuel consumption and GHG emissions per ton-km drops significantly as the truck is loaded up, but the rate at which it drops declines as the load factor approaches a full legal load"*. It is however difficult to draw definitive conclusions from these measurements since 60t trucks are compared to 42t semi-trailers (and not 40t) and that the maximum LHVs payload capacity is not achieved[5]. Further measurements would then be required.
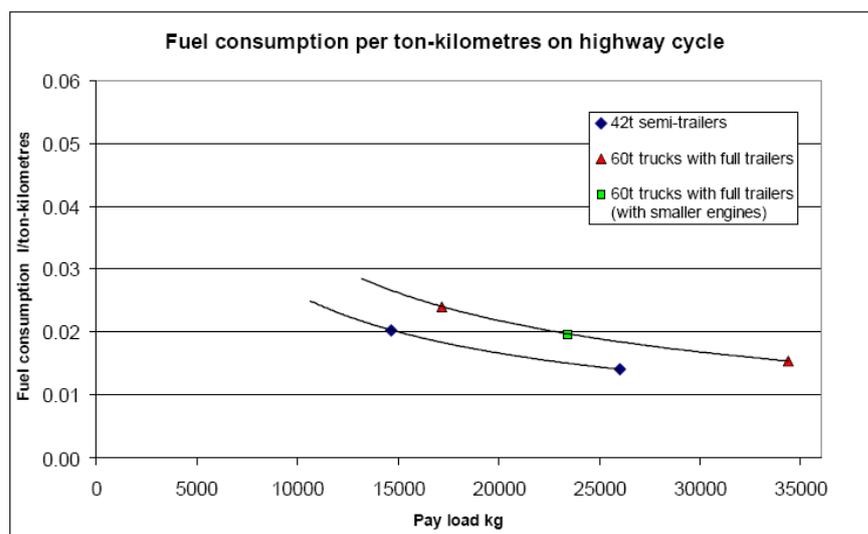
Figure 7: Influence of payload on specific fuel consumption
(based on chassis dynamometer measurements)
Source: [Nylund and Erkkila, 2005]

In 2008, the American Transportation Research Institute (ATRI) released an update of a previous study they carried out in 2004 on the benefits of changing truck size and weight with regard to fuel savings and emissions [ATRI, 2008]. Six vehicle combinations (i.e. tractor plus trailer(s)) were analysed in this study: two baseline vehicles and four so-called "Higher Productivity Vehicles" (HPVs) (see Figure 8). Their characteristics are summarized in Table 1 below:

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[5] Depending on the configuration, the maximum payload capacity is around 38-40t for LHVs, compared to around 25t for conventional semi-trailers (see e.g. [Aurell and Wadman, 2007]).

Configuration	Number of axles	Engine size (HP)	Trailer(s) length (m)	Tare Weight (tons)	GVW[6] (tons)
Baseline vehicles					
5-axle	5	400	16.15	14.5	36.3
DBL (Double)	5	400	8.53/8.53	16.1	36.3
Higher Productivity Vehicles					
6-axle	6	450/500	16.15	15.6	44
RMD (Rocky Mountain Double)	7	400/450/500	14.63/8.53	19.7	45.4 / 54.4
TRPL (Triple Trailer Combination)	7	400/450/500	8.53/8.53/8.53	21.5	45.4 / 54.4
TPD (Turnpike Double)	9	450/500/600	14.63/14.63	22.7	45.4 / 54.4 / 63.5

Table 1: Vehicle characteristics
Source: ATRI update report 2008 [ATRI, 2008]
Figures converted into EU units
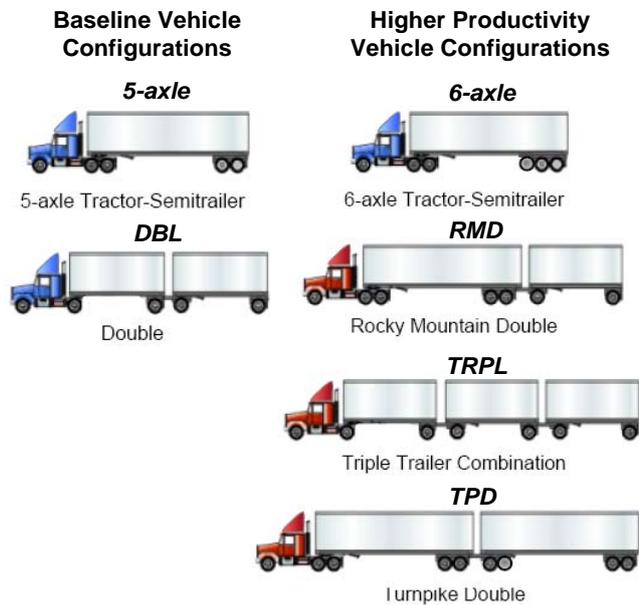
Figure 8: Vehicle configurations considered in the ATRI study [ATRI, 2008]

Although this study was based on US-specific type of trucks, some interesting results can be obtained from the weight-based and the volume-based analyses.

Weight-based analysis

Figure 9 below shows the specific fuel consumption related to the different configurations analysed in this study, over a generic route [ATRI, 2008]. Only the results obtained under the "weight-limited scenario" are presented hereafter.

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[6] Gross Vehicle Weight
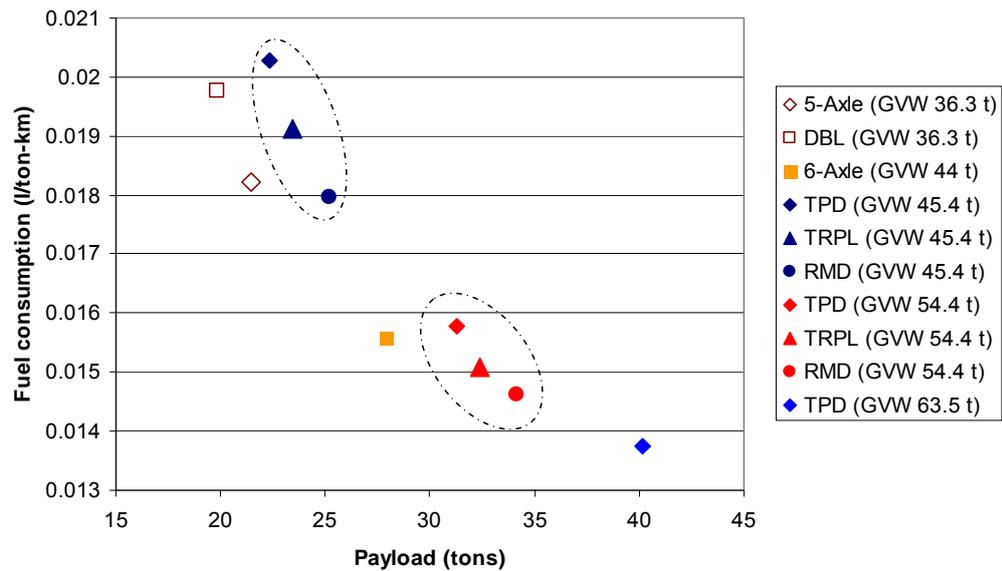
Figure 9: Specific fuel consumption vs. payload for the different vehicle configurations
Source: Own calculations based on [ATRI, 2008]

Two groups of trucks (in red and blue) can be highlighted from this chart. They are made of the TPD, TRPL and RMD vehicle configurations with a GVW of respectively 45.4 tons (in blue) and 54.4 tons (in red). In both cases, the TPD configuration presents the worst fuel consumption due to its higher tare weight and engine size. However, the TPD configuration becomes more energy efficient as the payload reaches its maximum capacity. One can conclude that:

- The first group (in blue) shows that there is almost no efficiency gains from using TPD and RMD configurations compared to the 5-axle (1% energy savings for RMD whereas TPD would consume 10% more). This is due to their higher tare weight (additional trailer(s) and number of axles, bigger engine size, etc.) combined with a low loading rate.

- The second group (in red) shows efficiency gains of respectively 25% and 15% for RMD and TPD compared to the baseline 5-axle.

Finally, the TPD configuration can reduce the specific fuel consumption by 33% compared to the 5-axle when fully loaded. As a rough estimate, one can assume that the TPD's specific fuel consumption starts becoming beneficial - compared to the 5-axle - only for loading rates greater than 26 tons approximately, i.e. around 64% of its loading capacity.

There is evidence that potential fuel consumption/CO_2 emissions reduction (in litre per ton-km) from longer combination vehicles will highly depend on the utilisation of their loading capacity. As shown in Figure 10, if we compare the TPD configuration to the 5-axle, one can see that the TPD tare weight is higher meaning that this handicap should be compensated by carrying a larger payload. As discussed before, the higher the load rate, the lower the specific fuel consumption will be.

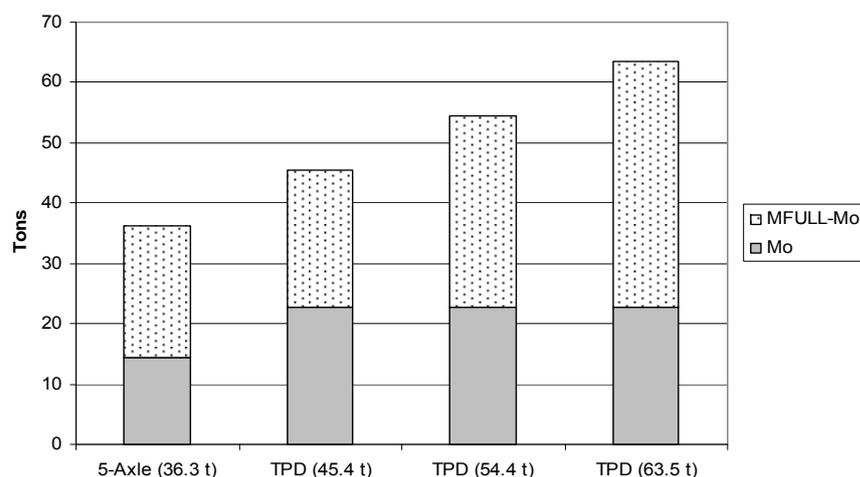**Figure 10: Differences in tare weight and payload between the TPD and the baseline 5-axle vehicle**

The ATRI study concluded that between 11% and 30% of fuel savings (in litre per ton-km) can be obtained from the use of LHVs compared to the baseline configurations. They reported that *"the vehicle's GVW and size of engine were the dominant factors in determining fuel economy with rolling resistance associated with the number of axles and vehicle configurations having less of an effect on fuel economy"* [ATRI, 2008].

Volume-based analysis

Important reduction in specific fuel consumption can also be achieved from LHVs when reasoning in terms of volume instead of weight capacity (see the "Cube-limited scenario"), ranging from 10% to 22%.

Discussion about a "minimum" payload for LHVs

As mentioned previously, 60t LHVs can carry up to 50% greater load compared to standard 40t HDVs (at vehicle level; weight-based consideration). With regard to the number of pallets (i.e. volume), this would mean that a fully-loaded LHV can carry up to 52 pallets compared to 33 pallets with a standard 40t HDV, which can lead to a 25% decrease in specific energy consumption (litre per pallet-km, see [UBA, 2007])[7]. Therefore, the question is to estimate the load factor beyond which the specific fuel consumption of LHVs starts being beneficial compared to fully-loaded standard HDVs.

According to the UBA study [UBA, 2007], a LHV should be loaded by at least 77% of its maximum loading capacity so that its specific fuel consumption (in this case expressed in litre per volume-km or litre per pallet-km) can be comparable to a conventional fully-loaded HDV[8]. Of course, if we compare the specific fuel consumption of both vehicles at their maximum load, LHVs will be more energy efficient than standard HDVs, typically around 15-30% more. However, it should be noted that this range is a maximum potential reduction without considering the impacts of the introduction of LHVs on the European HDV fleet. Indeed, this potential fuel reduction can be obtained at vehicle level, but the assessment of the environmental impacts of LHVs at EU level is subject to economical effects that might offset (or not) this advantage. Even if as a first order analysis one can expect significant environmental improvements from the introduction of LHVs (two LHVs could replace three standard

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[7] Lower emissions of air pollutants are also expected.
[8] UBA [UBA, 2007] also specified that the German average carrying capacity was around 64% in 2005, meaning that the average payload of LHVs would need to be higher than this 64% to be environmentally advantageous.

HDVs i.e. the number of vehicles would be theoretically reduced by one third), the situation is much more complex due to second order effects that need to be carefully addressed (e.g. the road freight demand is expected to increase due to cost reductions, which - besides others - makes road more competitive vis-à-vis other modes and thus contributes to the increase in road freight demand). These aspects have been analysed by recent studies (see e.g. [JRC, 2009], [ISI, 2009], [TML, 2008], [TRL, 2008]).

2.2 Drag resistances

At constant speed and on horizontal road, the power required to maintain this speed can be expressed by:

$$P = \eta P_{engine} = \frac{1}{2}\rho_a C_d A V^3 + mg C_r V \qquad \text{(Eq. 1)}$$

where:

$P(W)$ is the power needed to maintain a steady speed *(= Force*velocity)*

η is the efficiency of gear and rotating parts

ρ_a is the density of air (~1.2 *kg m^{-3}*)

C_d is the aerodynamic drag coefficient (number determined by the shape of the vehicle and its angle of attack) which can typically vary from 0.6 to greater than 1 for HDVs.

A is the frontal area (m^2); typically between 8 and 12 m^2 for EU trucks.

V is the vehicle speed (ms^{-1}) (note that we assume no wind speed otherwise the component of wind speed on the vehicle's moving direction must be added).

C_r is the tire rolling resistance coefficient. It depends on the type of tyre, its pressure, the road surface texture, but also on the speed. Its value is determined experimentally.

m is the mass of the vehicle (kg)

g is the gravitational acceleration (~ *9.81 ms^{-2}*)

The term $\frac{1}{2}\rho_a C_d A V^3$ is related to the aerodynamic drag while the quantity $mg C_r V$ is related to the rolling resistance (caused by the tire deformation). However, to be more precise, the climbing resistance (which can be positive or negative) should be added to the total drag force F_D. It is defined as $F_{CR} = mg \sin\alpha$ where α is the angle of inclination of the road grade. The total drag force (horizontal component) is then expressed by:

$$F_D = F_{AERO} + F_{RR} + F_{CR} = \frac{1}{2}\rho_a C_d A V^2 + mg C_r + mg \sin\alpha$$

In this case, the power required to maintain the speed would become:

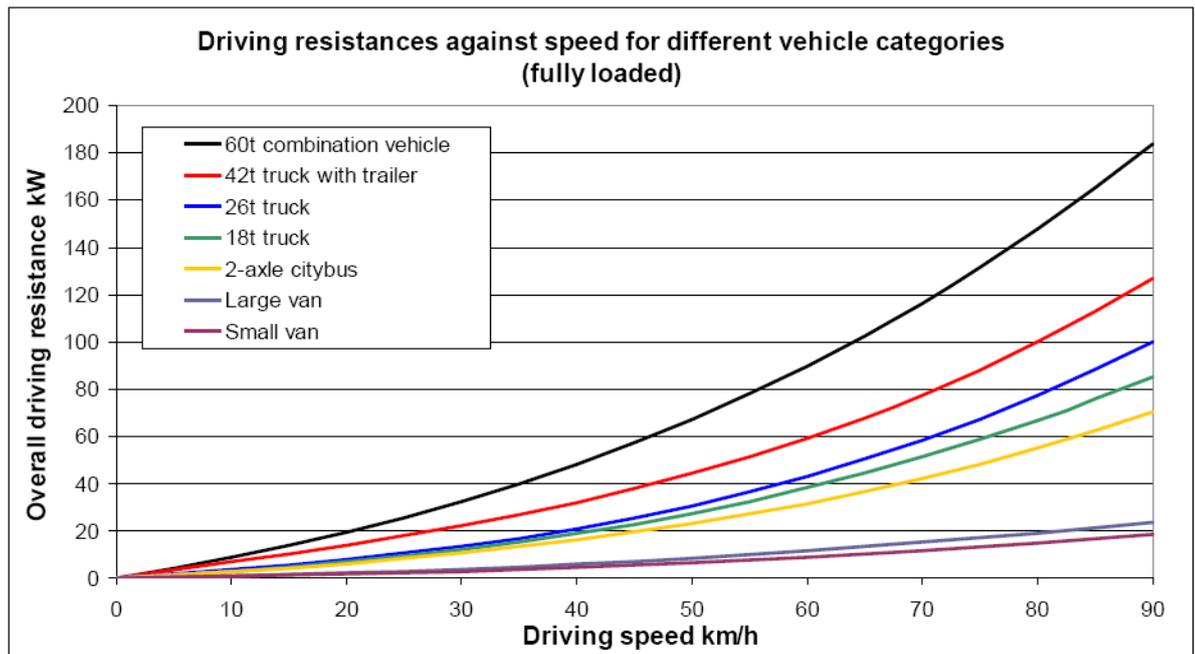$$P = \frac{1}{2}\rho_a C_d A V^3 + mg V (C_r + \sin\alpha)$$

Figure 11: Power needed to overcome the tractive resistance vs. speed
Source: [VTT, 2006]

The importance of both the aerodynamic and rolling resistances on the power requirements will therefore highly depend on the vehicle speed. Figure 11 shows the influence of speed on the overall driving resistance for different vehicle configurations. As expected, the 60t combination presents a much higher overall resistance than conventional trucks. Globally, it is estimated that at a speed above 70 km/h, the aerodynamic drag dominates the rolling resistance, while it is no longer the case at lower speeds where the rolling resistance accounts for a greater share of the power requirements. On highway, the aerodynamic drag can typically account for two thirds of the tractive load[9].

2.2.1 Aerodynamic resistance

Based on Equation 1, the power lost due to the aerodynamic drag is expressed by the quantity $\frac{1}{2}\rho_a C_d A V^3$ (horizontal road). If we assume that both standard HDVs and LHVs drive at the same speed, the aerodynamic drag coefficient C_d[10] will be the main physical parameter to take into account when comparing these vehicles. Broadly speaking, the aerodynamic drag is mainly caused by the difference in pressure (pressure drag) between the front and wake of the truck. The main source of aerodynamic drag stems from the turbulent air flow around the vehicle; the other sources originating from the friction of air passing over the body (e.g. axles, underbody) and from the airflow through the different components.

Figure 12 provides a very simplified view of the additional sources of aerodynamic resistance related to one type of LHV configuration. Compared to a standard semi-trailer which has typically one point of discontinuity, a modular combination vehicle will have two points of discontinuity i.e. one between the cabin and the semi-trailer and

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[9] It corresponds to the power that reached the wheels i.e. after being produced by the engine and passed through the transmission (not to be confused with the engine power).

[10] Aerodynamic engineers rather refer to the aerodynamic drag area (C_dA) which is the product of frontal area by the drag coefficient. This value is widely used as it enables comparisons to be made in terms of aerodynamic efficiency of different vehicles.

the other one between the semi-trailer and the additional trailer (see Figure 12). It means that further recirculation (turbulent air flow) and friction zones will be generated thus increasing the aerodynamic drag.
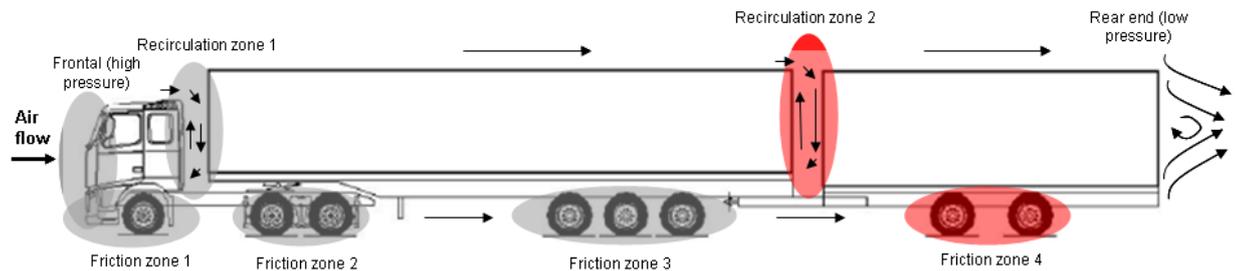
Figure 12: Illustration of additional drag sources for LHVs (e.g. tractor, semitrailer and centre-axle trailer)
(Own chart based on original picture from [Aurell and Wadman, 2007])
In grey: typical drag zones of standard HDVs; In red: additional drag zones

Unfortunately, to our knowledge, there are no reliable and accurate sources of data providing the aerodynamic drag coefficients of all European LHV configurations[11]. Therefore only an analytical approach can be carried out here based on basic fluid mechanics considerations (note that the drag coefficient is usually deduced from wind tunnel testing).

As a rough indication of its order of magnitude, the final report of the COST 346 project [COST 346, 2005] reported a range of drag coefficients for different HDV types. For articulated trucks and truck trailers, it was found that the drag coefficients typically range from 0.5 to 0.9 (Figure 13). In terms of drag area, truck trailers and articulated trucks with GVW of respectively 50t and 60t present an average drag area of around 5 m^2 compared to approximately 4.5 m^2 for standard 35-40t trucks [COST 346, 2005].
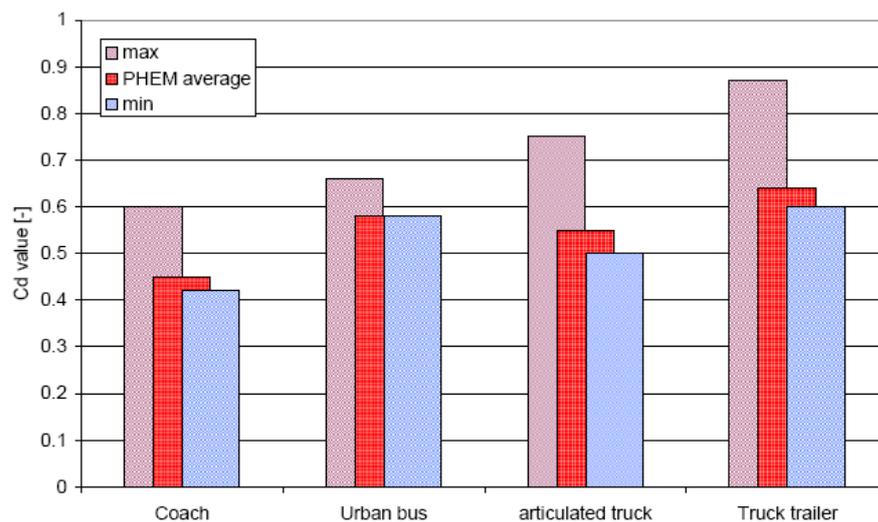
Figure 13: Range of aerodynamic drag coefficients of different HDVs
Source: [COST 346, 2005]
PHEM stands for "Passenger car and Heavy duty Emission Model"

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[11] e.g. Tractor+semitrailer+centre axle trailer; truck+dolly+semitrailer, etc.

Box 1: Potential technologies for reducing aerodynamic drag

There is evidence that LHVs will suffer from higher aerodynamic resistance compared to conventional HDVs. The question is therefore to know whether some enhancing technologies could be implemented on such vehicles in order to reduce their aerodynamic resistance and at what cost. Currently, the average drag coefficient of HDVs is around 0.6 (see Figure 13) which is the result of high improvements carried out by truck manufacturers during the last decades. However, even though significant reduction in drag coefficient might be technically achieved in the short to medium term, a steady evolution is more likely. It is recognised that a 10% decrease in C_d could lead to fuel savings of about 0.2 to 0.3 l/100 km depending on the driving cycle. According to Ogburn et al. [Ogburn et al., 2008] typical tractor-trailer's drag coefficient can be reduced from 0.6 to 0.45 thanks to the use of current "add-on" devices. There is a high potential to reduce fuel consumption and CO_2 emissions by implementing aerodynamic "add-on" devices on the tractor and/or the trailer(s). Cost-benefit assessment of such devices has been widely covered in literature (see e.g. [GPG, 2001]). Some examples are given hereafter:

For the tractor, aerodynamics can be improved by using fairings/deflectors (roof and side) or cab extenders (help reducing the gap between the tractor and the trailer). Overall, the potential savings from tractor aerodynamics is around 4-6% which is roughly equivalent to those expected from trailer aerodynamic improvements. From an optimistic point of view, fuel savings of 15-25% can be achieved for heavy trucks [EERE, 2004]. The TMA (Truck Manufacturer Association) reported that combined effect of all aerodynamic improvements (tractor and trailer) could result in a 23% reduction in aerodynamic drag[12]. Assuming that every 2% reduction in aerodynamic drag corresponds to a 1% improvement in fuel efficiency[12], this would save more than 10% of fuel. On average, a 4% fuel potential reduction can be achieved from aerodynamic improvements by considering the tractor only. As an example, Wood and Bauer [Wood and Bauer, 2003] estimated that the aerodynamic drag coefficient can be reduced by around 0.1 by implementing aerodynamic fairings on a conventional tractor-trailer combination[13].

For the trailer(s), aerodynamics can be improved by adding different type of devices such as belly fairings or side skirts. Usually, the four most common drag problems as defined by Ogburn et al. [Ogburn et al., 2008] concern the underbody (area beneath the trailer); the trailer base (area behind the back of the trailer); the trailer leading edge (area in front of the trailer that is not sheltered by the roof fairing) and the gap (area between the tractor and the trailer and also between each trailer). In the 'HDEnergy' project report [VTT, 2006], it was estimated that *"changing the type of trailer (from a 4- to 5 axle) and by adding an air deflector to the truck tractor, the fuel economy of a full-trailer vehicle driving at a speed of 80 km/h will improve by some 10%"*. It is shown in Figure 14.
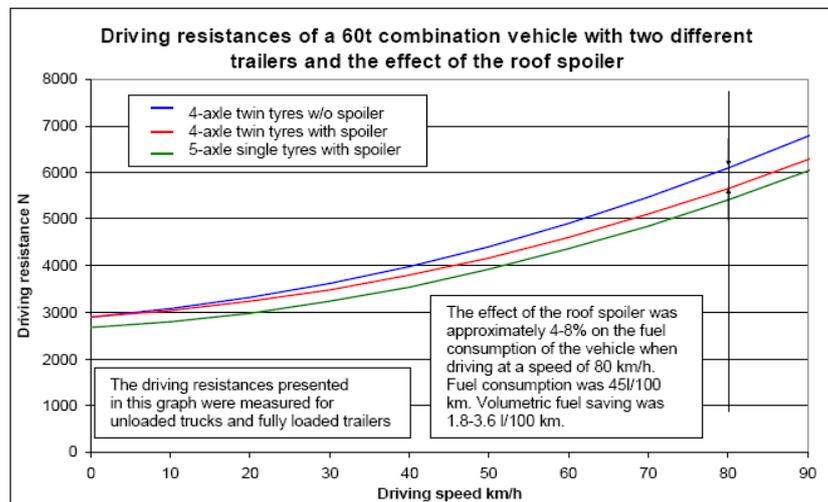
Figure 14: The air deflector's –and different trailer type's effect on the tractive resistance
Source: [VTT, 2006]

Additional costs associated with add-on aerodynamic devices can vary widely, depending on the number of elements and whether they are mounted on the tractor and/or trailer(s) (see Annex II). Even if most new long-haul trucks today are already equipped with aerodynamic devices, significant potential reduction in aerodynamic drag can still be achieved. This potential can be even more important for LHVs than for standard HDVs, in relative terms.

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[12] http://www.greencarcongress.com/2006/11/study_improveme.html
[13] Note also that if these aerodynamic devices are not well installed, this can lead to adverse effects increasing fuel consumption.

2.2.2 Rolling resistance

Contrary to aerodynamic improvements that mainly affect the truck energy efficiency through modifications of its shape (which is not quite exact since the implementation of aerodynamic devices will also influence weight and thus safety, but to a limited extent), reducing rolling resistance is more complex. Indeed, reducing the rolling resistance means either acting on the vehicle mass and/or on the tyres through the rolling resistance coefficient. There is therefore a trade-off to be achieved between energy efficiency, safety and road wear. This is illustrated in Figure 15.
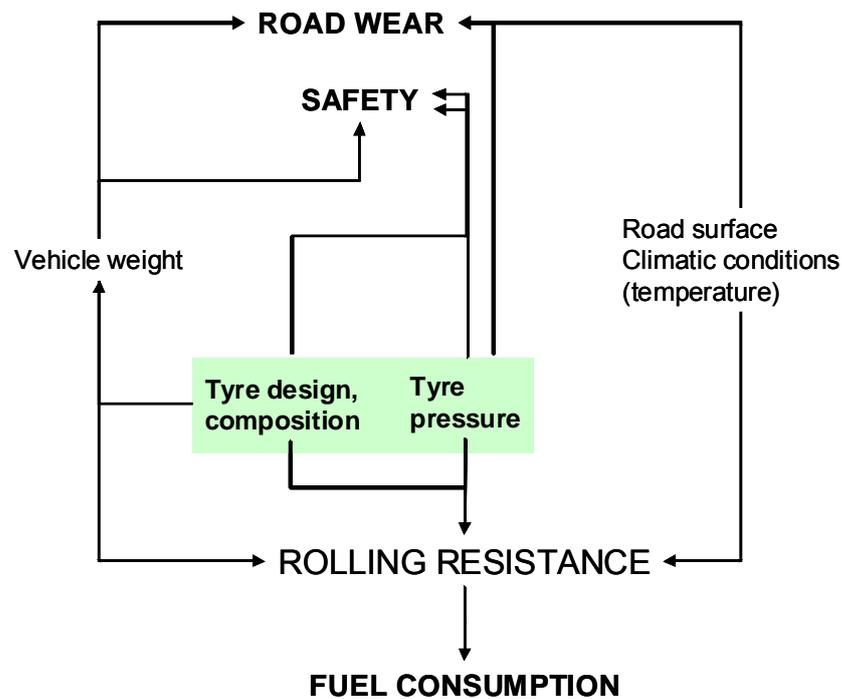
Figure 15: Schematic view of the effects of tyres on energy, safety and road wear (vehicle speed is not considered)

It is important to keep in mind that more energy efficient tyres will reduce the energy consumption but they can produce adverse effects on safety and pavement wear. Also, over inflated tyres can help reduce fuel consumption but at the expense of pavement wear. Trade-offs are then required with regard to the most important benefits/consequences the new tyres can provide. As for aerodynamics, there is very limited literature providing a comprehensive analysis of the rolling resistance for different LHV configurations (see e.g. [COST 346, 2005] giving rolling resistance coefficient for truck trailers and articulated trucks).

Box 2: Potential technologies for reducing rolling resistance

Significant reduction in rolling resistance can be obtained by controlling the tyre pressure and by using more energy efficient tyres. On average, it is generally assumed that a 10% reduction in rolling resistance leads to a 2-3% reduction in fuel consumption. Some well-known cost-efficient measures available on the market are briefly described hereafter:

- *Tyre Pressure Monitoring Systems (TPMS):* As for passenger cars, the use of TPMS for trucks is a very cost-efficient way to reduce fuel consumption/CO_2 emissions while improving safety. It is estimated that in the EU, the tyres in service are under-inflated by 0.2 to 0.4 bars on average for passenger cars and 0.5 bars for trucks [IEA, 2007]. According to Continental[14], *"more than 75% of the trucks on the roads in the European Union have tires which are, on the average, 12% underinflated, thus increasing costs by more than €4 billion each year in Europe"*. As an example, results from a study on tyre pressures in Germany are presented in Figure 16. The effects of tyre pressure in vehicle safety and environment have been addressed by recent literature (see e.g. [Paine et al., 2007]).

Figure 16: Tyre pressure on truck tractor units in Germany (from Continental)
Source: [Stock, 2005]

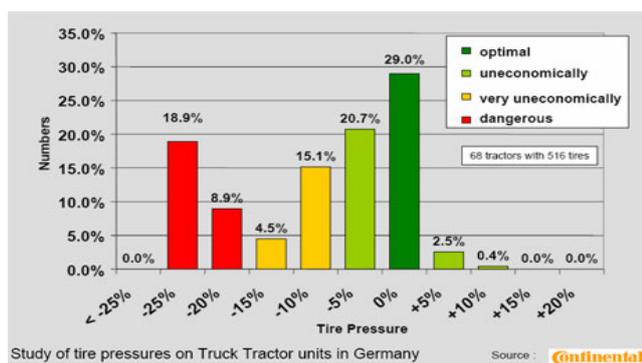There also exist several types of automatic tyre inflation systems which can be installed on long-haul trucks on drives and trailer tyres. However, this type of devices is quite complex (and relatively costly) and its market penetration is still very limited. Note that the recent proposed EU regulation (see chapter 4) only mandates TPMS for passenger cars and does not cover HDVs.

- *Tyres with Lower Rolling Resistance (LRRT):* The incorporation of silica in the tyre's tread composition can result in a reduction of rolling resistance up to 20%, which could save up to 5% of fuel. Globally, the use of LRR tyres can decrease fuel consumption by approximately 2-5%, depending on driving conditions. Such tyres have been available on the market for many years and proposed by several tyre manufacturers. It is for instance estimated that if all tyres on all axles are changed from conventional ones, this would reduce the fuel consumption by about 6 to 7% in long haulage [Larsson, 2008]. Moreover, LRR tyres do not present adverse effects on safety (wet braking can be even improved) and can extend the tyre's lifetime.

- *Wide-base tyres:* Wide-base tyres or "Super singles" can be used to replace dual tyres on drive axles. Wide-base tyres are lighter, have lower rolling resistance, are more "stable" and offer lower maintenance and repair costs. Depending on the tyre manufacturer[15], they can reduce fuel consumption by 2-5% compared to dual tyres [EPA, 2004]. It is worth mentioning that the use of wide-base tyres requires the truck to be equipped with TPMS and ESC systems (see chapter 4). Moreover, non-negligible weight savings can be obtained if they are mounted on aluminium rims (around 90 kg of weight savings per axle). Wide-base tyres will help to improve the truck energy efficiency but they can lead to adverse effects to the road wear. This is mainly due to their higher pressure and smaller contact area (see e.g. [Al-Qadi, 2007], [COST 334, 2001]). Note that the choice of using or not wide-base tyres also depends on the axle loads and configurations (e.g. tandem/tridem). There is a wide number of research studies carried out worldwide dealing with the effects of wide-base tyres on pavement wear, environment and safety. Results from the COST334 project [COST 334, 2001] and from the "International Workshop on the Use of Wide-Base Tires" organised by the Federal Highway Research Administration (see e.g. [FHWA, 2007]) are very relevant sources of information in this area. Contrary to the U.S., wide-base tyres have been widely used in Europe and their market penetration is expected to increase in the short to medium term.

2.3 Other energy-related issues with potential relevance to LHVs

Specific driver training

It is well known that "Eco-Driving" is a very cost-efficient way to improve fuel economy. The goal of the training is clearly to improve driver awareness and practices regarding environmental concerns. Typical techniques learnt are e.g. progressive shifting, speed control, idle reduction, optimal gearing, smoother braking and acceleration, how to fix aerodynamic devices correctly, checking the condition of tyres, etc. It is expected that more than 5% of fuel economy can be achieved after effective training programmes. Even though several studies show higher potential fuel savings (up to 20%), the EPA SmartWay reported a 4% potential reduction [EPA, 2004]. As mentioned by [FM, 2008], important benefits are expected from driver training at different levels such as for transport operators (reduced costs), HDV drivers (reduced stress) and for organisations and the environment.

Special skills for LHV drivers would be required through intensive specific trainings. Moreover, the use of ITS technologies could help monitor and bring solutions for optimising the energy efficiency (see chapter 4).

Minimum engine power requirements?

Regarding LHVs, the key question is to know whether the engine is sufficiently powerful to correctly propel the vehicle over all types of EU road profiles (at least on the roads where LHVs would be allowed to travel). Insufficient engine power would increase the energy consumption (and air emissions) when travelling uphill, which may also lead to negative impacts on the social acceptability of LHVs. To cope with this problem, it could be envisaged that all LHVs on the road should be equipped with a minimum engine power[16].

Using the maximum fuel tank capacity?

The maximum fuel tank capacity of LHVs is basically the same as for standard HDVs (they can carry up to 1000 litres of diesel, or even more). However, in order to limit their refuelling frequency, thus generating undesirable effects (e.g. traffic congestion, idling), it seems necessary for such vehicles to systematically use fuel tank with the maximum allowed capacity.

Finally, many other technical and non-technical potential fuel reduction improvements can be applied to all type of HDVs (not only to LHVs). They are related for instance to the engine efficiency (e.g. new HCCI[17] diesel technology, advanced injectors), the transmission (e.g. automatic gearboxes[18], new lubricants), hybrid technologies (even though it might be not very relevant for long haul trucks since they most often drive on highways), the use of alternative fuels, better freight logistics management, infrastructure optimisation, etc. The study carried out by Faber Maunsell in 2008 [FM, 2008] for the European Commission provides an in-depth analysis of technical and non-

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[16] Engine power of at least 500ch might be a minimum requirement for LHVs. It is also worth mentioning that more powerful engines do not necessarily mean higher fuel consumption and air emissions.
[17] Homogeneous Charge Compression Ignition
[18] Note that most of the new trucks equipped with automatic gearboxes are also equipped with ESC systems (see chapter 4). The retail price is around €3500 (including the ESC system of about €2000) and can significantly reduce fuel consumption and improve safety.

technical potentials for reducing GHG emissions of HDVs. An overview of reduction potentials and additional costs of different technologies is given in Annex II.

2.4 Key messages

- The additional weight from LHVs (i.e. from increased tare weight and payload) is the most relevant factor regarding the energy efficiency. Minimising the tare weight and maximising the load rate is the central objective.

- At vehicle level, the specific energy consumption of a LHV, when expressed in litre per ton-km or in litre per pallet-km is generally lower than for a standard HDV, depending on its payload. Based on literature, it can be estimated that the payload of LHVs should be roughly above 65-70% of its maximum carrying capacity to be more energy efficient than a fully-loaded conventional HDV. A close monitoring of the payload of LHVs seems to be necessary.

- Significant fuel saving potentials can be achieved through technological and non-technological improvements, with in some cases a higher relative potential associated with LHVs.

Aerodynamics: as the vehicle mass does not influence the aerodynamic resistance, LHVs may benefit from higher relative reduction potentials compared to standard HDVs. Indeed, the higher the aerodynamic drag coefficient, the higher the potential reduction through the implementation of add-on aerodynamic devices (mounted on both the tractor and trailers) will be. No impacts on safety and pavement wear are expected. Unfortunately, to our knowledge, there are no EU research studies systematically providing or comparing values of aerodynamic drag areas (AC_d) for all types of LHV configurations.

Rolling resistance: it is more complex due to the influence of the vehicle mass and road surface properties. More energy efficient tyres (e.g. wide-base tyres and LRR tyres) will reduce fuel consumption but can lead to adverse effects on safety and road wear (and also to aerodynamic drag but to a lesser extent). Due to their higher number of wheels, there is no doubt that fitting Tyre Pressure Monitoring Systems (TPMS) to LHVs would be necessary.

3   INFRASTRUCTURE

This chapter focuses on the impacts of LHVs on road wear and bridges. Further (non-negligible) impacts on infrastructure related to parking space, roundabouts (e.g. by examining the swept path of LHVs), road crossing and tunnels are not analysed in the present study.

3.1   Road wear

The interaction between heavy vehicles and road pavement is far from being trivial due to the large number of variables involved related to the vehicle characteristics, the pavement type and the environment conditions. As reported by Dodoo and Thorpe [Dodoo and Thorpe, 2005] it is important to keep in mind that the damaging effects of heavy vehicles will vary over time and space. Key parameters to be taken into consideration are (see Figure 17):

- Axles: load and configuration (e.g. number, spacing, single, tandem, tridem)
- Tyres: type and configuration (e.g. single, dual, single wide-base). Tyre pressure is also an important factor.
- Suspension type (e.g. air, steel)
- Type of road surface (e.g. flexible, rigid, semi-rigid)
- Climatic conditions (e.g. moisture, temperature)
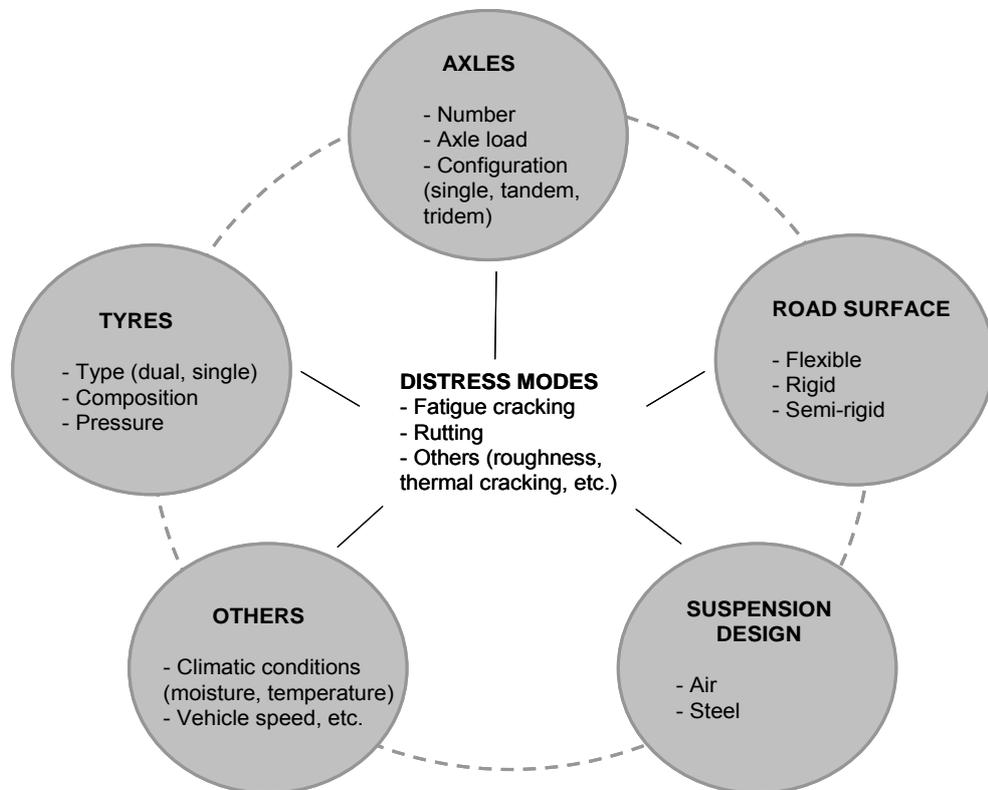- Vehicle speed (static vs. dynamic load)

Figure 17: Tentative representation of driving factors affecting road wear

Therefore, the "aggressiveness" of a load not only depends on its configuration (single axle, tandem, tridem, single or twin wheel) and its intensity, but also on the pavement

structure, the tyres, the type of suspension, climatic conditions, etc. The number of repetitions of axle loads combined with all these vehicle and road surface characteristics-related parameters will damage, at different level, the road pavement by increasing e.g. fatigue cracking, rutting and roughness. The most important factors being the dynamic axle load and the road surface properties [Dodoo and Thorpe, 2005].

With so many parameters, evaluating the pavement wear caused by different types of LHVs (and HDVs in general) is therefore complex and challenging and will also affect other areas. As an example, the distance between individual axles within a tridem-axle group can affect both the pavement wear and bridges. Extending the length between axles would increase the pavement wear (e.g. fatigue) but also lower the stress on bridges due to a better longitudinal distribution of the weight. On the other hand, reducing the space would reduce the pavement wear but at the expense of the stress on bridges (higher load concentration). A trade-off (i.e. an optimum inter-axle spacing) is therefore to be achieved[19].

Depending on the variables taken into consideration and whether the analysis is 'static' or 'dynamic', several models have been elaborated to assess the damages of HDVs on pavement, from the simplest to the more elaborated ones. It is out of the scope of this chapter to go into details on the interaction between heavy vehicles and pavement (see e.g. [COST 334, 2001] for an in-depth analysis). Some general conclusions based on relevant literature are briefly presented below.

Most often, the concept of an Equivalent Single-Axle Load (ESAL) is used by engineers to assess the effects of heavy vehicles on pavements. In the 1960s, The American Association of State Highway Officials (AASHO) undertook research to evaluate ESAL values for different axle configurations (single, tandem, tridem), at different weights and on different types of pavements. It resulted that ESAL values varied approximately as the fourth power of static axle load. In other words, the effect of a 11.6t single axle compared to a reference 10t would be roughly $(11.6/10)^4 = 1.81$ i.e. around 80% greater.

This so-called "fourth power law" is the most widely formula used to get a rough estimate of the impacts of different axle loads repetition on the road wear. The number N of ESALs can be expressed as (see e.g. [Aurell and Wadman, 2007] [COST 334, 2001]):

$$N = \sum_{i=1}^{n} \left(\frac{W_i}{W_{REF}} \right)^{\alpha} \qquad \text{(Eq. 2)}$$

where:

W_i is the load of axle i (tons)
W_{REF} is the reference axle load in tons (e.g. $W_{REF} = 10\,tons$ is often used as reference)
n is the number of axles
α is a controversial value which is commonly fixed at 4 (in this case road wear is dependant on the 4th power of the axle load). But the fourth power is only an

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[19] This is e.g. discussed in the "Comprehensive truck size and weight study" from the U.S. Department of Transportation, available at: http://www.fhwa.dot.gov/reports/tswstudy/tswfinal.htm

approximation which can vary significantly depending on the distress mode considered e.g. fatigue cracking or rutting. This has been widely discussed in literature.

The Swedish Road Administration (see e.g. [NVF, 2008]) uses an alternative formulation of Equation 2 taking into account an effect reduction factor for single axle or group of axles (in this case the ESAL values are not obtained by summing the contributions of all the individual axles). It is given by:

$$N_{10} = \sum_{i=1}^{n} \left(\frac{W_i}{10}\right)^4 * k_i \qquad \text{(Eq. 3)}$$

where:

n is the number of axles (or axles group)
W_i is the weight of axle (or axle group) for axle (group) i
$k = 1$ for single axle
$k = \left(\dfrac{10}{18}\right)^4 = 0.0952$ for tandem axles
$k = \left(\dfrac{10}{24}\right)^4 = 0.0302$ for tridem axles

The Danish Road Directorate uses a more elaborated model (but still an alternative of the fourth power law) taking into account axle configuration, tyre configuration and suspension design-related factors, and differentiated between road surface types. The model is described in detail in a recent report from the Nordic Road Association [NVF, 2008].

As an example, let us calculate the ESAL values from Equations 2 and 3 for two types of vehicles: a typical tractor-semitrailer combination (GCW: 40 tons and max. payload: 25 tons) and a modular vehicle combination made of a tractor, semitrailer and centre-axle trailer (GCW: 60 tons and max. payload: 40 tons). These examples are taken from [Aurell and Wadman, 2007]. In the first case, the pavement wear N_{10} is simply given by:
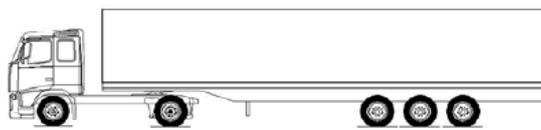
6,9 t   11,6 t   21,5 t

$$N_{10} = \left(\frac{6.9}{10}\right)^4 + \left(\frac{11.6}{10}\right)^4 + 3 * \left(\frac{21.5/3}{10}\right)^4 = 2.8 \text{ (from Eq. 2)}$$

$$N_{10} = \left(\frac{6.9}{10}\right)^4 + \left(\frac{11.6}{10}\right)^4 + 0.0302 * \left(\frac{21.5}{10}\right)^4 = 2.7 \text{ (from Eq. 3)}$$

For the modular vehicle combination, it becomes:

7,0 t   11,6 t   20.9 t   20,0 t

$$N_{10} = \left(\frac{7}{10}\right)^4 + 2*\left(\frac{11.6/2}{10}\right)^4 + 3*\left(\frac{20.9/3}{10}\right)^4 + 2*\left(\frac{20/2}{10}\right)^4 = 3.2 \text{ (from Eq. 2)}$$

$$N_{10} = \left(\frac{7}{10}\right)^4 + 0.0952*\left(\frac{11.6}{10}\right)^4 + 0.0302*\left(\frac{20.9}{10}\right)^4 + 0.0952*\left(\frac{20}{10}\right)^4 = 2.5 \text{ (from Eq. 3)}$$

(note that the wear caused by a tandem/tridem is generally greater than twice/three times the damage of a single axle. There are several other relationships, more or less complex, that take into consideration these aspects).
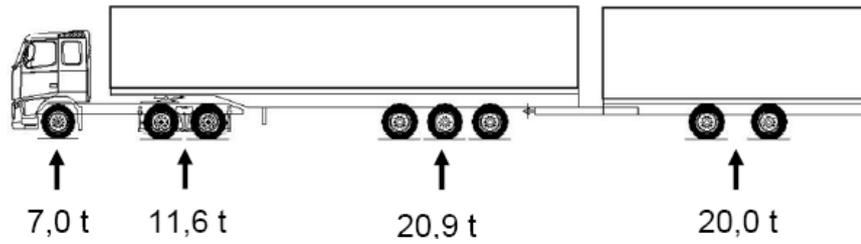
Even if the second configuration can present higher pavement wear than for the conventional tractor-semitrailer (if derived from Equation 2), it is no longer the case when these numbers are normalised with the maximum vehicle weight i.e. analysing in terms of pavement wear per tons of goods transported. In this case, some modular combinations can generate less road damage than standard 40t HDVs, since the load is more 'spread out' across the (higher number) of axles[20].

Based on this principle, Aurell and Wadman [Aurell and Wadman, 2007] made a comparison of number of ESALs (normalised with GCW) for current and prospective modular vehicle combinations (with total length greater than 25.25 m). They led to the conclusion that road wear from such vehicles is typically less than with current EU vehicle combinations. Further studies (see e.g. [Akerman and Jonsson, 2007], [Ogburn et al., 2008]) also reported less pavement wear from LHVs when expressed in ESAL per tons.

It should be kept in mind that the N_{10} per tonnes calculated are normalised with the GCW meaning that the results can be very different if the modular vehicle combination is not fully-loaded (for instance, it was estimated that the N_{10} per tonnes of a fully-loaded tractor semi-trailer is similar to the one of a modular combination loaded at 63%). As for the energy consumption (see chapter 2), the loading rate is of high importance.

The fourth power law derived from the AASHO tests presents however some limitations and several studies have raised concerns about the validity of this model for conditions which are not exactly the same as in the AASHO road test. It is important to point out that AASHO road tests were purely empirical and did not take into account the physical properties of the pavement. As underlined in the OECD-DIVINE project [DIVINE, 1998a,b] and also mentioned in the report from the Nordic Road Association [NVF, 2008]: *"For the same reasons that empirical design procedures should not be used beyond the range of data from which the model was developed, the use of the "fourth power law" may not be appropriate in all situations unless the environment, traffic, pavement type and pavement construction methods are the same as, or very similar to, those in the AASHO Road Test. In addition, vehicle damage factors derived from the AASHO Road Test may not give an indication of long term pavement performance which depends on a range of other factors"*

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[20] The maximum load per axle (single, tandem or tridem) is limited (see Annex 1 of Directive 96/53/EC) meaning that the higher the gross vehicle weight, the higher the number of axles.

In recent literature, the TRL study [TRL, 2008] calculated the impact of eight vehicle configurations on road wear for a typical lading pattern, based on the fourth power law. No conclusions about the impacts of LHVs on road wear compared to conventional HDVs can be drawn from this analysis. Depending on the LHV configuration, the relative wear factor per 100 tonnes of goods transported was found to be either lower (as in the case of the 11 axles 82t LHV) or higher than for the base vehicle (single-deck, 44t, 6 axles).

The TML study [TML, 2008] compared the aggressiveness of several vehicle combinations (a 40t tractor semi-trailer is taken as reference) using a more sophisticated pavement model. The results showed that the aggressiveness per tonne of goods transported can be greater or lower than the reference case, depending on the load repartition and the type of pavement (flexible, bituminous, etc.). It was observed that the aggressiveness of LHVs with 50t weight limit was around half of the one of the reference. On the other hand, two LHVs with 60t were found to be twice as aggressive as the reference.

The Bast study [Bast, 2006] carried out laboratory measurement to evaluate the impacts of LHVs with regard to rut formation and fatigue cracking. In the first case, they concluded that *"tractor-trailer combinations with their temporally dense axle sequence do not appear to be the cause for an increase in damage of the asphalt surfaces. If we additionally take into consideration that the number of axles necessary for transporting a freight unit of one tonne increases when using tractor-trailer combinations and thus the axle loads decrease, then the problem of an increased rut formation through the high frequency of axle overruns of these vehicles does not occur."* while in the second case *"fully as well as partially loaded tractor-trailer combinations lead to a reduction in road stress and thus to less damages on the road itself as far as weight is concerned, than in the case of the vehicle types commonly used nowadays."*

The VDA/FAT project (see e.g. [Pflug, 2008]) investigated the impacts of several truck-trailer combinations (EuroCombi "Volume" and EuroCombi "Weight") on road surface. It was found that EuroCombis cause less road damage compared with the standard 40t combinations (30% reduction in road surface load i.e. road surface fatigue, grooving).

The CRR study [CRR, 2007a][21] analysed the impact of four types of LHVs on road infrastructure. The model used for evaluating the aggressiveness K of the traffic is based on the following equation:

$$K = n\alpha \sum_i f_i \left(\frac{P_i}{P} \right)^{\gamma}$$

where:

F_i is the frequency of the load P_i within the load spectrum
n is the number of axles per vehicle
α is fixed at 0.143 for flexible road and 1 for the other road types

The results showed that in most of the cases the impacts of LHVs on the road surface are lower than for a standard tractor-semitrailer (5 axles). This study enables to underline the great influence of road surface type on the aggressiveness.

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[21] See also [CRR, 2007b] for a more thorough analysis.

Road surface	Relative impact (compared to reference S_{23})			
	CDS	TSR_{23}	TSR_{33}	CRR
Flexible	0.96	1.24	0.79	1.26
Semi-rigid	0.09	1.00	0.0003	0.09
Rigid	0.49	1.02	0.06	0.59

Table 2: Aggressiveness of different LHVs configuration on three road surfaces
Source: Centre de recherche routières [CRR, 2007a]

TSR_{33}: tractor (3 axles) + semi-trailer (3 axles) + trailer (2 axles)
TSR_{23}: tractor (2 axles) + semi-trailer (3 axles) + trailer (2 axles)
CDS: truck (3 axles) + dolly (2axles) + semi-trailer (3 axles)
CRR: truck (3 axles) + 2 trailers (2 axles each)
S_{23}: reference truck i.e. tractor (2 axles) + trailer (3 axles)

Box 3: Reducing the dynamic load – The importance of suspension design

As clearly shown from the outcomes of the OECD-DIVINE project[22] (see e.g. the technical and policy reports [DIVINE, 1998a] [DIVINE, 1998b]), the type of suspension (e.g. air or steel) is a critical factor for assessing the effect of heavy vehicles on pavement. The dynamic load, which can be either higher or lower than the static load, is directly related to the type of suspension the vehicle is equipped with, and has generally a greater effect on pavement wear than tyres.

It was found that air suspensions can increase pavement life by 15% for thinner pavements to 60% for thicker pavements, leading to a significant decrease in road maintenance costs. The use of air suspension could reduce dynamic loads by about 10-12% and therefore lead to important reduction in pavement damage and associated costs. Globally, air suspensions were considered to be by far more "road friendly" than steel suspensions.

3.2 Bridges

As underlined in the TML report [TML, 2008], the impact of LHVs on bridges is most often analysed at Member State level and cannot be extrapolated to the rest of the EU. Due to the heterogeneity of bridge conditions and related policy regulations across the EU, such an evaluation would be indeed very challenging. Most of the conclusions available results from country-specific analyses. They can lead to negative (see e.g. [TRL, 2008] for the UK, [Bast, 2006] for Germany) or rather positive findings (see e.g. [CRR, 2007] for Belgium). The TML study [TML, 2008] provided a relevant analysis along with an interesting literature review in this area. The impacts of different LHVs configuration on extreme loads and fatigue of bridges (also differentiated between lengths) were assessed. The key parameters to be taken into account are:

- For the vehicle: number of axles, axle spacing, axle loads, total vehicle weight, speed.
- For the bridge: structure, bridge length, age, etc.

It is very difficult to draw any conclusions about the impacts of LHVs on bridges compared with standard 40t HDVs. In this case, the distance between axles is at least as important as axle loads (the longitudinal distribution of load is key factor). In theory, a longer truck associated with wider axle spacing would result in less concentrated loads thus reducing the stress on bridges.

On the one hand, LHVs can present a better longitudinal mass repartition that can be seen as positive, but on the other hand they will probably reduce the bridge lifetime and

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[22] The OECD-DIVINE project is a reference research study about the interaction between heavy vehicles and the infrastructure. This project provided scientific evidence of the effects of HDVs and their suspension systems on pavements and bridges.

would require the implementation of specific and costly adaptation measures[23]. The TML study [TML, 2008] mentioned different countermeasures that could be implemented for reducing the impact of LHVs on bridges. There are for instance minimal spacing between two LHVs (e.g. ramp metering), no overtaking measures or the use of on-board load measuring systems (WIMs).

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[23] Adaptation would be required to the road infrastructure in general including bridges, roundabouts, tunnels, parking spaces, etc. Overall, lack of experience and data does not allow for a general evaluation of the additional impact of LHVs on the road infrastructure. For this, further analyses would be needed.

4 SAFETY AND ITS TECHNOLOGIES: AN OVERVIEW

Firstly, the increase of weight from LHVs means greater kinetic energy and thus higher destructive force in case of accidents compared to standard 40t HDVs. Secondly, the extended length of LHVs may lead to overtaking (see e.g. [Hanley and Forkenbrock, 2005]) and stability problems. This is of course true at vehicle level, without considering global effects of the introduction of LHVs on the road freight demand (the probability of accident increasing with the number of vehicle-km, the key question is thus to assess whether introducing LHVs would increase or decrease the vehicle-km travelled).

The objective of this chapter is not to assess/review the impact of LHVs with respect to the number of accidents[24] and their related severity (see e.g. [Forkenbrock and Hanley, 2003]), but rather to focus on some enhancing safety technologies that could be of high relevance to LHVs. Braking, stability and visibility enhancements are key areas where new technologies can help significantly reduce the risks of accident[25].

4.1 Safety technologies under EU policy regulation

In 2008, a European Commission proposal for an EU Regulation on vehicle general safety was presented [EC, 2008a]. Among others, the objective of this proposal is to improve the safety of heavy vehicles by requiring the mandatory fitting of some advanced safety technologies. Three options are taken into consideration: the Electronic Stability Control systems (ESC), the Lane Departure Warning Systems (LDWS) and the Advanced Emergency Braking Systems (AEBS). The safety impact of Tyre Pressure Monitoring System (TPMS) is also covered by the proposal but only for passenger cars.

According to the EC proposal, it is foreseen that Advanced Emergency Braking Systems and Lane Departure Warning Systems will be mandatory for all new types of heavy-duty vehicles that are type-approved after October 2013 and for all existing types (new registrations) after October 2015[26]. ESC systems will be mandatory to all vehicles first type-approved after October 2012, and for all existing types from October 2014.

Safety performance and cost-benefit analysis of these systems have been deeply analysed under the research works carried out for DG ENT[27] (see e.g. the TRL specific studies on LDW and LCA systems [Visvikis et al., 2008] and also on Automated Emergency Brake Systems [Grover et al., 2008]) and for DG TREN [COWI, 2006] whose the findings have been used in the impact assessment study [EC, 2008b]. A brief definition[28] of these technologies is given hereafter.

The **Electronic Stability Control (ESC)** system automatically acts on the braking or power systems of a vehicle to assist the driver in maintaining the control of the vehicle in a critical situation (caused e.g. by poor road conditions or excessive speed during cornering) thus reducing the likelihood of accidents involving skidding and/or

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[24] It is difficult to draw any conclusions to this respect. For instance, "Finland has basically concluded that the risk of heavy vehicles being involved in accidents is proportional to the mileage driven and not to the size of the vehicle" [CEDR, 2007]. Note also that the safety risks associated with LHVs in tunnels (greater fire loads) need to be carefully addressed.

[25] Reducing the maximum authorised speed for LHVs can be a solution but it would slow down the traffic flow.

[26] See the "Car Safety Package" proposal at: http://ec.europa.eu/enterprise/automotive/safety/new_package.htm

[27] See 2005 study projects list "Technical assistance and economic analysis in the field of legislation pertinent to issue of automotive safety" available at: http://ec.europa.eu/enterprise/automotive/projects/index.htm

[28] Partly derived from the EC website.

overturning. ESC usually acts by sensing wheel slip in individual wheels and reducing power or applying braking to one or more wheels to regain stability.

The EC impact assessment study [EC, 2008b] reported that ESC can reduce accidents by more than 20% in normal conditions and more than 30% in wet or icy conditions. Although it has been largely implemented on passenger cars in the last years due to significant cost reductions, their market penetration rate regarding HDVs has not yet achieved a comparable level. The EC Impact Assessment study [EC, 2008b] suggested that this could be explained by *"cost reasons and possibly because drivers of heavy vehicles are considered to be less vulnerable in an accident and less likely to benefit from ESC (although some of the main beneficiaries may be the occupants of smaller vehicles who are less likely to be struck by a large vehicle equipped with ESC)."*

Today in Europe, a wide number of new trucks are already equipped with ESC systems (note that HDVs with automatic gearboxes are also systematically equipped with the ESC system).

The Lane Departure Warning System (LDWS) (or Lane Guard System (LGS)) warns the driver when the vehicle is crossing road markings. It relies on video-based sensors which monitor the position of the vehicle in the lane, and activates an alarm when there is a risk of the vehicle leaving its lane. Further developments include the Lane Change Assistant (LCA) and the Lane Keep Assist (LKA) systems:

- The LCA system assists the drivers intending to change lanes. This system monitors the adjacent lanes and warns the driver if another vehicle is likely to come within colliding distance during the lane change. Predictive sensors are needed to scan the surrounding vehicles. Most systems warn the driver of such a problem with a visual warning (e.g. red flashing side mirror). The aim is to limit side collisions.

- LKA is a system whose goal is to maintain the vehicle within the lane it is travelling (by means of a corrective steering input).

The **Advanced Emergency Braking System (AEBS)** uses radar or laser systems to detect if the vehicle in front is too close. It can detect an emergency situation and brakes may be activated automatically if necessary to decelerate the vehicle so that to avoid or mitigate a collision. These systems already exist on a few vehicles but there are still at an early development stage, depending whether we consider warning systems or active (intervening) systems which are more expensive and require safety standards[29]. The cost-benefit of this technology was analysed by Grover et al. [Grover et al., 2008] for different types of HDVs.

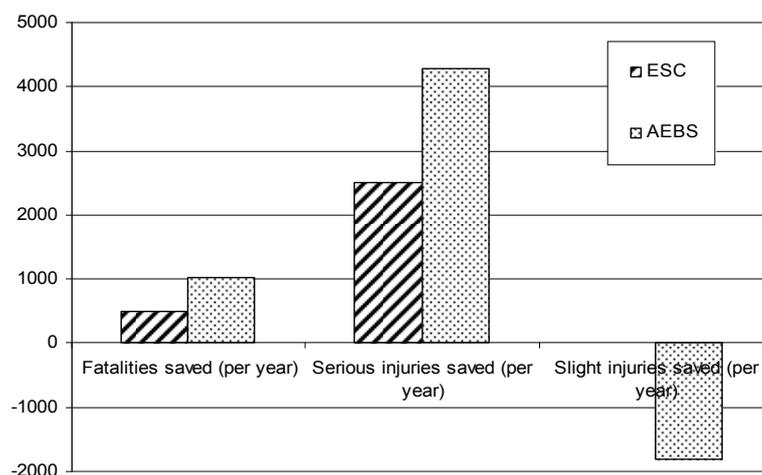[29] See e.g. UNECE Regulations R79, R13, R13H.

Figure 18: Effect of ESC and AEB systems on safety for heavy vehicles
Source: Own chart based on [EC, 2008b]
Positive effects are also expected from the LDW system but figures are provided for all vehicles, not only for HDVs.

4.2   Safety technologies with relevance to LHVs

Secondary braking systems

Broadly speaking, the role of secondary brake systems (retarders) is to 'augment or replace some of the functions of primary friction-based braking systems'. It is worth mentioning that not all HDVs today are equipped with secondary braking systems, which mainly depends on the road profile where the vehicle will be used (e.g. most of the HDVs driving in the Pyrenean region are equipped with such systems while it is not systematically the case for other less mountainous regions). Assuming that LHVs would be driven across different Member States (and thus occasionally down steep hills), the use of a secondary braking system is recommended. Moreover, these systems will also improve the energy efficiency, tyres wear and brakes lifetime.
There are basically two types of technology on the market, namely hydraulic[30] or electro-magnetic[31] retarders. Their additional cost (retail price) is estimated to be around €5000-7000 with an overweight of 150-200 kg approximately, depending on the technology.

Roll Stability Control (RSC) systems

As for the ESC system, this system belongs to the family of automated stability control systems. Globally, this technology reduces the risk of rollovers due to excessive speed in curves by automatically acting on the throttle, the engine retarder and brakes (drive axles and trailer brakes) if a critical lateral acceleration is detected by the sensors[32] (an accelerometer is integrated in the ABS for monitoring the lateral acceleration). This would significantly improve the manoeuvrability and the stability of LHVs. It should be noted that RSC and ESC are two different systems. The RSC focuses on the roll instability while the ESC system addresses both roll and yaw instability. An interesting study about costs and benefits of the RSC system has been carried out by the U.S. Department of Transportation [US DoT, 2009]. They reported for instance that *"an investment in the technology may still be considered judicious for added protection against rising insurance costs. In addition, avoiding the indirect costs of crashes, such*

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[30] See e.g. ZF Intarder on MAN and Renault trucks, Scania (own retarders) or Volvo (Retarder VR). These systems are integrated in the transmission.
[31] See e.g. Telma Hydral on Mercedes trucks.
[32] Main parameters are vehicle's centre of gravity, lateral acceleration threshold and wheel speed.

as impact on safety ratings, public image, and employee morale, can add to the benefits of purchasing onboard safety systems".

Moreover, there are independent systems for trailers available on the market (Roll Stability Support[33]) based on the same principle as for the RSC system i.e. the trailer brakes are automatically activated if the lateral acceleration limit threshold is exceeded.

Improved visibility

Cameras and video monitors can be used to aid the driver in viewing other vehicles (and also people) around the vehicle beyond what can be seen in conventional mirrors. There are for instance rearward visibility systems.

4.3 The high potential from ITS technologies

The application field induced by the strong development of Intelligent Transport Systems (ITS) is considerable and will benefit energy efficiency, safety and infrastructure-related impacts of LHVs.

With the development of new real-time traffic data collection techniques (see e.g. [Leduc, 2008]), HDVs and thus LHVs can provide a continuous flow of high quality information. The parameters collected are of different nature and can be transmitted from different means, e.g. directly from the vehicle (e.g. on-board sensors, GPS, mobile phones) or through fixed measurements located along the roadside (permanent, semi-permanent or portable sensors). The large amount of data recorded is afterwards processed by traffic centres and used for many applications. These include inputs to different models dealing with the interaction between heavy vehicles and the infrastructure such as models focusing on fuel consumption, pavement and bride design, safety, etc. (see e.g. the work carried out by Eichhorn et al. [Eichhorn et al., 2008] in the framework of the HeavyRoute project[34]). Some examples of ITS applications with relevance to LHVs are briefly described in the following. A (non-exhaustive) list of EU relevant projects and initiatives in this area is given in Annex III.

Optimising the routes and minimising empty running

Even with higher relevance than for standard HDVs, the implementation of cost-efficient tools for optimising the routes of LHVs seems to be necessary. This would avoid unnecessary running that would cause 'extra' undesirable fuel consumption, air emissions, congestion and of course 'extra' costs to the hauliers. Several private service providers using different sources of real-time traffic data (e.g. from fixed detectors complementing by floating vehicle data based on GPS or mobile phones)[35] are available on the market. On the other hand, the use of Computerised Vehicle Routing and Scheduling (CVRS) systems has proved to help significantly reduce operational costs

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[33] See e.g. http://www.wabco-auto.com/
[34] http://heavyroute.fehrl.org/
[35] The principle of collecting real-time traffic data by locating the vehicle via mobile phones or GPS over the entire road network is called Floating Car Data (FCD). This source of data (also combined with fixed measurements) is used by private service suppliers worldwide (e.g. TomTom, Airsage, ITIS Holdings, etc.) to provide their customers with real-time traffic data of high quality and optimised routes. Moreover, further information can be recorded from on-board sensors (usually called 'Extended Floating Car Data'), which can e.g. help report about traffic jams, detect weather conditions (e.g. data from the activation of windshield wipers, temperature sensors and headlights), road surface conditions (e.g. the operation of ABS system can be used to detect slippery road conditions, risk of aquaplaning or black ice). For instance, if the vehicle is driving on a slippery surface, information about the low traction can be detected and immediately transmitted to the following vehicles in real-time. The data is also simultaneously forwarded to a control centre to be processed and displayed on websites.

through e.g. reducing empty mileage[36]. A more detailed analysis of the benefits of these systems was carried out by [FM, 2008].

The development of on-board WIM systems

As already mentioned in the present report, a close monitoring of the payload of LHVs seems to be unavoidable. For this purpose, payload measurement by means of new dynamic Weigh-In-Motion (WIM) systems is of high importance. WIM systems are widely used for collecting information about the vehicle loading which is required for pavement and bridge design (assessment of the maximum bride loading, bridge components, etc.), maintenance operations and for overload enforcement (e.g. monitor the overloading that could threat competition between companies). Permanent or semi-permanent WIM systems are already implemented on a large number of roads and bridges (B-WIM systems). They provide a wide variety of raw information such as axle and vehicle weights, distribution of loads, vehicle speed, associated with a high level of accuracy (see e.g. the final report from the WAVE project[37] for more detailed on B-WIM technologies).

Alongside the on-going development of fixed WIM technologies, there is a high interest of developing on-board WIM technologies capable of measuring continuously the axle loads of LHVs all over the journey[38], while running at highway speeds. This would require the implementation of more or less complex data processing flows (data storing, data processing and data transmitting equipment) and thus additional costs to be supported by the companies. Note that these systems, even if already available and used, still need further R&D efforts in order to improve their accuracy and reduce costs. Moreover, they are not expected to be used for enforcement, at least in the short term in the EU. The research works presented in the framework of the "International Conference on Heavy Vehicles" held in Paris in May 2008[39] are relevant sources of information (among the rich literature in this area) about the current developments of WIM technologies.

Example: towards a real-time pavement damaging assessment?

A new approach for assessing in real-time the pavement damage and axle weight is described by [Dodoo and Thorpe, 2005]. The objective is to develop *"fairer and more efficient systems for determining the amount of pavement damage caused by HDVs for charging purposes"*. A prototype system has been successfully tested in on-road trials (see Figure 19).

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[36] See e.g. all the publications from the 'Freight Best Practice' programme funded by the UK DfT at: http://www.freightbestpractice.org.uk/
[37] http://wim.zag.si/wave/download/general_report.html
[38] Today, heavy duty vehicles equipped with pneumatic or mechanic suspensions are also systematically equipped with sensors for measuring the axle load (actually the basic role of these sensors - based on the pressure difference for pneumatic suspensions - is to provide information on the vehicle weight as inputs to the software in charge of the braking systems).
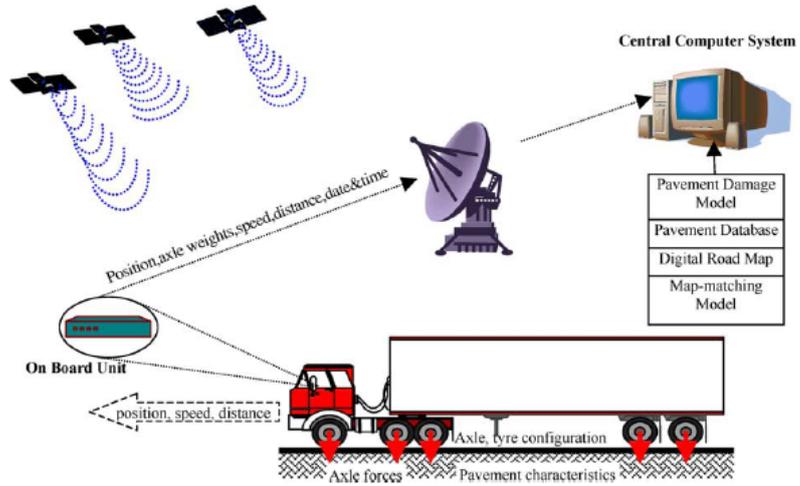[39] http://hvparis2008.free.fr/

Figure 19: Overview of the pavement damage allocation system described by [Dodoo and Thorpe, 2005]

5   CONCLUSIONS AND FURTHER RESEARCH NEEDS

The present report aimed at providing an overview of the complexity level of the technical aspects associated with Longer and Heavier Vehicles. Conclusions can be drawn mainly as regards the priorities and the potential of improved technologies for LHVs, but additional research is necessary for detailed technical options.

Energy efficiency

- Minimising the tare weight and maximising the load rate is a key issue for LHVs in order to optimise their energy efficiency. At vehicle level, the specific energy consumption of LHVs, expressed in litre per tonne-km or in litre per pallet-km, can be lower than for standard 40t HDVs, depending on the payload. From literature, it can be roughly estimated that the payload of LHVs should be above 65-70% of its maximum carrying capacity to be more energy efficient than fully-loaded conventional 40t HDVs. In this respect, further research work would be necessary to well identify the behaviour of the specific energy consumed (e.g. litre per tonne-km) vs. the payload for HDVs with total weight greater than 40t.

- With regard to the aerodynamic drag, LHVs may benefit from higher relative reduction potentials compared to standard HDVs. Indeed, the higher the aerodynamic drag coefficient, the higher the potential reduction through the implementation of add-on aerodynamic devices (e.g. gap fairings, side skirts) will be. No impacts on safety and pavement wear are expected. Further studies that systematically analyse the aerodynamic drag coefficient of all possible configurations of LHVs would be helpful.

- With regard to rolling resistance, it is more complex since it will affect fuel consumption, safety and pavement wear. The implementation of TPMS, wide-base tyres and low rolling resistance tyres is of high relevance to all HDVs, not only to LHVs (even though the systematic use of a tyre pressure monitoring system would lead to higher potential reduction, in relative terms).

Furthermore, significant fuel saving potentials can be achieved through the implementation of technical and non-technical measures. Even if most of them would benefit to all types of HDVs, some are particularly relevant to LHVs. This is for instance the case of the implementation of special training to LHV drivers, which is considered as a very cost-effective solution for reducing energy consumption and accident risks.

Infrastructure (road wear and bridges)

Assessing the impacts of LHVs on pavement wear and bridges is very complex due to the wide number of variables and interactions involved. Depending on the model used, very different results can be obtained.

With regard to road wear, what is essential is the load distribution and not only the gross vehicle weight (the axle load of 60t LHVs is not necessarily higher than for standard 40t HDVs).

Results from modelling or experiment-based research suggest that LHVs would, in most cases, not increase the pavement wear compared to standard 40t HDVs when expressed in unit of damage per tonne of goods transported, mainly because the load is spread over a larger number of axles. However, the results obtained highly depend on the approach used, the LHV configuration, the distress mode considered and many other variables (e.g. road surface properties, tyres, suspensions type, payload).

Due to the complexity level of such an analysis, results from the literature do not enable to clearly identify what configuration of LHV could be considered as the 'least aggressive' with regard to road wear, e.g. in terms of number of axles and axle configuration. Additional research studies would then be required to further assess the impacts of all types of LHVs (and going beyond the fourth power law-based figures) on pavement wear before drawing any definitive conclusions.

With regard to bridges, the load per axle is not the main driving factor. It is rather a matter of longitudinal mass distribution meaning that both axle spacing (inter-axle distance) and the number of axles used are key factors. No conclusions can be drawn about the LHV's impact on bridges from the present analysis.

Safety and ITS technologies

Several technologies for improving safety and reducing/minimising the impacts of LHVs on the infrastructure are already on the market and, for some of them, covered by (on-going) EU policy regulation. Although these technologies can benefit to all types of HDVs, there is no doubt that a combined implementation of the newest safety technologies along with specific driver training would significantly reduce the risks of accident.

Moreover, the application field resulting from the huge development of Intelligent Transport Systems (ITS) in the road freight sector is considerable and could significantly reduce the energy efficiency, safety and infrastructure-related impacts of LHVs.

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LIST OF ABBREVIATIONS

AEBS   Advanced Emergency Braking Systems

APU   Auxiliary Power Unit

EPA   U.S. Environmental Protection Agency

ESC   Electronic Stability Control

GCW   Gross Combination Weight

GVW   Gross Vehicle Weight

HDV   Heavy Duty Vehicle

ITS   Intelligent Transport Systems

LCA   Lane Change Assistant

LDWS   Lane Departure Warning Systems

LHV   Longer and Heavier Vehicle

LKA   Lane Keep Assist

LRRT   Low Rolling Resistance Tyres

RSC   Roll Stability Control

TPMS   Tyre Pressure Monitoring System

WIM   Weigh-In-Motion

ANNEX I – Key parameters and potential improvement measures*

	ENERGY EFFICIENCY	ROAD WEAR	BRIDGES	SAFETY
Extended vehicle length	Affect drag resistances (mainly aerodynamic drag)	The load distribution is important, not only the vehicle length (it also depends on the distress mode considered).	The load concentration is important, not only the vehicle length.	Overtaking problems Visibility problems
Increased number of axles	Affect drag resistances (mainly rolling resistance)	Change in load distribution (road wear generally decreases with increasing number of axles). **Key parameter**	The load concentration is important, not only the number of axles.	Stability-related issues
Axle spacing	Affect drag resistances (mainly rolling resistance)	The shorter the inter-axle distance, the better (but depends also on many other parameters).	The wider the distance between axles, the better (but depends also on many other parameters). **Key parameter**	Stability-related issues
Total vehicle weight	Increased tare weight and loading capacity **Key parameter**	Road wear increases with GVW. But what is important is the load distribution, not only the vehicle weight.	The load concentration is important, not only the vehicle weight.	Higher kinetic energy thus higher damage in case of crash. **Key parameter**

	ENERGY EFFICIENCY	ROAD WEAR	BRIDGES	SAFETY
Aerodynamic drag *Add-on devices (tractor / trailers)*	●			
Rolling resistance				
TPMS	●	●	●	●
LRR tyres	●			●
Wide-base tyres	●	Subject to discussion	Subject to discussion	●
Specific driver training	●	●	●	●
ITS - *WIM technologies (payload monitoring)*	● Indirectly	●	●	●
ITS - *Optimising routes*	●	● Indirectly	● Indirectly	● Indirectly
Safety technologies				
Stability (ESC, RSC, etc.)				●
Braking (AEBS, retarders, etc.)	● Indirectly (e.g. retarders)			●
Lane keeping control				●
Enhanced visibility				●

● **means that the technology could contribute to reduce the impact of LHVs related to the areas in each column heading.**

* Most of these measures can be implemented on HDVs, but they would be particularly relevant to LHVs.

ANNEX II – Overview of potential measures to reduce the fuel consumption of HDVs

REDUCING AERODYNAMIC DRAG

Measure	Potential fuel consumption reduction [1]	Additional cost per vehicle [2]	Sources	Comments
Tractor aerodynamics (general)	2% 4%	$1050 €2000-3000	[Ogburn and Ramroth, 2007] [Ang-Olson and Schroeer, 2002] Personal contacts	
Trailer aerodynamics (general)	4%		[Ang-Olson and Schroeer, 2002]	
Trailer aerodynamics - Trailer side-skirts - Gap Reducer - Boat Tail	5%	$2400	[EPA, 2004]	High potential for LHVs.
Tractor aerodynamics - Roof fairings - Cab extenders - Side fairings - Front bumper air dam	Up to 15%		[EPA, 2004]	Most of new long haul trucks are already equipped with such aerodynamic devices.
Trailer side skirts	4% >6% 5%	$1679	[Ogburn and Ramroth, 2007] [EPA, 2004]	See e.g. the "DOE Consortium for Heavy Vehicle Aerodynamic Drag Reduction" www.eere.energy.gov
Base flaps	6%	$3150	[Ogburn and Ramroth, 2007]	
Air deflector	4-8%		[VTT, 2006]	
Cab roof deflector	2%	$750	[Vyas et al., 2002] [Langer, 2004] See also [GPG, 2008]	Widely implemented
Gap closing/fearing	2.5% 2% 2%	$1500 $891	[Vyas et al., 2002] [Langer, 2004] [Ogburn and Ramroth, 2007]	
Replacing mirrors with electronic vision systems	1-2% (3-4% reduction in Cd)	Around $1000		2010

REDUCING ROLLING RESISTANCE

Measure	Potential fuel consumption reduction [1]	Additional cost per vehicle [2]	Sources	Comments
Wide-base tyres	5%	$5913 ($5880 due to aluminium wheels)	[Ogburn and Ramroth, 2007]	Lower M&R costs Each 3% reduction in RR results in 1% fuel economy.
	3%		[Ang-Olson and Schroeer, 2002]	
	Typically 2-5%	Around €100 (e.g. 2 WB tyres can replace 4 single tyres on drive axles)	[EPA, 2004] Personal contacts	Aluminium wheels can be costly.
TPMS	>1%	€500-1000	See e.g. [Stock, 2005] Personal contacts	
LRR tyres	If all tyres on all axles are changed from conventional, fuel consumption can be reduced by about 6-7%		See e.g. [FM, 2008]	Low resistance tyres have about 20% lower rolling resistance.
LRR tyres	3% 4%	$55	[Vyas et al., 2002] [Langer, 2004] [Ogburn and Ramroth, 2007]	

REDUCING ENGINE LOSSES [3]

Measure	Potential fuel consumption reduction [1]	Additional cost per vehicle [2]	Sources	Comments
HCCI (Homogeneous Charge Compression Ignition)	Limited		IFP[nn]	Important reduction of air pollutants (especially NOx emissions).
Increased peak cylinder pressure	4%	$1000	[Vyas et al., 2002] [Langer, 2004]	For the US
Waste heat/thermal management	5%	$1000	Rocky Mountain Institute[oo]	
Improved injection and combustion	6%	$1500	Rocky Mountain Institute[oo]	
Low-viscosity lubricants	2% 1.5% (engine) 1.5% (engine/drive train)		[EPA, 2004] [VTT, 2006] [Ang-Olson and Schroeer, 2002]	
Hybrid - Stop/Go for duty cycle	Up to 50%		[Greszler, 2006]	

REDUCING AUXILIARY LOSSES

Measure	Potential fuel consumption reduction [1]	Additional cost per vehicle [2]	Sources	Comments
Idle reduction [4]	3.4% (direct-fire heater)		[Ang-Olson and Schroeer, 2002]	
Idle reduction	9% (APU) Up to 10% (APU-SOFC)	$8500	[EPA, 2004] [Ang-Olson and Schroeer, 2002]	
APU diesel electric	80% (of fuel normally required for idling)	$7429	[Ogburn and Ramroth, 2007]	
APU battery-electric	92% (of fuel normally required for idling)	$3932	[Ogburn and Ramroth, 2007]	
Electric auxiliaries for long-haul	3-5% 1.5%	$500	[Greszler, 2006] [Vyas et al., 2002] [Langer, 2004]	
Fuel Cell Auxiliaries	6%	$1500	[Vyas et al., 2002] [Langer, 2004]	US 2012
Exhaust after treatment device – PM Filter		$6000	[EPA, 2004]	90% PM reduction
Exhaust after treatment device – Diesel Oxidation Catalyst (DOC)		$1200	[EPA, 2004]	20-50% PM reduction

OTHER POTENTIAL IMPROVEMENTS

Measure	Potential fuel consumption reduction [1]	Additional cost per vehicle [2]	Sources	Comments
Weight reduction	5%		Rocky Mountain Institute[oo]	Use of lightweight materials
IT Systems	Typically 5-10%		[FM, 2008]	From telematics and Computerised Vehicle Routing Systems (CVRS)
Driver training	>4% 4% At least 5%	Around €200 (depending on the country)	[EPA, 2004] [Ang-Olson and Schroeer, 2002] [FM, 2008]	Cost-efficient measure

[1] Average figures (driving cycle, etc. not taken into consideration).

[2] Indicative figures only. Additional costs generally refer to retail costs.

[3] Note that considerable R&D efforts have been made on truck engine efficiency and current engine technologies equipping new trucks are already very efficient. The maximum thermodynamic efficiency (Carnot) of a diesel process is estimated at 63-65%. Present truck engine is around 43% [Larsson, 2008].

[4] Important quantities of diesel can be consumed while idling during loading/unloading, vehicle inspections and to maintain a certain comfort to the driver. Idling time of LHVs is not expected to be significantly longer than for standard HDVs. Anti-idling measures would benefit to all types of HDVs but there are particularly relevant in North America [Kraaij et al., 2009] (in Europe idling times are generally lower due to earlier implementation of anti-idling measures). For instance, it is estimated that an additional fuel gained of 6% could be obtained by not idling truck engine overnight [Gaines, 2004] (see also [Gaines et al., 2006]). There are several idle-reduction technologies available on the market that typically refer to either "On-board" equipment (e.g. battery systems, thermal energy storage, APU-diesel, etc.) or to "Off-board" equipment (e.g. electrified parking space), with different potential reductions and costs. In the medium to long term, the deployment of fuel cell APU systems is likely to represent a cost efficient solution to cope with truck idling problems. Two types of fuel cells are the major candidates for future on-board APUs, namely solid oxide fuel cells (SOFC, fuel: NG or liquid fuels) and proton exchange membrane fuel cells (PEMFC; H2 as fuel). The use of a SOFC-based APU can result in significant fuel savings depending on the idling hours displaced. Several research studies about the fuel cell potentials as APUs have been carried out in literature (see e.g. [Jain et al., 2006], [Lutsey et al., 2007], [Contestabile, 2009]). It was reported that SOFC-based APUs might become the "first major automotive application of fuel cells". However, potential costs of such systems are somewhat speculative [Jain et al., 2006] even if one can expect that manufacturer costs will be gradually reduced with time. The main market for truck fuel cell APUs is likely to occur in the U.S. [Kraaij, 2009].

ANNEX III – List of EU relevant projects and initiatives on ITS

Project name	Description

ERTICO-ITS Europe
http://www.its-europe.org/
 	
Public/private partnership to develop ITS in Europe
	Examples of projects coordinated by ERTICO:
	• EuroRoads Project
	  http://www.euroroads.org
	• TMC Forum
	  The TMC Forum is the focal point and workshop of the Traffic Message Channel (TMC) community
	  http://www.tmcforum.com/
	• GST (Global System for Telematics enabling On-line Safety Services)
	  www.gstforum.org (see e.g. the GST-RESCUE subproject)
	• CVIS (Cooperative-vehicle-infrastructure systems)
	  http://www.cvisproject.org/
	• ISTER (Promoting the integration of satellite and terrestrial communication with Galileo for road transport)
	  http://www.sister-project.org/

eSAFETY Support http://www.esafetysupport.org	eSafety is a industry/public initiative driven by the EC and co-chaired by ERTICO-ITS Europe and ACEA. The objective is to promote the development, deployment, and use of Intelligent Vehicle Safety Systems to enhance road safety throughout Europe.
European Congress and Exhibition on Intelligent Transport Systems and Services www.itsineurope.com	The objective of this event is to present the latest ITS innovations including advanced vehicle control systems, travel information and traffic management systems, digital mapping, public transport applications, smart card and communication technology.

TEMPO programme (Trans-European intelligent transport systeMs PrOjects) 2001-2006	Euro-regional projects:
	• CORVETTE (Coordination and validation of the deployment of advanced transport telematic systems in the Alpine area)
	  http://www.corvette-mip.com/
	• ARTS (Advanced Road Traffic in South-west)
	  http://www.arts-mip.com/
	• CENTRICO (Central European Region Transport Telematics Implementation Co-ordination)
	  http://www.centrico.org/
	• SERTI (Southern European Road Telematic Implementations)
	  http://www.serti-mip.com/
	• VIKING
	  http://www.viking.ten-t.com
	  http://www.travel-and-transport.com/
	• STREETWISE (Seamless Travel Information Services for the Western Isles of Europe)
	  http://www.streetwise-info.org/

EASYWAY Programme (2007-2013) "Towards European sustainable mobility: increase safety, improve mobility and reduce pollution"	The deployment of ITS is expected to meet the following objectives by 2020: 25% congestion reduction 25% improved security 10% CO_2 reduction, mainly in urban areas The experiment and deployment of new data collection technologies are covered (e.g. floating car data, 3G communication, GPS/ Galileo).

TRACK&TRADE (FP6) http://www.trackandtrade.org/ "Building a data mart for floating car data"	The objective is to develop of a web-based data mart for the collection of Floating Car Data (FCD) and the provision of value-added services. The ground is prepared for new traffic services and applications based on FCD (especially from GPS and xFCD, but not from cellular phones).
eMOTION (FP6) http://www.emotion-project.eu/	The objective is to investigate and specify the framework for a Europe-wide multimodal traffic information service offering real time information and special services for the road and public transport user.
Heavyroute (FP6) http://heavyroute.fehrl.org/	The project focuses on applying and combining existing and newly developed systems, technologies, databases and models to develop an advanced HGV management and route guidance system. The objectives are to improve road safety and capacity while reducing the negative impacts on the environment and the road and bridge maintenance costs (reducing the rate of deterioration caused by heavy traffic).
FREIGHTWISE (FP6, part of the Logistics Action Plan) Management Framework for Intelligent Intermodal Transport http://freightwise.info/	FREIGHTWISE develops a freight transport management framework that aims to facilitate interoperability between all stakeholders in transport. The goal is to provide a blueprint reference architecture for the development of an effective management and IT infrastructure for setting up, monitoring, and managing intermodal chains. This infrastructure will support the interaction with other service partners in the chain, but also with external actors such as traffic management services, customs offices, and other relevant public bodies.
E-Freight initiative (DG TREN, part of the Logistics Action Plan)	The objective is to establish a roadmap for the development of an integrated ICT application that is capable of following the movement of goods into, out-of and around the EU. A vision for eFreight (i.e. Electronic information exchange in freight transport) is: - Zero paper documents shall be needed for planning, executing and completing any transport operation within EU. - There shall be zero waiting time related to administrative procedures at all border crossings within EU or from countries outside EU.
SMARTFREIGHT (FP7) Smart Freight Transport in Urban Areas http://www.smartfreight.info/	The main objective is to specify, implement and evaluate Information and Communication Technology (ICT) solutions that integrate urban traffic management systems with the management of freight and logistics in urban areas. The actual transport operations carried out by the freight distribution vehicles will be controlled and supported by means of wireless communication infrastructure and on-board and on-cargo equipment.
New VTT project (RASTU research consortium)	Development of ITS applications for improved safety and more particularly "to develop ITS technology to reduce energy consumption and improve safety and service levels for heavy-duty vehicles".

Abstract

Within the frame of the Logistics Action Plan, the European Commission is analysing the impacts of a potential introduction across the EU of Longer and Heavier Vehicles (LHVs), i.e. vehicles measuring up to 25.25 m and weighting up to 60 tons. Such vehicles are expected to improve the efficiency of the road freight sector but their impacts on the environment, infrastructure and safety need to be analysed in more depth.
The present study aims at providing an overview of the technical aspects associated with LHVs regarding energy efficiency, infrastructure (road wear and bridges) and safety issues. This is carried out at vehicle level based on a comparison with standard 40t heavy duty vehicles (HDVs). Some technologies that can potentially improve the performance and reduce the damage caused by LHVs are described and issues that require further and detailed research are also identified.

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