Defining road and rail vehicles with a low environmental footprint

- Final report -

By

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Executive summary

There is growing concern about the increasing number of vehicles, both road and rail, and their impact on the environment as well as the infrastructure on which they operate as transport has to contribute its share towards reducing its environmental impact including greenhouse gas emissions.

The major impacts have been identified from an analysis of the socio-environmental costs which is currently borne by society rather than the user. In discussion with stakeholders through a series of eight workshops, it has been possible to assess these impacts and the technical options for reducing these impacts. The quality of the data has also been reviewed in order to classify such impacts.

The logical and most efficient way of reducing such impacts is to develop the concept of an environmentally friendly vehicle and evolve a methodology of characterising these impacts in the form of a vehicle's environmental footprint.

The outcome of these analyses is to propose the concept of an EU type label which classifies the 4 major impacts that is noise, gaseous emissions, fuel consumption and damage to the infrastructure. Such a label would not only be able to initiate a dialogue between buyer and seller, but also encourage manufacturers to differentiate their vehicles through being more environmentally friendly.

To initiate the transition to the use of more environmentally friendly vehicles, it is suggested that road usage and track access charges should be related to the size of their environmental footprint as classified on its environmental label.

Recommendations

Impacts

Road and rail vehicles should be classified in terms of their major impacts with their environment and infrastructure

Such impacts should include noise emissions, carbon dioxide emissions, fuel consumption and interaction of vehicle with its infrastructure

Impacts to be measured wherever possible by realistic operating conditions of mass, speed and infrastructure alignment

Where such Euronorms do not exist, a mandate should be given to develop such norms

Measurement methods

Where these are lacking norms should be agreed so characteristic data can be collected

Track friendly suspension

The concept of a track friendly suspension should be defined to encourage the uptake of such suspensions in order to reduce track maintenance

Labels

The impacts should be displayed on an EU type of energy label

Impacts should be classified in terms of classes A to G or threshold limits

Classification should provide scope for classes or limits yet to be achieved

Vehicle classes should be agreed for both road and rail modes in order to encourage transport of goods and people by the most environmentally friendly mode.

User charges

User charges should be related to the size of a vehicle’s environmental footprint through a bonus/malus system of payment

Way forward

A dialogue should be initiated with stakeholders including industry, authorities, European Commission’s labelling committee and European Parliament’s Transport and Environment committees

Contents

Acknowledgements

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1 Introduction

We live in an interconnected world with globalisation of production resulting in products being designed in one country, manufactured in another country and then sold in yet other countries. In the 60 years since the transport of goods in containers began [1], container traffic has become the dominant mode of transport for manufactured goods and the largest vessels now in service can move up to 20,000 containers. These containers have to be distributed by road and/or rail to their markets (Figure 1.1)

Figure 1.1 Container terminal at Port of Felixstowe showing quay cranes unloading and containers waiting to be transported to their destination.

During the same time period there has been a very substantial increase in the number of passenger cars and tourism has likewise increased.

Thus the environmental impact of transport is still increasing. However, following the agreement in Paris in December 2015 [2] to limit the average global temperature rise to 2° C and if possible to 1.5°C, it has become increasingly necessary for all transport modes to reduce their emissions of greenhouse gases. While these emissions have *global* impact, the other environmental impacts of road and rail vehicles cannot be neglected particularly for those people living alongside traffic corridors such as noise emissions and local pollutants. Rather than concentrate on one impact, this Eureka project has taken a *holistic* view of the impact of a vehicle with its environment and the infrastructure on which it operates.

Environmental footprint

To decide which impacts should form part of an environmentally friendly vehicle, the project has considered the analysis of socio-economic costs of road and rail transport by the Swiss Federal Office of the Spatial Development [8]. As discussed in more detail in section 2, the dominant impacts are –

- Health through the generation of air pollution
- Audible noise

- Climate change through production of greenhouse gases arising from the combustion of fossil fuels

To these three external impacts, it was agreed to add the magnitude of the interaction between a vehicle and its infrastructure as this is the principal cost element of maintaining the infrastructure.

These four impacts can then be used to define a vehicle's *environmental footprint* and so the larger a vehicle's impact(s), the bigger will be its footprint [3]. An *environmentally friendly* vehicle can then be defined as one with a *small* environmental footprint.

Relating impacts to costs

The guiding principle of environmental economics is that the user should pay for *all* the costs that are incurred resulting from a vehicle's interaction with the environment rather than just the marginal costs that is the 'polluter pays' principle. To provide a legal basis for this principle, the Greening Transport package as agreed by the Member States in 2008 [4] introduced the bonus/malus system. This has enabled Member States to make a bonus payment to operators of vehicles which are more environmentally friendly and for operators to make a malus payment so that the income could be revenue neutral. An example of a bonus payment is the noise bonus offered by Dutch, German and Swiss governments to operators of quiet rail freight vehicles [5].

While some of these impacts can be measured in the laboratory as part of type approval testing, these impacts can and should also be measured by an array of sensors in or adjacent to the pavement or track as developed in a preceding Eureka project E! 2486 Footprint [6]; although this is not often done.

Layout of report

The four environmental impacts listed above have been assessed and options for reducing them have been reviewed in a series of workshops with stakeholders and each is summarised in a subsequent chapter. The quality of the data which characterises these impacts is then reviewed. Encouraged by the successful introduction of the EU tyre label [7], it is then proposed that the best way of displaying this information for each vehicle is to develop an EU type energy label for environmentally friendly vehicles. The proposal is that a label will not only facilitate a dialogue between buyer and seller, but also encourage manufacturers to differentiate their products through being more environmentally friendly.

The existence of such a label can then help to initiate the transition to more environmentally friendly vehicles if the road usage and track access charges are related to the socio-environmental costs of these impacts.

2 External costs of transport

A recent study by the Swiss Federal Office for Spatial Development has documented the external costs of transport [8] The study calculates the external and social (national economic) environmental, accident and health-related effects of transport in Switzerland in 2010. In doing so, previous calculations relating to road and rail transport are subject to a methodological review, and recalculated for 2010 using fully updated data sources for the following 12 cost areas: air pollution-related damage to health, damage to buildings, crop shortfalls, forest degradation, loss of biodiversity, noise, climate change, nature and the landscape, soil degradation, upstream and downstream processes, accidents, and additional costs in urban areas (figure 2.1).

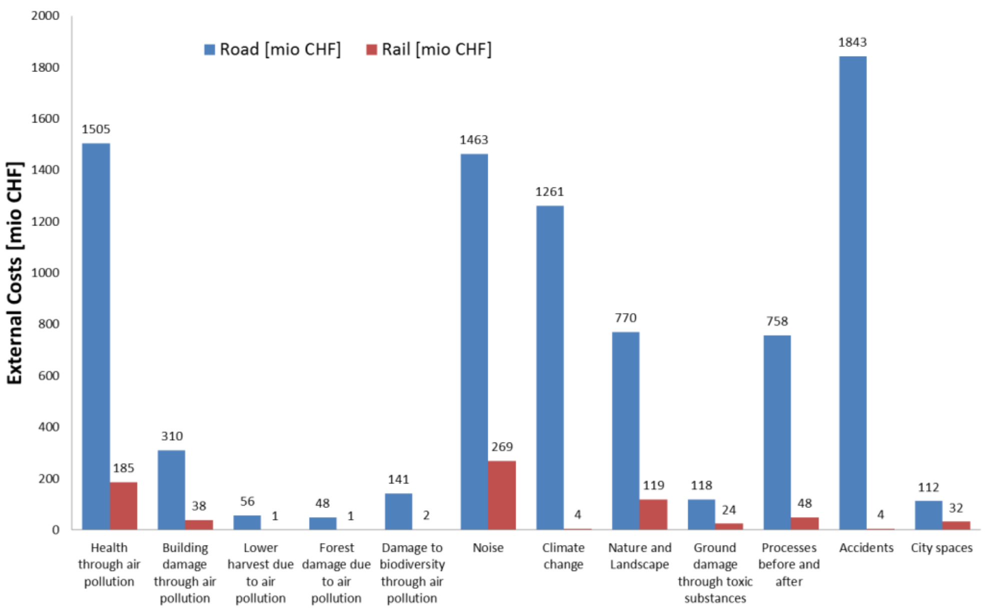


Figure 2.1: External costs of transport for road and rail transport modes [8]

In these cost categories, the external costs of air and waterborne transport in Switzerland were also calculated for the first time, and the road transport section of the study has been extended to include non-motorized transport (pedestrian and cycle traffic) (figure 2.2). The positive effects on health of the physical exercise involved in non-motorized transport are also quantified.

Aggregated across the four modes of transport, total external costs come to over CHF 9'400 million for 2010. At CHF 5'500 million, private motorized road transport is the main originator of these external costs, followed by road freight transport at CHF 100 million (a share of the Swiss heavy vehicle fee, HVF (LSVA) has been factored in as an internalization measure), and by public road transport, with a contribution of CHF 190 million. Air transport resulted in external costs of CHF 920 million, while rail transport accounts for CHF 740 million. Waterborne transport generated external costs of CHF 57 million. In addition to external costs of CHF 900 million, non-motorized transport generates external health benefits worth CHF 1'300 million. The significant differences in distances travelled using the individual modes of transport must be remembered when comparing these absolute figures. Considerably more person and tonne kilometres are travelled by road than by other modes of transport, while figures for waterborne transport are much lower.

Considering the external costs in terms of transported tonnes, the report shows that the freight traffic cost 7.1 Rp/tkm* of which 4.4 Rp/tkm was internalized through the heavy vehicle fee (LSVA), implying in turn that 2.7 Rp/tkm was not recovered by the fee (Fig 2.2). The external cost of rail on the other hand was 2.8 Rp/tkm, air freight 7.6 Rp/tkm whereas the cost of ship transport on the Rhein was 0.5 Rp/tkm.

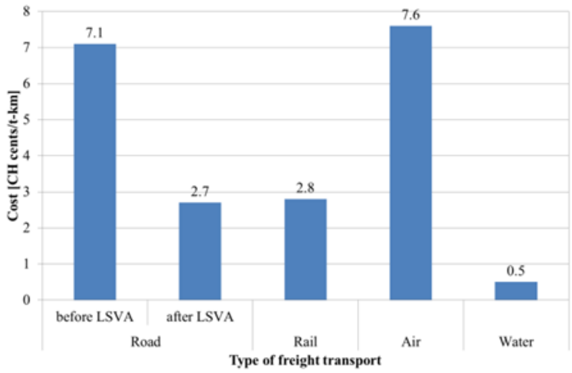


Figure 2.2 Freight traffic: external costs pro tonne kilometer in 2010 [8]

Furthermore these external costs have been defined for various types of heavy vehicles as follows: The total external costs of heavy vehicles that are paying the fee are CHF 1'293 Mio. These costs are partially recovered by the LSVA in the amount of 720 Mio CHF. This means that the remaining CHF 573 Mio are not recovered of which the freight trucks (Lastwagen) bear 65%, articulated and semi-trucks (Sattelzuge) 24% and buses (Gesellschaftswagen) 11%.

Setting aside the cost of accidents, the major external costs are linked to air pollution, noise and climate change (Figure 2.1). These relate to emissions of nitrous oxide, carbon dioxide and vehicle noise. The greatest internal cost is that of maintenance of the pavement or track which is caused by the magnitude of the both the static and dynamic interaction (i.e. force) between a vehicle and its infrastructure. Each of these major impacts is considered in the following sections.

* 1 Rp (rappen) equals 0.88 euro cent; 1 CHF = 0.88 €

3 Data Quality

Data quality can be defined in a number of different ways, but are considered to be of a high quality only if it is fit for purpose, i.e. it can be applied to provide strong, reliable and reproducible documentary evidence for policy decisions, planning or operational use.

The goal of this European cooperative project is to define road and rail vehicles with a low environmental footprint. The principal tasks include: analysing data from real time measurements, defining limit values for environmentally friendly vehicles and defining a combined environmental label for vehicles. Characterising the environmental impact of individual vehicles enables the polluter pays principle to be applied to land transport. This impact can be measured via a sensor array (Weigh in Motion or WIM) located within, or alongside, the road or rail. The objectives of this particular part of the Ecovehicle project are [9]:

1. To develop a limited and simplified evaluation for a quick assessment of the quality of the WIM data;

2. To provide the first international benchmark on the data quality management, procedures and criteria used by different users of WIM systems in Europe.

Objective

It is generally accepted that no WIM system can produce perfect data, even with high quality equipment and ideal site conditions. Data files are more than likely going to contain some invalid data. Regardless of the minimum data quality requirements, any WIM system should be regularly monitored and maintained. The key is to reduce bad data to a minimum and to quickly recognise, identify, isolate and correct the cause of erroneous data [10].

Therefore, the objective was to develop a set of tests and criteria that will allow the user to make a quick verification of the quality of the data from any WIM system in Europe so that it could be reliably used for this project. These tests can then be used to compare the relative quality of different WIM sites (the quality of the data from site A is better than that of site B) and, if possible, to give an indication of the absolute quality of the data of a particular site (the data from site C has a quality that is acceptable). In general, the tests look at the stability of certain elements or characteristics of the measured data. The selection of the characteristics was based on an evaluation of international literature on WIM data quality management and the practical experience of project partners.

It is important to realise that the quality tests are not able to distinguish between variations in the measurements by the WIM system and variations in the traffic at a certain site. This means that in case the test results produce a “questionable” verdict on the quality of data, because of large variations in the WIM data, the reason for this could be explained by variations in the traffic flow and not because of the WIM system.

In general, the tests looked at the stability of certain elements or characteristics of the measured data and provided an idea of the relative quality of the WIM data. However, the data may still contain a stable – and possibly significant – measurement error.

Quality Checks and Criteria

The checks that were applied to the data sets were based on finding characteristics of certain types of vehicles that show a very small variation in daily practice and are commonly found throughout Europe. This can either be caused by international regulations for heavy goods vehicles (examples a. and b.) or by standards in vehicle design (examples c and d). The following examples of such characteristics were used in the quality checks:

a. The vehicle length of Truck+Trailer combinations and that of Tractor+Semi-trailer (articulated) combinations. For most EU member states the maximum allowable lengths for these combination are respectively 18.75m and 16.50m;

b. The Gross Vehicle Weight (GVW) of 3 axle Trucks and that of 5 axle Tractor + Semi-trailer (articulated) combinations. For most EU member states the maximum allowable GVW's for these combination are respectively 26 tonne and 40/44 tonne;

c. The axle load of the first (steering) axle of – fully loaded - 5 and 6 axle articulated vehicles. International experience has shown that the load on this axle lies normally in a narrow bandwidth between 6.5 and 7.0 tonnes;

d. The axle distance between the 2nd and 3rd (driven) axles of 6 axle Tractor + Semi-trailer combinations. International experience has shown that the distance between these axles is very stable at 1.30m as this allows the highest axle loads.

Criterion	Min. Value	Max. Value
Av. GVW of 3 axle rigid	15t	20t
Av. GVW of 5 axle articulated	25t	40t
Av. Steering Axle Load	6.5t	7.0t
Av. Vehicle Length	15.5m	17.5m
Av. Axle Distance	-	-
Variation in # of registrations	-	-
Percentage of unclassified	-	5%
Percentage of measured errors	-	5%
# hours without registrations	-	5 per week

Table 3.1 Possible quality checks and criteria for heavy goods vehicles

Findings

Since the outcomes of the tests are sensitive to the choice of week the data are from, it is important that the selected weeks should represent normal operational conditions. Weeks with known variations due to holidays, infrastructure works or extreme weather conditions should be avoided.

In the case of a negative result from these tests, the data should be interpreted as: “Do not use this data without additional checks on the quality of the data.” If a positive result is found then this should be interpreted as: “There are no reasons to suspect the quality of this data however this is not a guarantee”.

By repeating the tests on data of one system from a number of different weeks from different periods over a year, the results will give a more reliable indication of the actual performance of the system.

Quality check, rail WIM data

Weight in motion is of even greater importance in rail transport because an overloaded vehicle can induce very large forces in tracks which could result in the initiation of cracks and subsequently lead to broken rails and possible derailment. Quality checks of data for rail vehicles should be developed which are the analogue of the data in table 3.1 for road vehicles. These data should include gross vehicle mass, the number of axles and most importantly the (vertical) static axle load which may not exceed 225 kN and dynamic load may not exceed 322 kN. There is also a lateral load limit of 68 kN.

4. Impacts and options to reduce noise

Noise exposure of residents depends on the source strength and the propagation attenuation from source to receiver. To increase sound propagation attenuation, obstacles that interrupt the sightline can be installed. However, acceptance is generally limited due to disturbance of the visual impression. In urban environments only noise barriers of low height are applicable. Under specific circumstances they prove to be surprisingly efficient [11, 12]. As the sound field in an urban situation is heavily influenced by reflections at building facades, the shape and form of the street canyons play an important role [13].

Even more effective is a reduction of the emission. The source strength of traffic noise can be lowered by measures taken at the infrastructure or at the individual vehicle. On the road side, low noise pavements are very promising. Railway noise reduction on the side of the infrastructure can be achieved by rail grinding to smooth the tracks and rail damping to absorb vibrational energy. Both on road and rail there is a pronounced spread of the emission of individual vehicles [14]. From the view point of the authorities, it seems therefore interesting to provide incentives to motivate vehicle owners to reduce the emission of the individual vehicle. This can be achieved by fitting low noise tyres on the one hand and for rail vehicle by maintaining wheel quality due to the use of favourable braking systems on the other hand [15].

Quieter roads

Noise emitted by road vehicles can be split up into a contribution of the tire/pavement interaction (rolling noise) and a contribution of the engine and the exhaust system (propulsion noise). Rolling noise depends mainly on vehicle speed, the number of axles, the tire and pavement properties and the temperature. Propulsion noise is determined by the configuration of the engine and the exhaust system and by the condition of the engine, that is to say the rotational speed of the engine and the engine load. At low vehicle speeds, propulsion noise dominates while rolling noise is most relevant at higher speeds. According to the European Traffic Noise Model CNOSSOS, the speeds for equal contribution are 30 km/h for passenger cars and 75 km/h for heavy vehicles. Recent measurement data suggests that in today’s fleet these speeds are even lower. Figure 4.1 shows propulsion noise and tire noise contributions according to the Swiss road traffic noise model sonRoad [16].

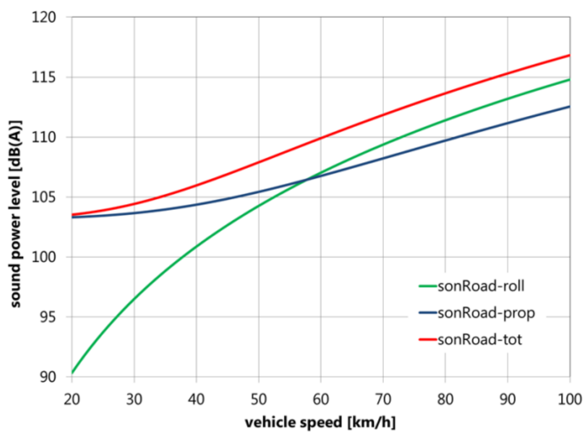


Figure 4.1 Noise emissions of heavy goods vehicles according to the Swiss model sonRoad, showing that engine noise (sonRoad-prop) dominates at low speeds while tire noise (sonRoad-roll) dominates at high speeds

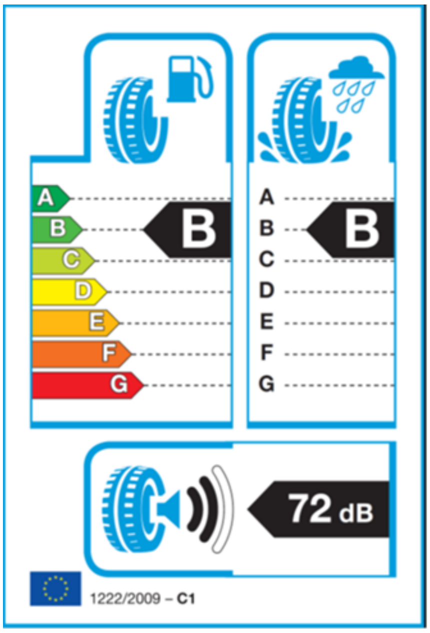


Figure 4.2 EU tyre label

Depending on the vehicle category and the speed regime either the reduction of rolling noise or propulsion noise is the most effective noise abatement strategy. Rolling noise can be lowered by application of low noise tyres and or the installation of low noise road pavements. A reduction of propulsion noise of combustion engines can be achieved by enclosing the engine. While this is standard for passenger cars there is a large potential in engines of heavy vehicles. A very rigorous strategy to get rid of propulsion noise is the installation of electrical drive systems. An additional benefit of these systems is the prevention of high rev driving conditions.

With the regulation 1222/2009, the EU introduced in 2012 a label to characterise the properties of individual tyres [7]. It displays important information about safety and environmental aspects of a tyre. It allows comparing tyres in terms of fuel efficiency, wet grip and noise. Noise is specified as maximum pass-by sound pressure level at 7.5 m distance. In addition to the indication of the level [dB(A)], an allocation to one of three noise classes is also shown for a quick and easy interpretation. For the first time, customers that wish to buy low noise tyres have access to the necessary information.

A statistical analysis of available tyres has shown, that in truck tyres, on average, driving axle tyres are around 3 dB(A) noisier than front axle tyres and 5 dB(A) noisier than trailer tyres. In most cases there is a significant difference between the median and the minimum value. This suggests that a substantial noise reduction potential lies in the suitable choice of the tyre.

Low noise road pavements

Low-noise road pavements have become a popular and widely used measure in many western countries to reduce road traffic noise at its source. Recently, several countries have developed new innovative low noise pavement solutions as part of national and cross-boundary noise abatement policies and programs. These developments seek pavements with higher void content (to improve sound absorption and reduce air-pumping noise), finer texture and aggregate size (to reduce vibration noise) and an increased mechanical impedance (to reduce low-frequency vibration noise). The challenge is to preserve the acoustical benefit over a reasonably long lifetime.

Noise dependent heavy duty vehicle fee

Road access charges for heavy duty vehicles allow for the promotion of environmental friendly technology. With the introduction of Euro VI engines, gaseous emissions are down at very low levels. As in a few years the majority of heavy vehicles will be equipped with Euro VI engines anyhow, there is no need to further promote this technology with incentives. An evaluation of external costs caused by heavy duty vehicles has shown that the next relevant environmental aspect is noise. For that reason, Switzerland is evaluating a noise dependent heavy duty vehicle fee.

With help of the road traffic noise model of CNOSSOS and under the assumption of a vehicle speed of 80 km/h, the reduction of total noise ΔL of heavy vehicles due to low noise tires can be estimated with help of the following equation

$$\Delta L \approx 0.0272 \cdot \Delta L_{tyre}^2 + 0.53 \cdot \Delta L_{tyre}$$

where ΔL_{tyre} indicates the tire noise modification. ΔL can be allocated to costs with help of external costs data. In Switzerland these have been determined as CHF 0.15 per km (EUR 0.143) for freight trucks. Assuming these costs C_{ref} to be valid for an average vehicle, the costs $C(\Delta L)$ of a vehicle with modified emission by ΔL can be calculated as:

$$C(\Delta L) = C_{ref} \cdot 10^{0.1 \cdot \Delta L}$$

Quieter railway lines

The main sources of noise from the railway system are: rolling noise from the interaction of the wheel and the rail, equipment noise (e.g. fans, engines, cooling systems or compressors), and aerodynamic noise [17]. In general, the spectral contents of railway noise is slightly shifted to higher frequencies in comparison to road traffic noise. Between speeds of 40 - 250 km/h rolling noise is most important. Rolling noise is caused by small irregularities on both the wheel and the rail, causing both to vibrate and emit noise. The most important parameters are the combined roughness of wheel and rail and the decay rate of the rail. The latter describes the vibration reduction of the rail over distance and is strongly influenced by track design. For instance stiffer rail pads increase the decay rate, decreasing noise creation. Further parameters influencing rolling noise creation are the traffic speeds (higher speeds lead to higher noise creation) and the traffic mix (freight trains with cast-iron brake blocks lead to larger wheel roughness which causes more noise).

Noise reduction on the side of the vehicle

Wheel roughness - the main parameter influencing noise - depends on the braking system. In systems with cast-iron brake blocks, braking is undertaken directly on the wheel, causing irregularities on the wheel running surface. This roughness can be reduced by replacing the cast-iron brake blocks with blocks consisting of composite materials. Currently in use are K- blocks and LL-blocks. A further possibility to reduce wheel roughness is the usage of disc brakes. The higher expense in comparison to retrofitting with LL-brake blocks and the increase in weight are negative aspects of this possibility. By the introduction of track access charges that differ according to the braking system, the owner of the infrastructure can stimulate the retrofitting process.

Noise reduction on the side of infrastructure

On the side of the infrastructure, rail grinding and rail damping are the most important noise reduction strategies. Grinding lowers the roughness of the rail and thus reduces contact forces and finally excitation of the rail/wheel system. An increase of rail damping suppresses excited vibrations to some extent and reduces the noise emitted from the track. Aside from the cost, rail dampers have the disadvantage of hindering track diagnostics and maintenance.

5. Pollutant emissions

Vehicles use, as primary energy converters, predominantly internal combustion engines. For freight transport, diesel (compression ignition) engines are the most important converters in Europe although alternatives such as spark ignition engines using compressed or liquefied natural gas/biogas, fuel cells using hydrogen or grid-charged battery-electric drive trains could be an option for certain applications. Internal combustion engines combust hydrocarbon fuels (being liquids such as diesel, bio-diesel, hydrotreated vegetable oil, fischer-tropsch fuel, petrol, methanol, etc. or gaseous fuels containing methane, ethane, carbon monoxide, hydrogen, etc.). A perfect chemical reaction of hydrocarbons with ambient air would lead to CO_2 and water. Because of imperfect combustion and chemical processes with atmospheric nitrogen, pollutants like carbon monoxide (CO), unburned hydrocarbon (HC), nitrogen oxides (NO and NO_2, summarised as NO_x) and particles are also formed.

The tightening of the regulations over the last decades has led to a strong reduction of unwanted fuel elements. Low *sulphur* fuels, for example, were introduced in order to reduce SO_x emissions and to enable durable catalysts in the vehicle's exhaust gas after-treatment systems. Today, sulphur for road transport fuels in Europe is limited to a very low level of 10 ppm which leads to the fact that the emissions of sulphurous chemical compounds from road traffic have decreased to insignificant levels. The same happened with *lead* decades ago. Therefore, the main pollutants caused by combustion are CO, HC, NO_x and particles. However, clean land transportation fuel is not available throughout the world as Figure 5.1 shows and fuel qualities used for shipping has completely different regulations [18].

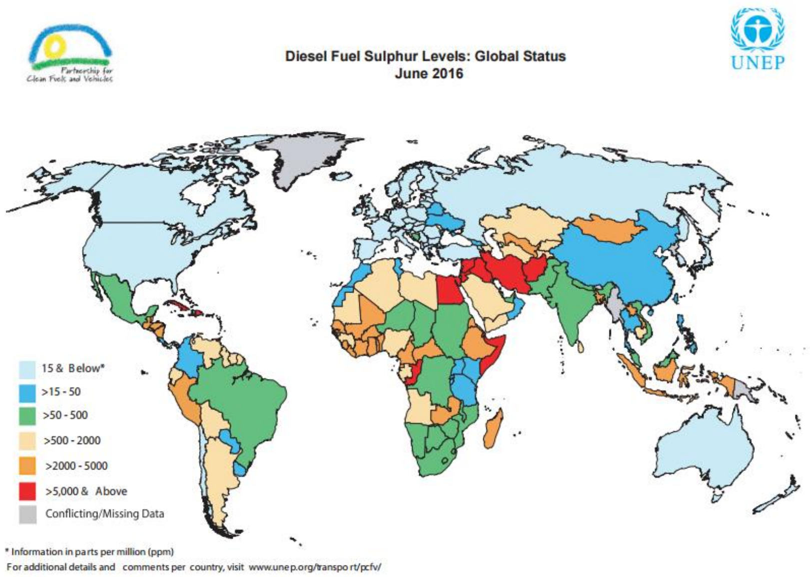


Figure 5.1: Sulphur Levels in Diesel Fuel [19]

The emission regulation for on-road vehicles (passenger cars, vans and heavy duty vehicles) were massively tightened over the last decades whereas heavy duty vehicles face the strongest regulations at the moment. Not only were their engine's emission limits continuously tightened but also the test cycles were more and more demanding over the last decades so that the actual Euro-VI test procedures [20] now includes for example also the start of the cold engine which was not tested in earlier legislations.

Additionally to changing test procedures of heavy duty engines, not only the mass of particles is limited but also their number so that all engines are now equipped with highly efficient particle filtration technology. Also, the engine has not only to fulfil emission limits during certification but also it can be tested using portable emission measurement technology (PEMS) by on-street driving during the first 700'000 km of its life. Similar in-use compliance regulations will also be implemented in the future for passenger cars with the intent to make them clean also under conditions which are not covered by the current emission certification procedure.

In the case of Switzerland, the Federal Office for the Environment publishes and updates regularly a comprehensive report where past and expected future emissions are quantified [21]. Figure 5.2 shows the situation for Switzerland and it can be seen that the continuous renewal of the vehicle fleet has had a drastic effect on the countries' emissions. It is expected that pollutant emissions from heavy vehicles will be nearly insignificant in the near future which also means that the share of pollutant emission on the external costs will strongly decrease. The remaining challenge from the power train side is to lower the energy demand of the vehicles and/or to integrate clean renewable energy. The EU is in the preparation phase for such actions [22].

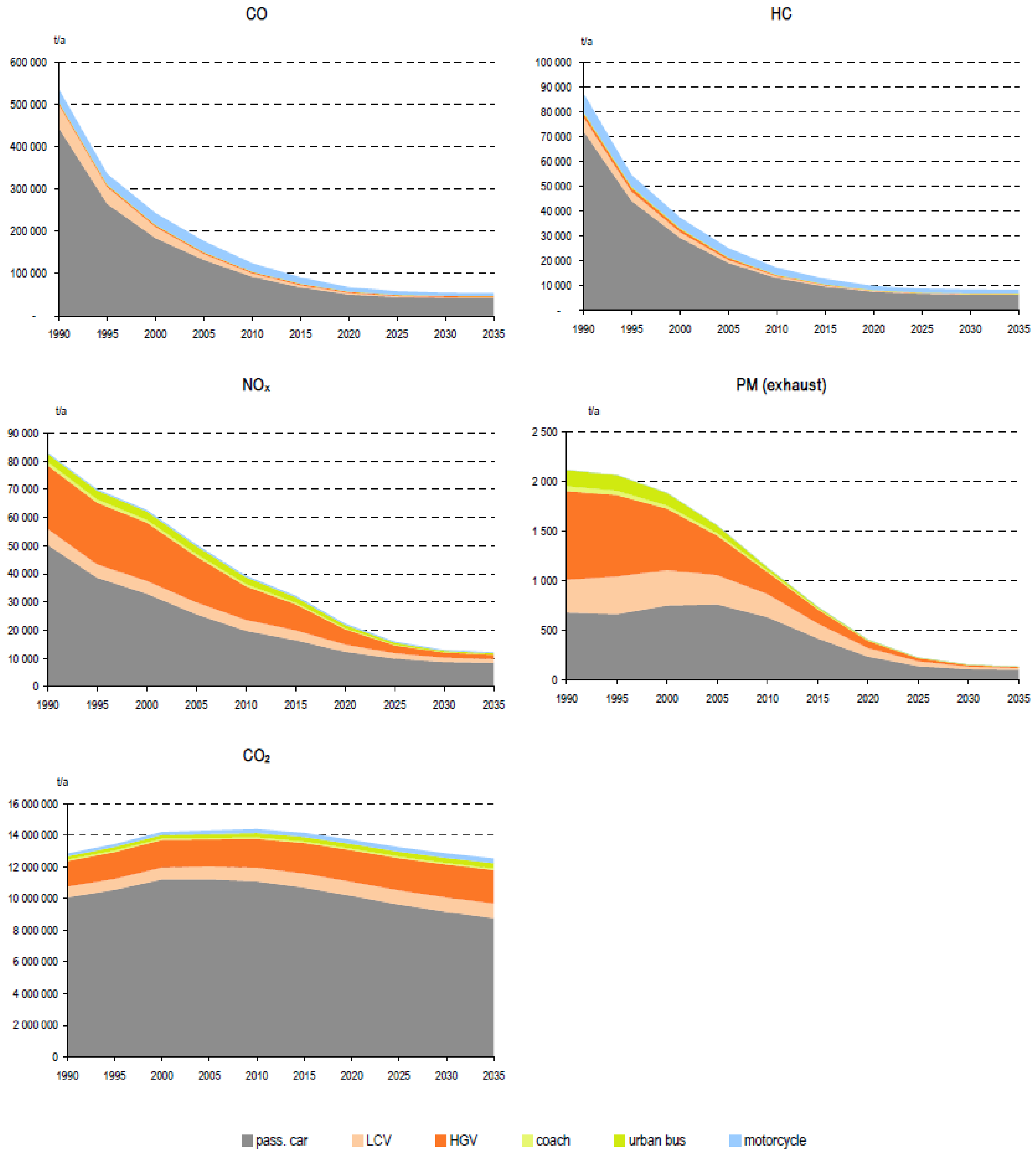
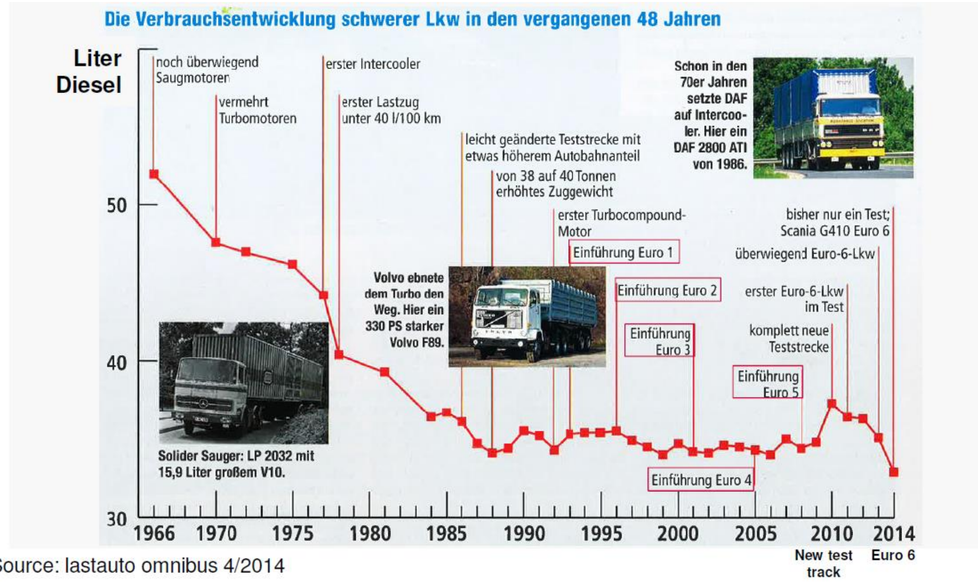


Figure 5.2: Emissions from road transport in Switzerland (from [21])

6 Fuel economy and impact of alternative powertrains

Maximising fuel efficiency was always a major development goal for heavy duty engines as fuel costs are a dominant factor for the vehicle owners. So, there was always a strong competition on fuel economy. As a result, the fuel consumptions for comparable vehicles are very close across all major manufacturers. Figure 6.1 shows independent fuel consumption test results from the German magazine “Lastauto Omnibus” over the last five decades.



Source: lastauto omnibus 4/2014

Figure 6.1: Fuel consumption test results of a German magazine (Lastauto Omnibus)

It can clearly be seen that fuel consumption dropped considerably (mainly due to the development of turbocharged and intercooled diesel engines) until emission limits were introduced in the 1990’s. The emission limits led then to a more or less stable fuel consumption level as the efficiency enhancement of the engines had to be surrendered to achieve the desired NO_x levels (there is a thermodynamical trade-off between efficiency and NO_x).

Since Euro VI, the engines can be optimised for low NO_x and better efficiency as NO_x is reduced by all manufacturers using a highly efficient after treatment process (SCR - selective catalytic reduction). Consequently, fuel consumption shows a decreasing tendency again (note in Figure 6.1 that the test track was changed in 2010 which led to a fuel consumption increase in 2010). Current Euro VI engines of model-year 2016 have reached a peak efficiency of around 46% and all manufacturers are working on new technologies to achieve 50% efficiency within the next decade which would roughly lead to a fuel consumption reduction of 10% compared with today. However, a peak efficiency of 50% would be very close to the maximum which can be achieved without using heavy, spacious and costly bottoming cycles (i.e. an additional heat engine which uses the enthalpy from the diesel engine’s exhaust as input).

The efficiency of the engine itself is a dominant, but not the only parameter which influences the diesel fuel demand of the vehicle. The driving patterns (which are given by the vehicle’s mission can also be influenced by the driver) as well as the vehicle’s driving resistances which also have a major impact on fuel consumption. While the driver’s influence can be mitigated to a certain amount by electronic driving aids, the reduction of the driving resistances (gearbox/axle friction, tyre rolling resistances, air drag) is technologically addressed. However, the limitation of the allowed vehicle length makes it difficult for goods vehicles to optimise aerodynamics while keeping the vehicle’s storage volume. This is not necessarily the case for other types of heavy vehicles like buses and coaches.

Especially for urban buses and vehicles with similar stop-and-go driving profiles, hybrid electric powertrains are gaining inimportance. Hybrid electric powertrains have, in addition to the internal combustion engine, at least one electric motor on board so that the vehicle’s power demand can be covered, if the combustion engine would have to run at inefficient low load, by a more efficient way and recuperation during braking can be used if on board storage is available. Hybrid electric vehicles can be either independent (autonomous hybrid) or dependent (plug-in-hybrid) from grid charging. Also, pure electric vehicles are being used which are either battery electric or use a contact wire. Alternatively, electricity can be produced on-board using fuel cells.

Additionally, alternative fuels for internal combustion engines are increasingly being considered, mainly to decrease greenhouse gas emissions. Alternative fuels are diesel-like liquid fuels such as biodiesel (XME), hydrogenated vegetable oils (HVO), biomass- or gas-to-liquids (BTL/GTL), ethanol-diesel (ED95), dimethyl ether (DME), power-to-liquid (PTL) and others. Also gaseous fuels are increasingly being used. This may be compressed natural gas (CNG) which consists mainly of methane which is often used in urban bus fleets and municipal vehicles. There are also initiatives to use natural gas in a liquefied form (LNG) for long-range transport, one example is the European “LNG Blue Corridors” project [23] where long-haul vehicles and fuelling stations along traffic corridors are being built-up. Also synthetic methane produced from electricity, called power-to-gas (PTG), is increasingly being discussed as it enables the long-term storage of electricity in the gas grid.

Comparing vehicles which use the same fuel is comparably simple as the measure for its primary energy use and for greenhouse gas emissions is the fuel consumption. Comparing different types of primary energy carriers gets more complicated as there are several parameters which have to be compared, such as primary energy and greenhouse gases. Using energy carriers which are produced from primary energy, such as hydrogen or PTG, or energy carriers which are produced from biomass are hard to be compared as their benefits and burdens are completely different compared to mineral fuels (e.g. land use, eutrophication, nuclear waste, value creation chain, burden/relief of the electric grid, increase/decrease of dependency, compatibility with fluctuating renewable energy, etc.).

Additionally, the judgement of benefits/disadvantages of alternative powertrains or energy carriers can be very national/regional. The use of electric vehicles can be, for example, socially accepted as a CO_2 reduction measure in regions which accept nuclear power or which have a constantly available excess of low-CO_2 electricity. In other regions which create additional electricity demand by coal power, plug-in vehicles do not make sense in terms of CO_2 reduction. The production of power-to-liquid or power-to-gas fuels makes economically and environmentally no sense in regions without temporal excess of low-CO_2 electricity but in regions with strong fluctuations of low-CO_2 electricity the production of such fuels can be used to maximise the use of green energy.

In summary, a comparison across different technologies and primary energy sources/carriers does not only depend on the vehicle alone but also strongly on the energy system of which the vehicle is part of. A meaningful labelling of vehicles therefore only makes sense on a regional basis. One such possibility is to assess primary energy demand by using regional/national primary energy factors and to assess CO_2 by using also regional/national factors. For example, Switzerland converts for its actual energy label on passenger cars all energy demand of vehicles to petrol-equivalents and accounts also for primary energy use of electricity by using a national primary energy factors (e.g. 1.36 $MJ_{primary\ energy}/MJ_{petrol\ fuel}$, 1.30 $MJ_{primary\ energy}/MJ_{diesel\ fuel}$, 1.07 $MJ_{primary\ energy}/MJ_{CNG}$, 2.79 $MJ_{primary\ energy}/MJ_{electric\ energy}$ according to [24]). However, if regional/national energy labelling for heavy duty vehicles should be developed a major problem is the actual lack of energy demand data. On EU level, a new legislation which would assess CO_2 emissions and energy demand from new HDVs is in preparation [25]. Once such data will be available, it can be used for the CO_2 / energy labelling of HDVs.

7. Characterising the interaction between a vehicle and its infrastructure

There is both a static and dynamic component of the interaction between a vehicle and the infrastructure on which it operates. The static load is characterised by the gross vehicle mass and the load per axle, and these loads allow goods vehicles to be classified [26]. The dynamic interaction for road vehicles is characterised by the *dynamic load coefficient* that is the average of the dynamic load divided by the static measured over a time interval [27].

For heavy goods vehicles, there is an agreed definition of what constitutes a road friendly suspension that is one that has a low interaction with the pavement [28].

The primary advantage of a 'road friendly' suspension is that it exerts a low axle force on pavements of motorway quality on which most mileage is accumulated. This low impact has resulted in a UNECE agreement to allow higher gross vehicle weights and drive axle loads (Table 7.1) [29]. Increasing the gross vehicle weight and axle loads has design implications for the residual life of bridges due to the increase in static loading. So there have been transitional periods in many countries to ensure that the infrastructure can withstand higher axle and vehicle loadings.

	non road friendly	**road friendly**	**comment**
gross vehicle mass (tonnes)	40	44	6 axles road friendly
drive axle load (tonnes)	9.0	11.5	
trailer axle load (tonnes)	8.5	9.0	

Table 7.1: Incentives for fitting 'road friendly' suspensions [29]

In countries like the UK, a further incentive to operators of such vehicles has been granted through a reduction on the annual road usage charge [30].

The dynamic load coefficient for 3 types of heavy goods vehicle suspension are shown in Figure 7.1. As air suspension is deemed road friendly, any other vehicle suspension whose dynamic load coefficient is equal or lower than that of air suspension should also be deemed road friendly although this is not the way that road friendly suspensions are currently defined [28]

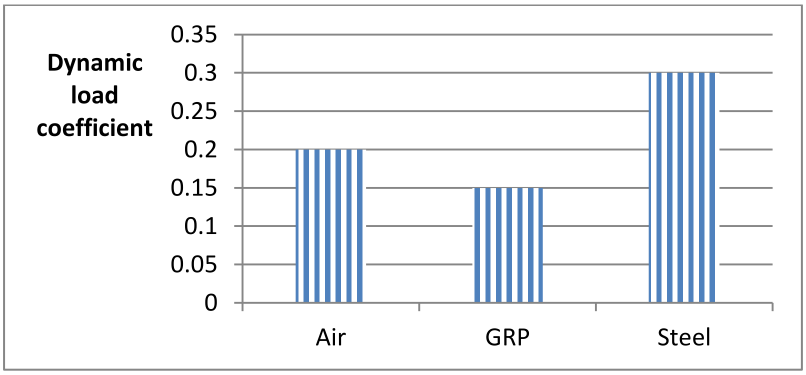


Figure 7.1: Dynamic load coefficient for three suspensions (typical worn concrete profile) at 90 km/h [27]

Equalising static load between axles

Road

In addition to low dynamic loading, it is also essential to equalise the static loads between axles and wheels. Shaker rig tests show that suspensions with a high proportion of friction damping are unable to equalise such loads. For freight vehicles this can be achieved by either fitting air suspension so enabling the pressure between air bags to be equalised or for GRP leaf suspensions by fitting low friction pads to the ends of the leaf [27].

Rail

Unlike road suspensions, there is no agreed definition of what constitutes a 'track friendly' suspension. This is because the dynamic interaction is more complex due to the way in which the steel wheel is guided (steered) by the rail. However, it is possible to characterise fundamental parameters of this interaction using an instrumented vehicle running on a track of known alignment or a vehicle shaker rig [27] through measuring the natural frequency and critical damping that characterise a vehicle suspension. This is illustrated in Figure 7.2 for 3 types of vehicle suspensions.

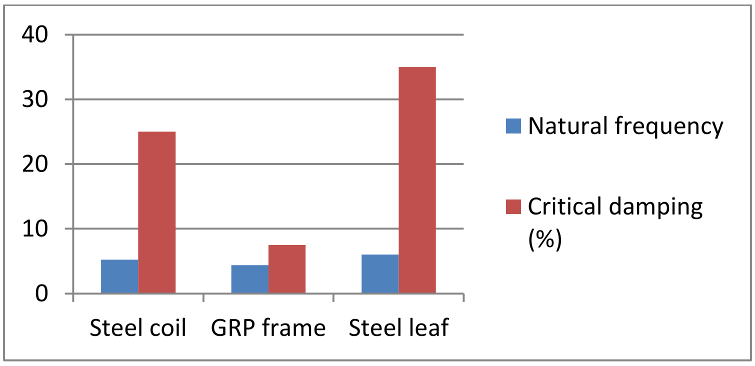


Figure 7.2: Characteristic parameters of the sprung mass resonance peaks for 3 types of rail vehicle suspension [31]

Evaluation of these suspension parameters will help not only to characterise a vehicle suspension but is also to control the dynamic load coefficient for an appropriate type of track alignment and vehicle speed. Such measurements would enable a definition of 'track friendly' suspension to be derived analogous to that for road friendly suspensions.

Equalising static wheel loads

European standards specify that the maximum misalignment between the two rails constituting the track cannot exceed 1% twist. For the axles of a bogie, this will result in a vertical offset of one wheel and the increased loads on the other wheels which must not exceed 60% of the static load [31]. For a rail suspension to be regarded as track friendly, an agreement should be sought to reduce such offset wheel loads significantly (from 60% to perhaps 30%?).

8 Damage to infrastructure

With increasing traffic the infrastructure maintenance costs are increasing and the time for maintenance is decreasing so limiting capacity. A combination of technology which creates more environmentally friendly vehicles and incentives for operators who operate such vehicles such as legislation for a bonus/malus system could presumably reduce this impact. This should be done on a European level in order to accelerate the introduction of a more sustainable European transportation system. Whereas the operator would like to move the greatest amount of goods as quickly as possible, the infrastructure maintainer wishes to minimise maintenance by reducing both static and dynamic loads.

On the road side, the damaging effects of the vehicle-pavement interaction are over simplified, as they are considerably different from the load configuration used in the current state-of-practice design procedures. Ignoring the speed, loading configuration and the viscoelastic pavement response in the current design procedures could result in underestimating the magnitude of the pavement response to a great extent. Furthermore, the state of the infrastructure plays an important role: higher surface roughness as a result of surface deterioration increase dynamic loads exerted on the pavement and eventually shortens the pavement surface life. An example is provided that shows the magnitude of the dynamic load coefficient (DLC) increased after 10 years resulting in up to 100% of increase in dynamic components of pavement response and resulting damage [33].

An important parameter in reducing vehicle infrastructure interactions is the suspension type. Road vehicles introduced road friendly suspension in 1992 and as a result vehicles with such suspensions can carry more loads [27]. To initiate the transition in the rail sector, it will be necessary to provide suitable incentives to vehicle operators as the benefits of ‘track friendly’ suspensions will be shared between the operator and the infrastructure maintainer.

Reducing static loads

The damage caused by static loads can be reduced by ensuring load equalisation amongst axles. In addition increasing the number of axles for a certain gross vehicle weight will also reduce loading on the infrastructure [28].

Reducing dynamic loads

Whereas it is relatively easy to specify axle load and gross vehicle mass limits, it is much more difficult to manage the dynamic loads which result from the interaction between the vehicle and the infrastructure. Road transport managed this 20 years ago through undertaking the research which led to the definition of ‘road friendly’ suspensions though the definition has been written around air suspensions rather than a performance specification [28].

If rail is to carry an increasing proportion of traffic as envisaged in various EU white papers then it would be desirable for rail to undertake the research now so that ‘track friendly’ suspensions could be defined which once adopted and encouraged could lead to lower track maintenance and high track usage.

However the full benefit of lower dynamic forces requires well aligned infrastructures as well as low track force suspensions because they form a coupled system.

Reducing noise and vibration

Reducing dynamic forces will also result in reduced audible noise and ground borne vibrations of which environmental noise is already prescribed by the Environmental Noise Directive 2002/49/EC. It is always preferable to reduce noise at source than erect noise barriers along the length of the track because of lower cost, reduced visual impact and greater effectiveness.

Further reductions in noise emissions will result if materials with high internal damping coefficients such as glass fibre plastics are used for the bogie frame. Noise reductions have been measured for road vehicles equipped with such suspensions, but not yet for rail vehicles.

Introducing bonus/malus payments

To reduce the environmental impact of road and rail transport, there needs to be incentives to both the vehicle operators and the infrastructure maintainers. The bonus/malus system introduced in the 2008 'EU Green Transport' package is being used to reward low noise emission railway vehicles and this could be extended to other vehicle and infrastructure parameters [4]. Reducing dynamic loading is an obvious choice as long life and low maintenance are equally important for infrastructures as well as suspensions. It is suggested that the bonus/malus system should be extended to encourage the introduction of 'track friendly' vehicles

Weigh in motion

Measurements made within the Footprint project and other studies [6] indicate that there are always a small number of vehicles (road or rail) which induce very high forces into the infrastructure, so initiating cracks which could ultimately result in extreme events like broken rails or damaged substructure. Whether these vehicles are overloaded or the suspensions poorly maintained is not known, but they can produce a disproportionate amount of damage.

Therefore, the use of in-situ weigh-in-motion (WIM) sensors embedded in the pavement or connected to the rail or sleeper is safety related and this information needs to be transferred to the operator and the owner in real time.

Discussion

With increasing traffic, the infrastructure maintenance costs are increasing and the time for maintenance is decreasing. A combination of better technology and incentives for operators to introduce such technology will reduce the impact of vehicles on the infrastructure. This should be undertaken on a European level in order to accelerate the introduction of a sustainable European transportation system for both road and rail.

In the on-going discussion on the adaptation of longer and heavier vehicles for road freight transport in order to increase the transport capacity the vehicle-infrastructure interaction should be taken into account. As the vehicle suspension and infrastructure form a coupled system, the resulting dynamic interaction can only be reduced by encouraging good design of both constituents. Long life and low maintenance for both vehicle and infrastructure are other very important design parameters as these affect reliability, safety and environmental impact of road and rail transport. With the ever increasing desire to move people and goods, the need to incentivise good design becomes ever more necessary.

9 Relating impacts to costs

In order to identify how to best internalise external costs from road freight transport, it was first necessary to understand how the costs might be linked to the different transport technologies currently on the road. Since, to a good extent, the costs are caused by the environmental impacts bound to the emissions of the vehicles, a first step was to identify how to relate costs to specific engine emissions.

The data used for the calculations presented in this section were obtained from the weigh-in-motion (WIM) and tolling monitoring site at Oberbuchsiten on the A1 Motorway, between Zurich and Bern, in Switzerland that was combined with a microphone for the noise measurements as explained in detail elsewhere [33]. The data were obtained in March, September and November 2011 from which data for 350’000 vehicles were analysed.

The external costs report [8] calculates the average cost per driven km for heavy vehicles due to pollutants to be 11.4 CH cents (Rappen) per km. Considering that this is the cost of the average truck, this value was assigned to the median heavy vehicle pollutants and the other vehicle pollutant emissions were calculated proportionally.

Furthermore, the external costs report [8] calculates the cost per driven km due to noise to be 15 CH cents (Rappen) per km. Considering again that this is the cost of the average truck, this value was assigned to the median of category eight or higher of the Swiss vehicle classes and the other vehicle noise emissions were calculated proportionally using a logarithmic scale.

Regarding infrastructure damage, the external costs [8] were calculated to be 400 Mio CHF. According to the data from the Swiss tolling office the transport performance was 69 billion tkm in 2014. Therefore the external cost of infrastructure damage can be calculated to be 0.58 Rp/tkm. In order to calculate the individual vehicle portion of the infrastructure costs the cost per t-km as calculated was multiplied by the tonnage carried by each vehicle in the data set.

The Swiss vehicle classification is shown in table 9.1

Swiss 1	Buses
Swiss 5	Delivery truck
Swiss 6	Delivery truck with trailer
Swiss 7	Articulated delivery truck
Swiss 8	Freight truck
Swiss 9	Freight truck with trailer
Swiss 10	Articulated freight truck

Table 9.1 Swiss vehicle classification

The total cost of each vehicle was calculated by adding all the individual costs for pollution, noise and infrastructure damage as listed above. The results for each Swiss 10 vehicle category are shown in fig 9.1. It can be seen that regarding cost per km, vehicle categories 9 and 10 bear the highest costs. However, if the cost per tonne and km is calculated a different picture is seen implying that it costs less overall if more tonnage is transported.

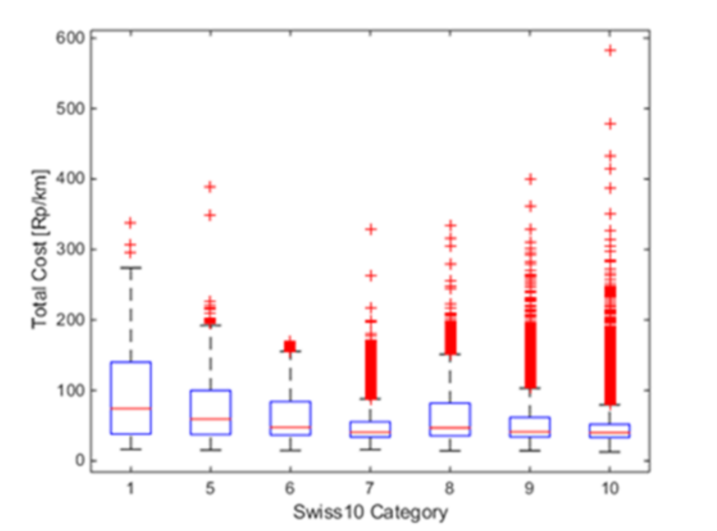


Fig 9.1 Total cost (Rp/km) for each Swiss 10 vehicle category (articulated freight truck)

10 Labelling environmentally friendly vehicles

A label is means of representing specific information about a product or system which will enable a buyer to select a product closest to his needs. The framework directive for the EU energy label was approved in 1992 [34] with refrigerators and freezers being the first energy consuming products to be labelled in 1994. Since then the labelling scheme has been applied to a very wide range of products and systems. This type of label does not merely display a classification of energy consumption, usually on a scale of A to G, but also makes provision for displaying performance classes and environmental impacts.

The advantages of a uniform method of product labelling are manifold –

- Each model of a product or system can be characterised
- The label can be affixed to every model so its characteristic performance and energy consumption can be compared with other models in its class
- The visual display allows the various classifications to be easily understood
- Enables initial and lifetime costs to be compared in terms of energy usage
- Facilitates a dialogue between buyer and seller which enables the buyer to select a product closest to his needs

While labelling was originally opposed by manufacturers, they soon realised that labelling could be used as a marketing tool to differentiate their products from those of their competitors. The success of the labelling scheme has resulted in the label being widely adopted not only within the EU but also in other non-EU countries such as those belonging to the European Economic Area and Turkey.

Labels already exist for fuel consumption and carbon dioxide emissions for cars; however, the label information differs in each country even though the vehicle models may be identical [35].

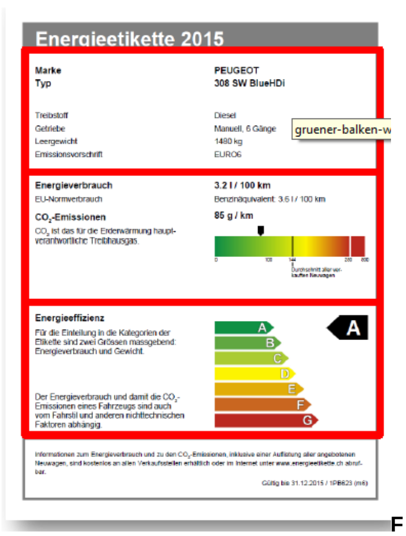


Figure 10.1: Swiss car label

What is easier to understand and compare is the EU tyre label which is the same in all Member States (figure 4.2). The successful introduction of this label suggests that this layout could also form the basis of a label for environmentally friendly vehicles.

We have adopted this layout to develop a label on which is indicated the four major external and internal impacts of vehicles with the environment and infrastructure that have been considered in preceding sections that is –

- Carbon dioxide emissions
- Fuel consumption
- Audible noise
- Dynamic interaction of a vehicle with its infrastructure (pavement or track)

By characterising each of these impacts it is then possible to define an *environmentally friendly* vehicle as one with a low environmental footprint [6].

The proposed label is illustrated in Figure 10.2

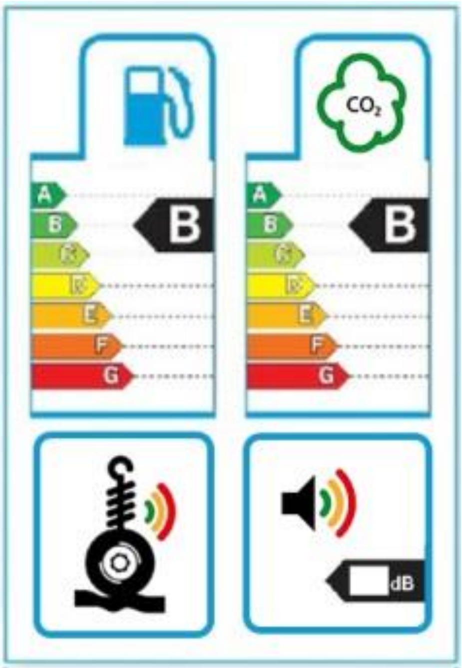


Figure 10.2: Proposed label for an environmentally friendly vehicle

For *CO_2 emissions and fuel consumption*, it would be appropriate to use the A to G scale commonly used on EU labels, with class A being the most fuel efficient or having the lowest CO_2 emissions and class G the least efficient and highest level of CO2 emissions. While such classes have been characterised for passenger cars, there is no agreed classification for other types of vehicles including heavy goods or rail freight vehicles.

For *noise* emissions, three limits are proposed – current, reduced and very quiet.

For the *dynamic* interaction between the vehicle and its infrastructure, whether the vehicle's suspension can be classified as road friendly or track friendly. Unlike road vehicles, the concept of 'track friendly' suspensions has yet to be defined and agreed for rail vehicles.

Clearly different limit values will be required for different classes of vehicles, road as well as rail. For some vehicles with a choice of fuel, the fuel type will also need to be specified.

The label by itself is unlikely to introduce a step change in the way vehicles are purchased. However both environmental pollution and damage to the infrastructure are external costs generally borne by society. As environmentally friendly vehicles will carry a lower socio-environmental cost, it should be possible to encourage their uptake by suitable incentives such as a reduction in road usage or track access charge.

By subsequently setting minimum efficiency standards, it will be possible to ban the most inefficient models of vehicles from the market thereby increasing the overall efficiency of the vehicle fleet and reducing the associated environmental emissions including greenhouse gases.

11 Discussion

To define vehicles that can be classified as environmentally friendly, it is necessary to analyse the external costs such as has been done in Switzerland (section 2) from which the major impacts of a vehicle with its environment and infrastructure have been identified as

- Noise emissions
- Carbon dioxide emissions
- Energy consumption
- Low dynamic loading on the pavement or track

Gaseous emissions such as NO_X and particulates such as PM10 are excluded because of on-going developments in terms of engine management, catalytic convertors and filters.

It is proposed that these impacts should form a vehicle's environmental footprint and that the size of the footprint should be classified through the use of an EU type energy label.

The benefits of such a classification will enable

- Communities able to develop strategies most likely to encourage the uptake of such vehicles thereby reducing their impact
- Operators able to identify and purchase vehicles which are environmentally friendly
- Manufacturers able to design and market products with a low environmental footprint
- Infrastructure maintainers able to identify and offer incentives to vehicle operators with a low environment footprint

For the *road* mode all these impacts are covered by normative measures and standard duty cycles though not necessarily for all types of vehicles. There are also labels defining noise from tyres and CO_2 emissions from cars and there is an agreed definition of what constitutes a road friendly suspension which exerts a low dynamic force. So where data already exist, this could be analysed to provide a classification provided the data are reliable and reproducible. Where data do not exist for certain types of vehicles, it should be agreed to collect such data so they too can be classified..

The situation for the *rail* mode is very different because no such labels currently exist nor is there any agreement on what constitutes a standard duty cycle nor what constitutes a track friendly suspension. For the EU goal of shift to rail to be achieved by 2030, it will be essential to encourage the uptake of environmentally friendly rail vehicles which will have to operate on existing tracks. The proposed label will help not only to identify such vehicles but, of equal importance, help infrastructure maintainers to offer suitable bonus payments to help transform the market for such vehicles on a European wide scale.

12 Conclusions

The most favourable way of reducing the impact of road and rail transport is to identify and encourage the uptake of environmentally friendly vehicles from an analysis of their respective socio-economic costs. As labelling has been successful in reducing energy consumption and environmental impact of energy using products, it is logical to consider labelling the entire vehicle in addition to individual components. It is then possible to characterise the environmental impacts so they can be displayed on an EU type label with the most environmentally friendly vehicles having the lowest environmental footprint..

The introduction of an environmental label will allow internalisation of some of the external costs of transport through the use of the bonus/malus rule introduced in the 2008 EU Greening Transport package.

References

[1] The first truly successful container shipping company dates to April 26, 1956, when American trucking entrepreneur McLean put 58 *trailer vans* [30] later called containers, aboard a refitted tanker ship, the SS *Ideal X*, and sailed them from Newark, New Jersey to Houston, Texas

[2] 21st Conference of the Parties to the UNFCCC (COP 21) (2015) see http://c2es.org

[3] The measurement of the environmental footprint of a road or rail vehicle was the subject of the preceding Eureka project E!2486 entitled Footprint from 2001 to 2009

[4] Communication from Commission to European Parliament and Council, Greening Transport , COM (2008) 433 (2008)

[5] Noise bonus per t/km are paid by the Dutch, German and Swiss authorities for rail freight vehicles whose emissions are less than 86 dBA

[6] Impacts of vehicles with infrastructure and the environment as measured by Footprint measuring systems , Final report Footprint project E!2486 (EMPA) (2009)

[7] Regulation (EC) No 1222/2009 of the European Parliament and of the Council of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters. European Commission, Brussels.

[8] Eco plan, Infras : Externe Effekte des Verkehrs 2010. Monetarisierung von Umwelt-, Unfall- und Gesundheitseffekten. Publiziert unter ARE, Themen, Verkehrspolitik, Kosten und Nutzen (2014)

[9] Lees, A., Van Loo, H., (2014), Project plan WIM Quality International Benchmark, internal document as part of the EcoVehicle Project;

[10] FHWA, (Federal Highway Administration), (2009), FHWA-IF-09-038, WIM Data Analysts Manual

[11] Ding, L., Van Renterghem, T., Botteldooren, D., 2011. Estimating the effect of semi-transparent low-height road traffic noise barriers with ultra weak variational formulation, Acta Acustica united with Acustica Vol 97, 391-402.

[12] Van Renterghem, T., Forssen, J., Attenborough, K., Jean, P., Defrance, J., Hornikx, M., Kang, J., 2015. Using natural means to reduce surface transport noise during propagation outdoors, Applied Acoustics Vol 92 86-101 .

[13] Echevarria Sanchez, G. M., Van Renterghem, T., Thomas, P., Botteldooren, D., 2016. The effect of street canyon design on traffic noise exposure along roads, Building and Environment Vol 97, 96-110.

[14] De Coensel, B., Brown, A.L., Tomerini, D., 2016. A road traffic noise pattern simulation model that includes distributions of vehicle sound power levels, Applied Acoustics Vol 111, 170-178.

[15] Heutschi, K., Bühlmann, E., Oertli, J., 2016. Options for reducing noise from roads and railway lines, Transportation Research Part A: Policy and Practice Vol. 94, 308-322.

[16] Heutschi, K SonRoad: New Swiss Road Traffic Noise Model, Acta Acustica united with Acustica, vol. 90, 548-554 (2004).

[17] Thompson, D., 2009. Railway Noise and Vibration: Mechanisms, Modelling and Means of Control, Elsevier

[18] International Maritime Organization, “Sulphur Limits in emission control areas from 1 January 2015,” 2015.

[19] Climate and Clean Air Initiative, “Market Baseline Study on Low Sulphur Fuels,” 2016.

[20] EU Commission, *COMMISSION REGULATION (EU) No 582/2011 of 25 May 2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy duty vehicles (Euro VI)*, vol. L 167. 2011.

[21] Swiss Federal Office for the Environment FOEN, “Pollutant Emissions from Road Transport, 1990 to 2035,” 2010.

[22] “EU Action: Reducing CO2 emissions from Heavy-Duty Vehicles.” [Online]. Available: http://ec.europa.eu/clima/policies/transport/vehicles/heavy/index_en.htm.

[23] N/A, “LNG Blue Corridors - Demonstration of heavy duty vehicles running with liquefied methane.” [Online]. Available: http://lngbc.eu/.

[24] BFE, “Grundlagen für die Berechnung der Benzinäquivalente und Primärenergie-Benzinäquivalente im Rahmen der revidierten Energieetikette,” 2014. [Online]. Available: http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=de&name=de_769553018.pdf.

[25] “Reducing CO2 emissions from Heavy-Duty Vehicles.” [Online]. Available: http://ec.europa.eu/clima/policies/transport/vehicles/heavy/index_en.htm.

[26] For vehicle classification in UK and Switzerland, consult reference [6]

[27] GRP suspensions, a new possibility for buses, Proc 30th meeting of coach and bus experts, Gyor, Hungary (1999)

[28] EU regulation, relating to road friendly suspensions 92/ 56

[29] EU directive 96/53/EC laying down for certain road vehicles the maximum authorised dimensions and maximum authorised weights

[30] Proceedings Ecovehicle workshop #3, refer www.empa.ch/ecovehicle (2014)

[31] UK Railway Group standard GM/RT 2141 (RSSB)

[32] Proceedings, Ecovehicle workshops, Empa, refer www.empa.ch/ecovehicle

[33] Poulikakos, L. D., Heutschi, K., Arraigada, M., Anderegg, P., & Soltic, P. Environmental footprint of road freight: Case studies from Switzerland. Transport Policy, 17(5), 342-348 (2010)

[34] The original framework directive for energy labelling of energy consuming products was published as 92/75/EEC and was revised in 2010 as 2010/30/EU

[35] Swiss car label is based on the requirements of EU directive 1999/94/EC on the fuel

consumption and emissions of new cars