Heavy-Duty Vehicle Weight Restrictions in the EU
Enforcement and Compliance Technologies

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Content

1. Introduction 3

2. Vehicle loading 4
   Loading issues 4
   New technologies 5

3. Traffic loading 5
   Freight traffic in Europe 6
   Traffic overloading 7
   Traffic loading and freight mobility 8
   Traffic loading and road infrastructure 8

4. Measurements of traffic loading 10
   Static weighing 10
   Low-speed Weigh-in-Motion 11
   High-speed Weigh-in-Motion 11
   On-board weighing 17
   OBW versus WIM 20

5. Enforcement of overloaded vehicles 21
   Current practices 21
   Enforcement strategies 22
   How many WIM systems would be needed for enforcement? 22
   Future enforcement 23
   How to mitigate overloading? 23

6. Conclusions 24

7. References 26
1. Introduction:

Heavy-Duty Vehicles (HDVs) including Heavy Goods Vehicles (HGVs), buses and coaches using European roads must comply with rules on weights and dimensions set out in Directive 96/53/EC. This Directive establishes maximum common measures to ensure that road safety is not jeopardised and that degradation to roads, bridges and tunnels is minimal. It also:

- ensures that the member states cannot restrict within their territories the circulation of vehicles which comply with these limits from performing international transport operations;
- allows for fair competition by preventing the national operators to benefit over their competitors from other member states when performing national transport; they are bound to comply with the standards set for international transport.

At the same time, the freight vehicle industry is working on:

- lowering the cost of freight transport which has direct economic consequences for users and for society;
- lowering the environmental impacts in line with social responsibility goals;
- improving safety.

However, certain limits on weights and dimensions set by the Directive constitute obstacles to these objectives and to modern transport in general. Three main groups of problems have been identified:

1. The current maximum dimensions of HGVs prevent the market uptake of more aerodynamic vehicles which would exceed the current HGV length limitations. Moreover, these rules are preventing the market uptake of electric/hybrid HGVs and coaches which, being heavier than the conventional types, would have to reduce their payload or number of passengers per coach.

2. The prescribed maximum dimensions do not keep pace with the technical developments of intermodal transport. For example, the 45-foot containers used in maritime transport can only be transported on land with special permissions.

3. In a context of fierce competition, operators maximising their load can gain a substantial competitive advantage over others who follow the rules. This issue requires more efficient enforcement policies and control practices that would prevent infringement while not impeding vehicles which comply with the rules.

On 15 April 2013, the Commission released a text for a revision of Directive 96/53/EC. In view of the above issues, it proposes that the member states establish a system for pre-selecting and for targeted checks of vehicles in circulation in order to ensure compliance with weight requirements. These weight measures may be obtained by using automatic systems set up in the infrastructure or on-board systems installed in the vehicles.

Considering the actual gross vehicle weights (GVW) and axle loads (AL) with respect to different types of vehicles of transport/of commodities as well as geographical differences is key to understanding the problem. One obstacle to rolling out heavier vehicles is the existing infrastructure which is not always capable of accommodating them. For example, over 50% of European bridges are over 50 years old and were built at a time when traffic loading was considerably lower. Further, as they deteriorate, their capacity and ability to sustain modern traffic load and loading are declining. This is less of a problem for international haulage because motorways on the main European corridors are newer and designed for higher loads.

To facilitate discussions about changes of weights and dimensions of freight vehicles, the revision of the Directive suggests that the member states should efficiently control traffic loading. They are supposed to perform a minimum number of vehicle checks, using either weigh-in-motion (WIM) systems or on-board weighing (OBW) sensors in vehicles which communicate remotely with roadside inspectors. These measurements would allow the inspection authorities to filter the vehicles so that only vehicles strongly suspected of infringement are stopped for manual inspection. Using this approach, the costs for correctly loaded haulers do not increase due to additional or unnecessary inspections.

This document begins by introducing the loading problem of typical modern vehicles, the kerb weight of which is well above that seen 20 years ago due to enhancements both planned and implemented.

The second chapter deals with traffic loading in Europe and highlights differences between national and international haulage. This second part examines the effect on pavements of HDV circulation. In civil engineering terms, ‘pavement’ is taken to mean any hard layered structure that forms a road carriageway, airfield runway, vehicle parking lot, or other paved area. It is composed of the wearing course (surface) and different layers of compacted bound and unbound materials.

The third chapter presents the available technologies for weighing HDVs: the static scales, the weigh-in-motion systems and on-board-weighing systems, each with their respective advantages and disadvantages.
The fourth chapter gives an overview of European overload enforcement practices with some ideas as to how these may look in the future.

2. Vehicle loading

The average loading of HDVs has been increasing in recent decades. The main drivers for this have been the needs of growing economies and, consequently, the roll out of the new vehicle technologies that made such an expansion possible. While the national legislation of the 11 EU countries that contribute 50% sales volume of the heavy freight vehicles (Ekander, 2013) has been adapted to higher weights and dimensions, Directive 96/53/EC has not kept pace. Its revision is a good opportunity to consider some of the obstacles that international haulage is facing. Two issues in particular stand out:

1. There are no tolerances or margins left for 4x2 tractors, the most common type of freight vehicle in international haulage.
2. Strategic decisions with respect to safety, environment and mobility of road transport require new technologies which increase the kerb weight of the vehicles. Existing limitations in the Directive pose a serious hindrance for the market uptake of these technologies.

LOADING ISSUES

Take as an example the most common long-distance vehicle in Europe, the 4+2 tractor with a 3-axle semi-trailer; its axle load and gross weight limits according to the 96/53/EC Directive are given in Figure 1. Today, its kerb weight is around 14,900kg which, at 40 tonne gross weigh allowance, leaves 25,100kg for potential payload.

The centre of gravity of such a fully loaded vehicle has its total mass divided roughly between one third to the tractor unit and two thirds to the triple axle of the semi-trailer. Of the load on the tractor unit, around 5/6 are borne by the driving axle. With optimal loading, these vehicles just comply with the limits from the Directive (Ekander, 2013), as shown in Figure 2 (Dahlberg, 2014). This is fine as long as the vehicles are delivering goods from point A to point B. However, many transportation trips are of the multi-drop delivery type in which the vehicle is only partially unloaded at each stage. In this case, the common rear-end loading affects the load distribution. Despite the lower gross weight of the vehicle, the centre of gravity moves to the front, which adds to the load on the driving axle. Already being on the limit, it can easily become overloaded Figure 2, bottom. This situation could, to some extent, be avoided by encouraging the greater use of 6+2 tractors which are friendlier to the road surfaces than the 4+2 tractors and could carry 4 or even 6 tonnes more without
increasing their impact on the road surfaces. Although such heavier vehicles would cause higher load effects on bridges, these would, on shorter spans, still be lower than legally loaded 4-axle rigid trucks.

NEW TECHNOLOGIES

The kerb weight of the average 4×2 tractor unit has increased by 10% since the introduction of 96/53EC Directive, ie roughly the time between the implementation of the European Emission standards Euro II to Euro VI. The main reasons for this are improvements of the products primarily dealing with:

• fuel economy;
• environmental performance (emissions);
• safety;
• driving experience.

In their development pipeline, vehicle manufacturers have a number of enhancements that will increase the safety and environmental friendliness of heavy transport, in line with the strategic decisions of the EU. However, they all increase the kerb weight of the vehicles. Examples include (Eknander, 2013):

- more aerodynamic front with improved crash protection: + 250kg
- Euro VI engine (now mandatory): +80-150kg
- hybrid truck: + 500-700kg
- waste heat recovery: + 250-300 kg
- electrified road system: + 700-1000 kg

Clearly, these developments cannot be applied within the limitations specified in Directive 96/53/EC without seriously reducing the payload. Such a situation prevents the market uptake of electric/hybrid HGVs and coaches which, being heavier than conventional vehicles, would be economically unfeasible.

3. Traffic loading

The current restrictions on vehicle and vehicle combinations weights are based on safety considerations and a desire to limit the wear that HDVs cause to road surfaces, substructures and bridges. Current EU law (Directive 96/53/EC) limits the maximum permissible vehicle mass to 40 tonnes, except for intermodal transports using 40-foot containers which are allowed a maximum weight of 44 tonnes. Maximum axle loads are 10t for a single axle and 11.5t for a driven axle, 11.5t to 19t depending on axle spacing for a tandem axle and 11t to 24t for a tridem axle. There is no specific mass limit for the steering axles, but other vehicle design constraints result in an effective mass limit of 8 tonnes. Vehicles which diverge from the EU regulations are permitted in national operations or after applying for a special permit.
Since the economic crisis of the late 2000s, the previously steady increase in freight traffic in Europe has slowed and has today recovered to the level seen in 2004 (EC, 2014). This is the case for all three main modes of transport: road, rail and sea.

It should be noted that proportion of international versus national haulage varies considerably between EU member countries. While the percentage of the international haulage in EU15 countries dropped from 37.0% to 31.2% since the year 2000, it has in the EU13 countries (that joined the EU in year 2004 and later) in the same period increased from 49.6% to 64.2%. As a result, the overall percentage of international haulage in EU28 countries is still rising.

Apart from Luxembourg, there are four EU13 states in the top 5 with the highest percentage of international haulage. For example, in 2012 in Lithuania and Slovenia, the percentage reached almost 90%, which is not surprising as they lie on the crossroads of the Trans-European Corridors. As such, they are typical transit countries. In contrast, other countries have on average 90% of national haulage.

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<thead>
<tr>
<th>COUNTRY</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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<tr>
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<td>Luxembourg</td>
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<td>92.1</td>
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<td>Latvia</td>
<td>75.5</td>
<td>78.5</td>
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There are at least four main reasons for overloading:
1. One of the primary reasons is economic. Carrying 10% more load is roughly the same as a 10% saving. The fine if caught overloaded is relatively high (though this varies significantly from country to country), but the likelihood of being apprehended is low. Accordingly, even if caught overloaded once, the cost of the penalty can be offset through additional overloaded runs.
2. A lot of axle overloading can be blamed on inappropriate vehicle loading, particularly in the case of multi-delivery transport. This can occur when portion of a payload is unloaded from the vehicle with unintended redistribution of the axle loads.
3. Vehicles with axles that can be lifted off the ground can end up with redistributed loads which can result in axle overloading.
4. Current rules in Europe discourage the use of 3-axle tractor units despite the fact that they would improve efficiency and road-friendliness of the vehicles. A single driving axle on a 2-axle tractor unit is more easily overloaded.

Overloading regulations must be enforced to ensure fair competition and to protect the infrastructure. Due to varying situations throughout Europe, overloading is detected at very different levels. In countries with strict enforcement policies, it is typically relatively low (except on local roads near quarries, gravel pits or in some agricultural areas). In countries where overloading is uncommon, it is usually a more serious issue. Last but not least, if enforcement is pursued, drivers learn how to load their vehicles, and the axle overloads are much lower than before the rollout of weight enforcement.

Information about traffic loading and overloading throughout Europe is difficult to obtain as it is not available to the public. Primarily, this is because not all countries have the weigh-in-motion systems in place to collect data on network level. Furthermore, not all European countries have WIM networks. Thus, for the purposes of this report and to get an idea about the characteristics of overloading in both national and international transport, the situation in Slovenia was analysed. There are three reasons for the selection of Slovenia: 1. Very detailed information is available. 2. Loading and overloading data is collected annually in over 50 locations on the motorways and on state roads. 3. With almost 90% of all freight in the country being international haulage, it is safe to assume that data from the state roads (Cestel, 2013) represent the national traffic and data from the motorways (Cestel, 2012) the international traffic.

Table 2 summarises the overloading results of weekly or monthly weigh-in-motion measurements from 40 state roads sections (Cestel, 2013) and from 16 motorways sections (Cestel, 2012). The table presents the minimum, maximum and average proportions of overloaded vehicles and

<table>
<thead>
<tr>
<th>COUNTRY</th>
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<th>2011</th>
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</tr>
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</tr>
<tr>
<td>Finland</td>
<td>14.9</td>
<td>11.6</td>
<td>13.8</td>
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Figure 6 displays the evolution of extra loading on pavement due to overloaded vehicles on state roads (national haulage) since 2002, when systematic WIM measurements and intensified static enforcement controls began. A steady decrease in overloading rates can be observed since 2006.
increments of traffic loading due to overloading expressed in standard axles (see the following chapter), per type of road and per traffic direction. While the percentage of overloaded vehicles (gross weight or axle loads) on motorways is only 45% lower than on state roads (10.8% vs 15.3%), the actual increment of pavement loading is 11 times lower than on state roads. Moreover, the variation between the minimum and maximum overloading is far smaller than on national roads. This confirms the assumption that international traffic has far lower overloading rates and is easier to predict than with local/national traffic.

### TRAFFIC LOADING AND FREIGHT MOBILITY

Efficient road transport enhances economic competitiveness. As such, it must be supported by an integrated, multimodal freight transportation system that provides safe and sustainable freight mobility. A system that facilitates the reliable and efficient movement of freight should:

- be competitive;
- relieve congestion;
- improve safety, security and resilience of the freight transportation system;
- preserve infrastructure;
- employ innovative technologies and practices;
- be environmentally-friendly.

Heavier and longer vehicles, particularly on long-distance corridors, would contribute to a number of the above issues. By carrying greater payloads with fewer vehicles, they would be more competitive and fuel-efficient. They would reduce congestion, which is a factor in fuel consumption, and would consume considerably less energy per unit of freight compared to the present fleet of vehicles (Cebon, 2014). On the other hand, depending on the increase of weight and dimensions, there would be some negative effects on the infrastructure, particularly bridges, which may have to be upgraded. Therefore, any changes must be well justified to ensure that these larger vehicles provide more efficient, sustainable transport and a suitable return on investment.

### TRAFFIC LOADING AND ROAD INFRASTRUCTURE

#### Pavement Loading

Heavy trucks increase pavement wear and, thus, contribute to premature pavement failure.

A pavement’s structure is subjected to moving traffic loading which deflects its surface. This induces tensile stresses in the bound asphalt or concrete layer which, over time, causes irreversible deformations in the underlying layers of unbound granular materials and in the subgrade.

The repeated action of the loading causes fatigue damage in the bound layers which eventually deform and crack, leading to permanent deformation of the road surface. The pavement reaches the end of its life when the severity of cracking and/or permanent surface deformation exceeds acceptance levels for safety, comfort and transport economics.

Traffic is typically reduced to units of Equivalent Standard Axle Load (ESAL). Its definition is over 50 years old (Cebon, 1999) and remains the same throughout Europe, but the parameters vary from one country to another (reference load, area of contact with the road, form of performance laws considered).
The equivalence factors are sometimes called “aggressivity” (COST 323, 2002). It is supposed that the aggressiveness of an axle is calculated according to the law in power $\alpha$:

$$ a = \left( \frac{P}{P_S} \right)^\alpha $$

where $a$ is the equivalence factor, $P$ is the measured dynamic axle load, $P_S$ is the reference weight of such axle, and $\alpha$ is the power related to the type of pavement (rigid, semi-rigid, flexible...). The fatigue damage of well-designed rigid pavements is around one half that of standard flexible pavements (Cebon, 1999), and weaker pavements are much more sensitive. Still, most countries use a constant power of 4 for all types of pavements.

For a whole traffic with $N$ axles, the total aggressiveness, $A$, is defined as:

$$ A = \sum_{i=1}^{N} \left( \frac{P_i}{P_{S,i}} \right)^\alpha $$

Here again, the traffic composed of flows of various vehicles and loads is reduced to a cumulative number of passages of a loaded reference axle. This equivalent traffic would produce the same rate of distress as the actual combination of varied traffic loads. The equivalent number of standard axles is converted into a service lifetime on the basis of assumed or simulated traffic flows and composition.

It is important to understand that the rate at which a vehicle wears down a road is proportional not to its gross weight but to the power of its axle loads. Therefore, assuming the 4th power, the effect of 5% overload would result in a $1.05^4 = 1.22$ or 22% increase and 20% overload in a $1.20^4 = 2.07$ or 107% increase in fatigue damage.

It should be noted that pavement fatigue damage per unit of payload generally decreases for larger vehicles (Cebon, 1999).

**Bridge loading**

Bridges are critical components of any road transportation network. It is therefore of utmost importance that they are kept in operation without major disturbances, such as closures due to repairs. During their lifetime, bridges deteriorate while loading increases. Both factors affect their safety. Unlike pavement failures, which primarily reduce driving comfort, bridge failures are not acceptable as they can cost lives and, consequently, undermine confidence in the entire transportation infrastructure.

The main problem with respect to European bridges and traffic loading is their age. More than half are well over 50 years old (SAMARIS D19, 2006) and they were not built for today’s traffic load. Figure 8 shows a bridge load test with typical heavy vehicles from the late 1960s. At that time, the number of twin axles was low and triple axles did not even exist.

Since the beginning of last century, seven bridge design codes have been used in Slovenia, beginning with the Austro-Hungarian code from 1904. However, only the most recent designs, built in the last 40 years, can withstand the modern traffic. Fortunately, many bridges are stronger than their theoretical design capacities suggest, particularly on the main corridors on which they are generally newer and have been built or strengthened according to modern standards. Consequently, it can be said that most bridges on the European long-distance corridors should be capable of carrying traffic conforming to Directive 96/53/EC’s requirements, even if the rules are updated.

![A bridge load test with typical freight vehicles from the late 1960s](image)

**Consequences of increasing traffic loading on infrastructure**

When discussing higher traffic loads, one should be aware of the fundamental difference between pavements and bridges:

- Pavements are built for specific numbers (a few 100-thousands to a few million) of standard axles. With the exception of under-designed structures, these should not fail under heavier axles, but may deteriorate faster.
- Bridges are designed with a maximum loading level in mind. If the loading increases, the safety factors decrease,
which is acceptable only to a certain degree. To assess a bridge's structural safety, the axle loads must be converted into load effects (moments, forces). The severity of the traffic load therefore depends on the type and size of the bridge.

Consequently, the capacity of pavements is easier to control for, and higher loading primarily means that they will have to be repaired sooner. The safety of bridges is a different issue and many countries are strict in ensuring that the safety levels for bridges are preserved. They are not in favour of increasing the dimensions and weights of freight vehicles per se. Others are more liberal, especially with respect to permitting special heavy transports. For example, due to the high number of special transports, the true loading on Dutch bridges is very close to the current design load (EN 1991 - Eurocode 1, 2009), or 40% higher than in four other compared countries (ARCHES D08, 2009). This resulted in the accelerated fatigue damage of steel bridges and a number had to be renovated or closed for traffic, resulting not only in high direct costs for repair but also significant indirect costs due to traffic delays and detours.

Strengthening bridges to allow higher traffic loads is, in respect to returns on investment, adjusted in terms of safety, environmental friendliness and efficiency of transport. As a result, only a few wealthier European countries have decided to systematically strengthen all of their bridges for higher traffic loads.

4.

Measurements of traffic loading

The most common devices for collecting information about traffic flows are traffic counters. Counting technologies vary from simple manual checking to rubber tubes, inductive loops and more modern optical and laser devices. Traffic counters are indispensable for collecting traffic flow information, but they do not provide any evidence about the true axle loading of the heavy vehicles.

To know the actual axle loads (AL) and gross vehicle weights (GVW) of the heavy vehicles, these need to be weighed. This can be done statically, in-motion or with on-board weighing systems Figure 9.

STATIC WEIGHING

Static weighing is by far the most accurate method for weighing vehicles. In most countries, it is the only legal reference to fine offenders. Three types of devices are used for weighing the vehicles:
• weighbridges;
• axle weighers;
• wheel weighers.

Weighbridges (or truck scales in the US) are composed of a set of scales, usually mounted permanently between a steel weighing platform and a concrete foundation. The mechanism weighs the entire vehicle and its contents. The weighing sensors are typically the load cells. These devices
are common at the entrances of factories, quarries, dumps, warehouses etc. In Europe they are rarely used exclusively for overload enforcement, unlike in the US. The main reasons are the high construction and operational costs and large area of land they require. The devices are certified and must be regularly calibrated.

More common in Europe are the axle and wheel weighers. They provide information on the axle loads, but their accuracy is lower than that of the weighbridges, because stop-and-go driving over them can cause considerable redistributions of the loading. Very popular are the portable wheel load scales Figure 11 that are moved from one site to another, which improves efficiency of overload enforcement. To avoid redistribution of axle loads due to different levels of the axles, the scales are placed between levelling mats. The devices are certified and must be calibrated as often as possible.

**LOW-SPEED WEIGH-IN-MOTION**

When performing a low-speed Weigh-in-Motion (or LS-WIM) measurement, the speed of the vehicle that crosses the sensors is limited to 5 or 10 km/h. In addition, accelerating and braking is not allowed so as to discount the dynamic behaviour of the moving vehicle. Therefore, LS-WIM systems are operated in a controlled environment, very different to the high-speed WIM systems that are operated at normal speeds and under free traffic conditions.

Due to the absence of vehicle dynamics, LS-WIM systems are reasonably accurate (up to 1% for gross vehicle weights for 95% of measurements). The International Organisation for Legal Metrology has issued international recommendations for low-speed weigh-in-motion (OIML R 134, 2009). These recommendations specify the requirements and test methods for automatic instruments for weighing road vehicles in motion that are used to determine vehicles' masses, axle loads and, if applicable, the axle-group loads of road vehicles when the vehicles are weighed in motion. It provides standardised requirements and test procedures to evaluate the metrological and technical characteristics of such instruments in a uniform and traceable way. It specifies 6 accuracy classes for the gross vehicle mass, with respect to permissible error:

<table>
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<th>Class</th>
<th>Permissible Error</th>
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HIGH-SPEED WEIGH-IN-MOTION

A high-speed Weigh-In-Motion system, often called just a WIM system, measures the dynamic axle loads of the vehicles passing at full highway speed under uncontrolled condi-
Heavy-Duty Vehicle Weight Restrictions in the EU: Enforcement and Compliance Technologies

WIM systems typically deliver: axle loads, axle group load, gross vehicle weight, number of axles, length of the vehicle, axle distances, speed and vehicle classification.

The following paragraphs give a short overview of the different WIM technologies.

In general, WIM-systems can be divided into (FHWA-PL-07-002, 2007):
1. External structures, either a pavement or a bridge, that serve as the physical framework for a WIM-sensor and transfers the axle loads of the passing vehicles to the sensor without damaging the sensing material;
2. Sensor or transducer that converts the axle load into an electrical signal. The most common sensing technologies are piezo-electric or piezo-quartz materials, strain gauges and fibre optics.

The combination of points 1 and 2 results in two different types of WIM installations:
- Pavement WIM systems
- Bridge WIM systems

Pavement WIM systems
A typical pavement WIM installation consists of inductive loops that measure vehicles’ velocity and detect the type and length of the vehicles and, with a number of WIM sensors, in different setups. Based on the width of the sensors, they are divided in two major groups Figure 13:
- Plate sensors
- Strip sensors

All pavement WIM systems should be installed on as smooth and flat sections of roadways as possible so as to provide results of sufficient accuracy. Additionally, to mitigate the effect of vehicle dynamics from uneven road surfacing, a few multiple-sensor WIM sites were constructed around the world for comparison, with up to 24 sensors with lengths of around 30 meters (COST 323, 2002). They can provide accurate results but are expensive to build and maintain.

Plate sensors
Their width is larger than the tyre, thus the total axle load is acting on the sensor Figure 13, left. Similar sensors are used for static and low-speed axle load measurements. The two prevailing technologies are:
- Bending plates which measure the strain due to bending of a plate caused by a passing wheel.
- Load cell devices which, with a number of load cells under the plate, measure forces during a crossing wheel.

As a rule, plate sensors provide more accurate results than strip sensors. However, their installation is more difficult. It cannot be done under traffic and can require a 2-day road closure.

Strip sensors
As the length of the tyre footprint is larger than the width of this type of sensor, only a part of the total axle load acts on the sensor at each time Figure 13, right. In order to capture the total axle load, the signals measured during the passing of an axle over the sensor must be integrated over time.

1. For more details, working principles and extensive explanations see the REMOVE project report (Rooke, Shipp, de Groet, van Loo, & Scorer, 2006) or visit the Internet site of the International Society of Weigh-in-Motion (ISWM, 2014)
Today most strip sensors are built around three technologies:

- Piezo-electric and piezo-polymer **Figure 16, left**, both are the cheaper options on the market but are generally less accurate.
- Piezo-quartz **Figure 16, right**, the most common sensor technology today; they are more accurate and stable but also more expensive to purchase and to install.

Strip sensors can be typically installed in less than one day, they also do not damage the pavement as much as the plate sensors do.

The main advantages of strip sensors are that they are a proven technology and have relatively high accuracy on smooth road surfaces. Their disadvantages are that road must be closed for installation and maintenance, which is not always easy to do, and that their accuracy suffers as the road surface deteriorates, which happens particularly if they are built into flexible pavements (i.e., asphalt with relatively weak sub-base).

**Bridge Weigh-in-Motion**

Bridge-WIM or B-WIM refers to a specific method that uses an instrumented bridge or culvert to weigh in motion the passing vehicles. These systems provide similar results as the pavement WIM systems (axle loads, gross weight, axle spacing, velocity, vehicle category). The sensors are mounted on the soffit of the bridge **Figure 17**, and in most cases, road closure during installation is not necessary.

Since its appearance 35 years ago (Moses, 1979), B-WIM technology has undergone considerable improvements. After being researched extensively in the 1990s (WAVE, 2001), it entered the market in 2002 (Žnidarič, Lavrič & Kalin, 2002) and is today used in a number of European countries.

The main advantages of B-WIM systems are:

- complete portability, without affecting accuracy;
- high accuracy, especially on smooth road surfaces;
- ease of installation, without interruption of traffic;
- unavoidability of bridges, so traffic is likely to actually pass over them;
- provision of additional structural information (influence lines, load distribution factors, dynamic loading) for advanced bridge assessment (Žnidarič & Lavrič, 2010).
The disadvantages are that a proper bridge is needed to install the system and that setting-up such a system requires considerable knowledge and expertise concerning bridges.

**Accuracy of WIM data**

The weighing performance of any WIM system is determined by the combination of the accuracy and reliability of its measurements. The most common way to describe WIM performance is that it has an accuracy of ±x% for y% of measurements, for example ±10% for 95% of measurements. Accuracy criteria vary for the measurement of single axle loads, axle group loads and gross vehicle weights. For example, for a system intended to achieve Class B(10) according to the European specifications for Weigh-in-motion (COST 323, 2002), the errors must be for a specific confidence interval, which depends on the test and environmental conditions and is typically around 95%, within ±10% for gross vehicle masses, ±13% for axle group loads, ±15% for single axle loads and ±20% for loads of axles within a group.

The actual accuracy of WIM results depends on a number of factors:

- **Road conditions.** Uneven and rutted road surfaces around the pavement WIM installation will almost certainly generate poor results. Smooth, rigid concrete pavements are better than the flexible ones. The WIM specifications (COST 323, 2002) list criteria for the selection of a good WIM location. A poor quality road surface will excite dynamic response of the passing vehicles, which could create difficulty for WIM systems when attempting to correlate the measurements with the static axle loads.

- **Quality of the installation.** For pavement WIM systems, the sensors must be installed properly in the roadway and the top of the sensors must be flush with the road surface. Otherwise, the sensors will create a bump that will affect the accuracy of the WIM system’s results. For bridge WIM systems, it is crucial to avoid cracks in the concrete and to properly attach sensors to the bridge. To mitigate these issues, all WIM sensors and systems should be installed by experts.

**Maintenance and calibration**

After installation, each WIM system has to be calibrated to control for measurement errors. Calibration is generally conducted using one or more calibration trucks with known static axle loads or using selected vehicles from the traffic stream. Because of wear and tear on the sensors and possible changes in roads’ conditions, the behaviour of all WIM systems will change over time. Therefore, maintenance and recalibrations are required at regular intervals, normally once or twice a year.

**Traffic conditions**

The traffic flow over a WIM system should be as smooth as possible, as stop-and-go traffic cannot be captured.

**Types of sensors**

Different sensor technologies each have their own characteristics related to accuracy, stability, durability and price.

**Speed of the vehicles**

Speed is largely related to the dynamic behaviour of moving vehicles. Generally, the higher the speeds, the more excited the vehicles become (which is particularly true on uneven road surfaces), which will likely lower the accuracy of the measurements.

**Temperature effects**

Although good-quality WIM sensors are not temperature-dependent, the WIM installations as a whole usually are. This is true for most pavements and some types of bridge. If not properly compensated for, the temperature effects can...
result in considerable data biases that vary with temperature. An example of 6-month B-WIM results before applying temperature compensation is given in Figure 18.

**Quality of WIM data**

In reality, most applications (e.g., traffic flows, statistics & planning, infrastructure assessment) rely on the average accuracy of all measurements. The only applications where the accuracy of each individual measurement prevails are direct enforcement and pre-selection of overloaded vehicles.

WIM systems generate an enormous amount of data that needs to be reliable. Walker and Cebon (2011) describe in their report how attitudes regarding data quality have changed since the beginning of the Long Term Pavement Performance Programme that in the US has collected WIM data systematically since 1992. Even 10 years after the start of the programme, many results were disappointing, as can be seen in Figure 19, left. The diagrams present the monthly distributions of the gross weights of the 5-axle semi-trailers. The two peaks, one for empty and the other for fully loaded vehicles, should not move but have, in this case, shifted by over 30% from the lowest to the highest value. The situation changed considerably 10 years later when the new installation specifications were set in place, which among others:

- banned piezo-electric cables
- required:
  - bending plates
  - concrete pavement
  - improved road roughness
  - regular calibration
- banned auto-calibration, a method where the calibration factors change according to statistically evaluated characteristic weights of traffic
- improved data quality checks which included daily checking of data

Results from the same location, but installed and maintained according to these specifications, are shown in Figure 19, right. Improvement is self-explanatory.

Today, most WIM systems have built-in temperature and (potentially) velocity calibration algorithms as well as quality checks that ensure that results are stable and of expected quality. In addition, the data owners, when importing data from the systems into the traffic databases, perform a number of their own data quality validations to eliminate the unreliable information.

**Overview of WIM situation in Europe**

A good overview of the WIM situation in Europe is not available. Years ago, COST action 323 (2002) collected information about the numbers of working WIM systems in different European countries Figure 20, but these figures have not been updated since. It would require considerable efforts to do so for all European countries. Instead, Table 4 shows some updated information about the present extent and application of WIM technologies in various EU countries, based on informal discussions by the author of this report with WIM experts from these countries. As noted in section 2, information on overloading was not readily available.
With the exception of France, in all contacted countries the number of WIM systems has risen since 2002. Some countries have established comprehensive networks that are used primarily for pre-selection. Others (Croatia, Slovenia, Sweden...) systematically cover the road networks with portable B-WIM devices that provide data for a number of applications. In Slovenia and Austria, for example, a number of WIM measurements were performed to provide loading data for optimised bridge assessment.

**Certification of WIM Systems**

Presently, HS-WIM systems are not certified for direct enforcement in any EU member state, except in the Czech Republic where a certification procedure has been developed. WIM systems are not yet used for direct enforcement. France is performing a feasibility study on this issue. LS-WIM systems are certified in several countries (also in the EU) for direct enforcement according to the OIML R134 (2009). The cost (for the type approval of one system) ranges between €15,000 and €25,000. In comparison, the validation of a WIM system used for data collection within the Long Term Pavement Performance program in the US costs around $20,000.

High-speed WIM systems should be subjected to certification in a form of type approval. Type approval is a confirmation that production samples of a system will meet specified performance standards. The specification of the product is recorded, and only that specification is approved. The test procedure to obtain a type approval certificate can only be performed once, until any modification is made to the system.

**Table 4**

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**Figure 20**

WIM systems in Europe in 2001

Source: COST 323, 2002
In the absence of international standards and certificates for WIM, the type approval system aims to provide a climate of mutual confidence and recognition of test results relating to a product. This is a key point for achieving assurance and confidence necessary between member states that an offence detected and processed in one member state has had the same rigor applied to it as it would in the country receiving the penalty.

For the future, it is necessary to identify and recommend a legal framework to achieve a vision of a harmonised and interoperable deployment of WIM systems. To attain a fully automated and legally accepted enforcement process built around WIM technology, it is firstly necessary to build on those standards already in place for the legal exchange of data and enforcement information throughout the EU.

**ON-BOARD WEIGHING**

On-board weighing (OBW) systems can be divided into two major groups that are based on measuring:
1. Gross vehicle weights
2. Axle loads

**Gross vehicle weight OBW systems**

Information for assessing the gross vehicle weights is already available in the vehicle computers of many modern trucks and buses (Dahlberg, 2014). If the legislator is targeting the GTW (Gross Train Weight) instead of the individual axle loads, this information could be sufficient for the purpose of collecting good estimates of the GTW data. Presently, it is needed for the gear change system, the engine and various other systems in order to optimise the performance of the vehicle. It is also used within fleet management systems, since hauliers want to have as much relevant data as possible for their operations in order to optimise logistics management.

The two most common and accurate methods heavy vehicle manufacturers use to calculate GTW in the vehicle in real time are based on the monitoring of:
1. The forces and acceleration during gearshift
2. Changes in acceleration

**Gearshift-based vehicle weight calculation**

Vehicle mass is estimated/calculated by comparing the traction force and the vehicle acceleration before, during and after a gearshift. The method is based on Newton’s second law and uses the assumption that all longitudinal forces acting on the vehicle, except for the traction force generated by the driveline, are roughly constant during short time periods. The method is not applied while the wheel brakes are being used, so the main forces assumed to be constant are those created by rolling resistance, air resistance and road inclination. Over time, after a reloading event, the accuracy becomes high given that air resistance is well understood and accounted for.

As an example, Figure 21 shows data of readouts from Scania trucks in EU28 countries in the period between January 2012 and April 2014. Numbers include 4×2 and 6×2 tractors with long haulage specifications (high cab, 6 or 8-cylinder engine, semiautomatic gear changing and rear axle air suspension) that had driven at least 20 000km (Dahlberg, 2014).

**Acceleration-based vehicle weight calculation**

Acceleration-based vehicle weight calculation estimates vehicle mass by making calculations during vehicle acceleration phases. Travelling resistance is divided into its three (approximated) components and inserted into the force equation. The vehicle mass, wheel radius and road slope are assumed to be constant over short periods, the force equation is derived and solved for the vehicle mass.

As data from the GTW OBW systems is available in the vehicle computers, transforming it into a pre-selection tool (or making it available for the driver or possibly somewhere else according to the legislator’s needs) could be fairly straightforward and cost-efficient, especially when compared to the axle load OBW devices.
Axle load OBW systems

Axle load OBW systems are built around existing vehicle sensors or as add-on sensors. Most heavy vehicle manufacturers have solutions for such advanced axle load sensing available, but for the moment, the technology is primarily used in the mining and waste industries, and only exceptionally and on request in heavy-duty vehicles. The reason is the high cost of industrialisation and, consequently, for installation and calibration. The only country with a notable number of installations is Australia, where vehicles with axle load OBW systems are allowed to carry higher loads on specific routes (Koniditsiotis, Coleman, & Cai, 2012) and operate within an advanced programme that, among others, involves incentives for installation of OBW devices.

The technology used for axle load OBW applications is guided by the type of vehicle, primarily its suspension type and the accuracy requirements of the weighing application. The systems are built around three main sensor technologies:

- Load cells, especially in steel-sprung suspensions;
- Air pressure transducer (APT), in association with air suspension;
- Strain gauges.

Table 5 Basic characteristics of OBW sensors

<table>
<thead>
<tr>
<th>LOAD CELL</th>
<th>APT</th>
<th>STRAIN GAUGE</th>
</tr>
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<tbody>
<tr>
<td>Accuracy</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>better than 1%</td>
<td>between 3-5%</td>
</tr>
<tr>
<td>Reliability</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Ease of installation</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Durability</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Costs per axle</td>
<td>from €8,000</td>
<td>from €600</td>
</tr>
</tbody>
</table>

* some sources report similar accuracy for Load Cells and APT sensors

Load cell-based systems are more accurate than APT-based ones. The reason is that air-based suspension can take more than a minute to stabilise after the vehicle becomes stationary. Also, the accuracy of APT-based systems can be affected by temperature variations of the air by operation of the suspension unit itself.

APT-based systems are less costly and more appropriate for aftermarket installation. According to some sources (Koniditsiotis, Coleman & Cai, 2012), the installation may take less than an hour as they are added into the existing airline to the suspension Figure 23, left. However, most vehicles today do not have air suspension on all axles. In contrast, the load cells become an integral part of the vehicle Figure 23, right and should ideally be installed at the point of assembly of the trailer/axle. The aftermarket fitment of load cells for an individual axle group may take a couple of days.

Figure 24 shows two examples of OBW displays that drivers have in their cabins.

Koniditsiotis (2012) also reports that these add-on axle load OBW devices need to be regularly checked and recalibrated. This can be a weakness with respect to their efficiency that is difficult to justify without providing a comprehensive cost-benefit analysis for OBW.

Certification of OBW devices

The certification of OBM systems is achieved by way of type approval. In Australia, the type approval of an In-Vehicle Unit (IVU) costs around €40,000 per system and
vehicle type, and it is expected that an OBW system will cost approximately the same. Approval is achieved through a certification process which tests end-to-end solutions against the requirements of the IAP Functional and Technical Specification. IAP applies to the Intelligent Access Program and is voluntary. It provides a system allowing heavier vehicles with access or improved access to the Australian road network. IAP includes:

- Performance-based specifications on vehicles and OBW devices that provide adequate/best vehicles;
- Driver training to get the best educated drivers of heavy vehicles;
- Fleet accreditation;
- Intelligent access associated with incentives: if equipped with the OBW devices, these vehicles have full access to designated routes, but the operator has full knowledge of location, speed, loads etc.

Koniditsiotis, with co-authors (2012), reports about improvements by a factor of 5 with respect to safety and a 30% increase in the transport efficiency of the vehicles participating in the AIP.

**Accuracy of OBW systems**

The accuracy of axle load OBW systems depends on:

- the performance of the on-board weighing solution, in particular the type and number of sensors;
- the frequency and type of the calibration procedure;
- road surface/road quality and evenness;
- vehicle behaviour.

After installation, an on-board weighing solution must be calibrated (initial calibration). The effective accuracy of the installed system is then assessed. As with WIM systems, the more extensive the test plan (regarding time, means and thus costs), the higher the confidence in its conclusions.

In 2008, the TCA (Transport Certification Australia) conducted a test program on commercially available OBW systems in Australia (Koniditsiotis, Coleman, & Cai 2012). Twelve OBW systems (APT and load cell sensors) from eight suppliers were tested across five Australian states over the course of seven months.

The accuracy and repeatability of the OBW systems were tested against a static weighbridge as well as an on-board reference system (also an OBW system) by axle group and by gross mass. Measurements were taken on a surface with the vehicle’s brakes off and with the engine running, i.e., with vehicles at standstill. All systems tested provided an accuracy of ±500kg for any axle group when compared to the weigh bridge. This is equivalent to a ±2.5% error on a 20-tonne axle group. In the following years, the OBW systems were tested on a trial route from the port of Brisbane to Toowoomba. Figure 25 gives an example of the signal from the OBW system before applying cleaning and filtering procedures. The results from the test route were encouraging, and Australia is extending its IAP programme into several states.

**Figure 24 Examples of OBW displays**

**Figure 25 An example of a daily OBW record**

*Source: Koniditsiotis, Coleman & Cai, 2012*
OBW system calibration

The purpose of the OBW solution should guide the selection of a calibration procedure. Different calibration methods exist, from static calibration to automatic self-calibration (COST 323, 2002), which depend on the type of sensor, the application and user requirements, as well as the time and means available.

Generally, the following accuracy levels are expected in combination with the respective calibration procedures:

• A 10% accuracy level, which allows for pre-selection for enforcement and corresponds to the COST 323 accuracy classes B+(7) or B(10), would require an accuracy check or recalibration at least every two years.

• A 5% accuracy level, which allows for pre-selection for enforcement and direct enforcement, and corresponds to the COST 323 accuracy class A(5), would require an accuracy check or recalibration at least once or twice per year.

• A 1-2% accuracy level, which allows for direct enforcement, would require an accuracy check or recalibration at least every 3-6 months. For example, the IAP programme in Australia that defines such high accuracy level requires recalibration of the systems on an “as needed” basis (when a vehicle or a component fails a verification test, the device must be recalibrated) which typically is between 3 to 12 months depending on the operating environment.

The last two examples seem to be too frequent to be acceptable without a systematic approach that would include certain incentives for the loss of operation time. Otherwise, the time-consuming recalibrations could become a serious hindrance to the efficiency of road transport, as well as raising societal costs in general.

Industrialisation of axle load OBW devices

As mentioned above, the manufacturers of HDVs have the GTW OBW calculations available in the vehicle systems, and it would be relatively straightforward and cost-efficient to make them available for the driver or as an OBW pre-selection tool. On the other hand, axle load OBW sensors are mainly provided as add-on solutions and have not yet been industrialised by any manufacturer for a broader range of vehicles. Outside of Europe, several manufacturers offer relatively complex solutions for certain vehicle specifications. They are currently rather high cost for customers, though this could be compensated for through the incentives that countries like Australia have put in place.

Nevertheless, mass producing a cost-effective axle load OBW product that could be installed in most commercial vehicles is a large task and would require substantial investments by each manufacturer.

Conclusion on implementation issues of on-board weighing

The following can be concluded with respect to OBW systems:

• A good estimate of gross vehicle weight is already available thanks to the vehicle computers of many modern trucks and buses. It can be processed for any application, including pre-selection, if the legislator is targeting the GTW instead of the individual axle loads.

• Technical solutions for axle load OBW exist for all vehicle types (with some limitations related to the lifting axles), but they have not yet been industrialised for mass implementation. There is also no harmonised calibration and certification regime across Europe.

• OBW would improve the enforcement capabilities of WIM systems allowing member states to overcome the limitation of most WIM systems that cannot be moved to another place once installed.

• Incentives are necessary to encourage the use of OBW devices. Only then can the expected number of installations rise and the cost of these devices become more competitive.

• OBW is not just the simple matter of installing a sensor, but should be a part of a system approach that includes performance-based standards for vehicles and OBW devices, drivers training, fleet management, incentives etc.

OBW VERSUS WIM

Most current WIM systems are part of national WIM networks. On the other hand, Directive 96/53/EC is focused on international haulage and OBW is seen as a potential means to improve the effectiveness of compliance checking. A combination of WIM and OBW may in the future be an optimal combination to ensure compliance with the weights prescribed in the Directive.

WIM networks will remain a key component of the national enforcement processes, especially because they measure all vehicles crossing the systems. WIM means proven technologies and leads to efficient controls with hit rates above 95%. Its drawback is that most systems are bound to certain locations (with the exception of portable B-WIM systems that are also spreading across Europe). The consequence could be the avoidance of WIM systems, although this is unlikely for international haulage if the Trans European Corridors are systematically equipped with such systems. The costs of installing the necessary WIM systems would be much lower than equipping all vehicles with the OBW systems.
Axle load OBW systems would be initially introduced only to the new vehicles above 3.5 tonne gross mass, but those vehicles could be controlled everywhere. The transport companies would also know if their vehicles are infringing the regulations or not, and what the consequences might be. However, the use of OBW for enforcement is new in Europe and further studies are needed to better understand their accuracy, calibration requirements, temperature resistance, certification procedures and costs associated with their implementation.

Finally, the WIM stations could and should be used to verify the weights detected by the OBW systems. This redundancy would increase the significance of the calibration methods. If the values diverge, this would be an indication that either the calibration is off or that the OBW system has been manipulated.

5. Enforcement of overloaded vehicles

The transport of goods by overloaded trucks creates a number of problems on European road networks. As explained in section 2.2, this is far less severe on Europe’s main roads (Trans European Corridors) than on other road networks. On the motorways, for example, over 80% of all axle overloading cases were reported to be below 10% overweight, with only 2% found to be over 20% overloaded (Cestel, 2012). Still, heavily overloaded vehicles are found on the European corridors and they do affect safety, mobility and fair competition. Overloaded vehicles gain significant fiscal advantages when compared with the operators who function with the restrictions. With increasing road transport and the potential designated routes for heavier vehicles, these problems will become even more significant, so a more efficient enforcement system will inevitably have to be deployed.

CURRENT PRACTICES

Weight compliance checking today is organised on a national basis, with different intensities and focuses between European member states. The basic principle is that if the offenders are to be fined, then the evidence for overloading needs to be court proof. With the exception of one WIM site in the Czech Republic (Doupal, Kriz, Stamberg & Corru, 2012) which was certified in 2012 and is still not in full operation, no other European country permits WIM for direct enforcement. It can only be done with certified static scales or, in a few countries (France and Germany), on dedicated low-speed WIM sites, in both cases in the presence of police.

As a result, the density and frequency of checks is low, because:

• Road and transport police forces’ focuses regarding traffic safety are speeding, alcohol and drug abuse, vehicle condition and driver’s fatigue as well as traffic fluidity. Overloading mainly causes damages to infrastructure, has negative effects on competitiveness and environment, but is only of interest to other stakeholders, not the police.

• Weight compliance checking is cumbersome and slow. A suspected vehicle is flagged and then guided to the closest available certified weighing scale. This is time-consuming and is only done when there is clear indication of substantial overloading (Hellemons, 2013).

Consequently, the risk of being caught with an overloaded vehicle is small, at least when driving outside areas known for weigh-in-motion installations or outside areas with a traditionally high enforcement presence, such as mountain passes or on border crossings.

Without WIM pre-screening, the likelihood of catching offenders is low. This is because overloading is not easily visible, except in extreme cases. The risk of being caught is higher if subject to organised campaigns. However, as these require substantial efforts to set up, they are, as with permanent enforcement sites in Europe, rare. In addition, the drivers are well organised and can make themselves aware of enforcement sites quickly if they need to avoid them.
ENFORCEMENT STRATEGIES

To be efficient, overload enforcement should not only be about catching offenders. Van Loo and Jacob (2011) suggest an enforcement system that includes:

- Planning and statistics;
- Pre-selection;
- Company profiling;
- Direct enforcement;
- Intelligence.

Similarly, the REMOVE project (Rooke, Shipp, de Groet, van Loo & Scorer, 2006) proposed that efficient enforcement requires a mix of different enforcement procedures supported by different types of WIM systems. A Lego approach, which builds the appropriate WIM system from different components according to the needs of enforcement activities, was recommended Figure 28.

The REMOVE project has also come up with the following important conclusions regarding overload enforcement:

1. Most member states do not regard overloaded vehicles as a high priority (yet).
2. Significant benefits could be achieved in terms of road safety with the introduction of effective strategies to reduce overloading.
3. Lack of effective cross border enforcement is a significant issue, particularly with international haulage.
4. Liability is not satisfactorily addressed by existing rules (the revised Directive is elaborating this part).
5. Road transport industry is generally in favour of a preventative/problem solving approach as a means to achieve compliance.
6. Existing methods of enforcement may involve additional costs to legitimate hauliers where they are unnecessarily screened by conventional weighing devices.
7. WIM devices have the enforcement potential, but this is dependent on the location of the station.

HOW MANY WIM SYSTEMS WOULD BE NEEDED FOR ENFORCEMENT?

As equipping all vehicles with the OBW devices in the near future is not realistic, the enforcement policy will have to rely on WIM systems. For enforcement purposes, only two levels of device are appropriate:

- Accuracy class B(10) or better for pre-selection
- Accuracy class A(5) or better for direct enforcement

To estimate the number of WIM systems needed, only the length of the road network is considered. This is related to the probability that a vehicle is checked per number of kilometres. The estimation is based on current practices in France and the Netherlands which have established successful systems of pre-selection WIM sites for enforcement:

- There are around 405,000km of motorways and national roads in Europe (EC, 2014);
- WIM installations for pre-selection would be placed at every 300km to 500km on the motorway network, and at every 1,000km to 1,500km on the national roads;
- WIM installations for direct enforcement would be placed at every 1000km on the motorways only.
Based on these assumptions, the whole EU road network would need 500 to 550 WIM systems for pre-selection and up to 75 systems for direct enforcement.

**FUTURE ENFORCEMENT**

The REMOVE vision promotes a harmonised approach to enforcement, where all member states are able, within their own national legislation, to apply sanctions which are in the main compatible across the whole of Europe Figure 29. It encourages the use of WIM and OBW technologies across all member states to improve compliance with vehicle weight legislation. If achieved, the efficiency and effectiveness of overload enforcement throughout the European community would vastly improve in a way acceptable to both member states governments and the road transport industry.

When looking at the measurement technology-related aspects of cross-border enforcement, the key issue is confidence. This confidence is built on the following points:

- Any record produced by an enforcement system should contain all relevant data fully describing the offence that is the subject under consideration for enforcement.
- All equipment for enforcing road traffic laws should have type approval, achieved through national organisations for legal metrology or other notified body, and must be subject to periodic checks whilst in service.

**HOW TO MITIGATE OVERLOADING?**

Overloading will always be present; the objective should be to find the optimal ways to reduce it by as much as possible.

**Prevention and Enforcement**

The REMOVE project suggests solving the overloading problem with a combination of enforcement and prevention activities. This dual carrot & stick approach is illustrated in Figure 30. For example, the experiences from the Netherlands and France demonstrates that collecting information about offenders with subsequent company visits can be more efficient than fining. Over 90% of the companies presented with overloading records have changed their attitude and started to pay appropriate attention to overloading.

**Incentives for permanent control**

Experience from Australia shows that incentives in the form of allowing longer and heavier vehicles, as long as their loading is controlled and if they do not leave the prescribed corridors, could be an efficient tool to increase the efficiency of the hauling industry. However, presently in Europe this seems a challenge, as some member states are strictly against any increase in HDV weights and dimensions.

**Fining policy**

If using WIM and OBW for enforcement becomes common, the fining policy should change. The current situation is very different among the EU countries, with some charging a few hundreds and others a few thousands Euros,
depending on the offence. At the moment, most vehicles are caught randomly. It is only likely to occur every few years. The fines are in general relatively high but, in most cases, are not proportional to the extra wear on the infrastructure. If all vehicles were controlled, then the fines could be considerably lower. Moreover, as all offenders would be fined, more money would be collected to finance repairs to the infrastructure. Additionally, the necessary general level of enforcement would decrease.

Control of vehicle loading
The extended use of WIM and OBW devices would play an important role in ensuring that the vehicles (axle overloading in particular, which is the dominant type of overloading in long-distance transport) are not overloaded by accident. The benefits of using OBW are obvious, yet are currently associated with high costs. However, the experience from countries with systematic use of WIM systems and static weighing for enforcement demonstrates that after a few years operators learn how to load the vehicles correctly. As a result, the rate of overloading decreases. If controls, within the systematic approach mentioned above, were combined with the regular training of drivers, a strong decrease of overloading should be expected.

Conclusions
Efficient road transport enhances economic competitiveness. This has historically led to increased maximum permitted weights and dimensions for HDVs. At the same time, the dimensions and weights of such vehicles must be controlled to ensure road safety and fair competition between the hauling companies, and to protect the infrastructure. In Europe, this is regulated by Directive 96/53/EC which is currently under revision. From the perspective of the heavy-duty vehicle manufacturers, the difficulty is that without adaptation of the weights and dimensions Directive, it will not be possible to reduce transportation costs. This would have direct economic impacts on users and for society, and could improve the environmental performance and safety of road transport, as:

- The freight transport sector is expected to grow by 60% in the next 25 years;
- There is no obvious modal shift of surface transport;
- The load factors, the proportion between the mass of goods carried vs maximum possible payload mass, is decreasing;
- There are shortage of drivers in Europe.

Road transport will have to become more efficient. Heavier and longer vehicles on long-distance corridors are a possible way forward, but this primarily requires changing public opinion which, currently in some European countries, is strongly against any change (Berndtsson & Lundquist, 2008). Fuel economics and safety figures could be the crucial arguments in gaining the necessary support. At the same time, infrastructure has to be protected, which means that in many cases it would have to be reinforced. Therefore, any changes would have to be well justified to confirm that they would provide more efficient and sustainable transport, and provide adequate return on investment.

Furthermore, the current limitations in the Directive raise at least two concrete issues related to European policies as they:

- Prevent the market uptake of electric/hybrid HGVs and coaches which, being heavier than the conventional vehicles, would have to reduce their payload or number of passengers per coach.
- Do not keep pace with technical developments in the field of intermodal transport, such as the use of 45-feet containers used in maritime transport which cannot be carried on roads without special permission.

The data available confirms that the incidence of overloading in long-distance haulage is far lower than in domestic transport. However, in the context of fierce competition, operators that overload can gain a substantial competitive advantage over others who follow the rules. This requires more efficient enforcement policies and control practices.

The two technologies that could contribute to establishing a more efficient enforcement system in Europe are Weigh-in-Motion (WIM) and on-board weighing (OBW). WIM networks will remain a key component of the national enforcement processes and would be used as independent control of individual on-board units. They measure all vehicles crossing the systems and are proven technologies that lead to efficient controls with hit rates above 95%. Their major disadvantage is that they are limited to one location and can be as such circumvented.

The OBW systems on haulage vehicles are still rare in Europe and are not used for any pre-selection or enforcement applications. However, most manufacturers can evaluate gross weight indirectly from the existing sensors that primarily monitor the performance of the vehicles. This information could be made available on relatively short notice and for reasonable costs by uploading it into proper GTW OBW devices. If linked to the WIM systems, the operators and legislators could get a fuller picture on vehicle loading.
For axle OBW devices, further work is needed to better understand their accuracy, calibration, temperature resistance, certification procedures and costs associated with their industrialisation, installation and maintenance. Nevertheless, their potential is not only in enforcement. If installed on-board, operators and their drivers would know if their vehicles were infringing the regulations or not, and what the consequences and liabilities might be.

Time will tell as to how the OBW market will develop in Europe. However at this stage, a comprehensive cost benefit analysis is required to clarify the performance characteristics of different OBW technologies. This includes the costs related to industrialisation and the benefits for society and to the environment etc.

Last but not least, the only successful way toward any efficient enforcement is a carrot and stick approach. The future system, with or without increased freight vehicle weights and dimensions, will have to combine enforcement with prevention and incentives. This will require a systematic approach that will include efficient planning and problem solving, such as visiting companies that systematically overload, training of drivers, new IT technologies to integrate information from different sources, etc. In the case of increased weights and dimensions, systematic reassessment would be required with, where necessary, upgrading of the road infrastructure to provide access for the new vehicle types.
References


