

# Impact of Heavy Vehicles on European Roads

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**ABSTRACT:** More than 500 billion € is spent yearly in the European Union on mobility. The road traffic is increasing at a rate of four to five percent each year, leading to an expected growth from now to the year 2020 of fifty to sixty percent. The road network is extremely important to Europe's economic and it requires efficient management using state of the art technology. The traffic volume of heavy vehicles using the road network has been increasing steadily over the last decades, as is the trend for increasing individual axle loads. The weighing of road vehicle axles in motion (WIM) is getting more and more an important factor for the record and analysis of the traffic stream. One chapter of this paper describes new applications of a special method SIM (stress in motion) for the measurement of force distributions under rolling wheels.

**KEY WORDS:** Heavy vehicles, pavement damage, weigh in motion, EU research programme

## 1 VEHICLE DESIGN AND TOTAL WEIGHT

For many years the European Commission has been seeking have to harmonised legislation throughout the European union for the maximum weights and dimensions of heavy motor vehicles and vehicles combinations. Progress has been made and Council Directive 96/53EC represents the current legislative position for motor vehicles circulating in the European Union. However, further progress, particularly with regard to legislation on the maximum weigh of vehicles, will depend on greater political willingness to control vehicle weights.

On 1<sup>st</sup> January 1993 a border free internal market within the EU was established, resulting in the abolition of border controls. This meant that there was no longer an effective means of systematically controlling different national rules concerning motor vehicles. It is, for example, now forbidden to have systematic controls of vehicles' weights at a border point.

### 1.1 Content of the current Directive

#### 1.1.1 Requirements for international traffic

Article 3 of the Directive states that a member state may not reject or prohibit the use in its territory in international traffic, of vehicles registered or put into circulation in any other member state for reasons relating to their weights and dimensions provided that such vehicles comply with the limit values specified in the Directive. Thus, as far as international traffic is concerned Directive 96/53 can be viewed in the same way as Directive 85/3, namely that it lays down maximum weights and dimensions, which if met, guarantee free circulation trough out the Union (except the UK and Ireland). The limit values laid down in the Directive (Annex I).

### 1.1.2 Requirements for national traffic

It had been intention of the Commission when it made its legislative proposal the Directive 96/53 should set maximum weights and dimensions for all transport within the EU. This would have meant that the requirements for national and international traffic would have been identical.

Table 1: Maximum authorised vehicle dimension (Directive 96/53/EC)

Vehicles/axles	1.1 Length [m]	1.2 Width [m]	1.3 Height [m]
Motor vehicles	12	2.55	4
Trailers	12		
Articulated vehicles	16.5		
Road trains	18.75		
Articulated bus	18		
Conditioned vehicles		2.6	4

Table 2: Maximum authorised axle and vehicle weights (Directive 96/53/EC)

Clause	Vehicles/axles 1.1	Remarks	Weight [t]
2.1.1	▪ two-axle trailer		18
2.1.2	▪ three-axle trailer		24
2.2.1a	Road trains: ▪ two-axle motor vehicle with three-axle trailer		40
2.2.1b	▪ three-axle motor vehicle with two- or three-axle trailer		40
2.2.3	▪ two-axle motor vehicle with two-axle trailer		36
2.2.2a	Articulated vehicles ▪ two-axle motor vehicle with three-axle semi-trailer		40
2.2.2b	▪ three-axle motor vehicle with two- or three-axle semi-trailer		40
2.2.2c	▪ three-axle motor vehicle with two- or three-axle semi-trailer carrying a 40 foot ISO container as a combined transport operation		44
2.2.4	▪ two-axle motor vehicle with three-axle semi-trailer	depending on axle spacing and suspension	36-38
2.3.1	▪ two-axle motor vehicles		18
2.3.2	▪ three-axle motor vehicles	depending on suspension if fitted with road-friendly suspension	25-26
2.3.3	▪ four-axle motor vehicles with two steering axles		32
2.4	Three-axle articulated buses		28
3.1	• single non-driving axle		10
3.2	• tandem axles of trailers/semi trailers	depending on axle spacing	11-20
3.3	• triaxles of trailers/semi trailers	depending on axle spacing	21-24
3.4	• driving axle		11.5
3.5	• tandem axles of motor vehicles	depending on axle spacing and suspension	11.5-19

In contrast, all other requirements – maximum vehicle weight, maximum axle weight, maximum height and even, for buses, the maximum length and width – could continue to be set by national legislation. Furthermore, such maximum could be lower than those laid down in Directive 96/53/EC, provided that they applied only to national transport.

## 1.2 Need for further legislative

The political will for EU wide harmonised limit is still some years away but it will eventually come about as the results of some independent factors. As cabotage becomes more commonplace in the next years the instance of vehicles from the country operating to their national weigh limits when performing cabotage in another country will probably increase.

Many EU members are generally unaware of the degree of vehicles overloading that occurs. This is partly because weighbridges for enforcement are relatively expensive and therefore scarce. In addition the effective use of weighbridges is limited by in-driver communications, which results in lorry drivers warning their colleagues, when the weighbridges on routes are in operation for control.

The modern weigh in motion equipment will enable for more widespread and random controls to be practised. When this is the realistic scenario it will then become apparent the degree of overloading that occurs on road. Therefore it is probably only when both these situations have occurred that there will be the political will to find a consensus on harmonising vehicle weights.

## 2 AXLE LOAD AND TYRE PRESSURE

### 2.1 Load Characterization

**Tire Loads:** Tire loads are the fundamental loads at the actual tire-pavement contact points.

**Axle and tyre configurations:** While the tire contact pressure and area is of concern, the number of contact points per vehicle and their spacing is critical. As tire loads get closer together their influence areas on the pavement begin to overlap, at which point the design characteristic of concern is no longer the single isolated tire load but rather the combined effect of all the interacting tire loads.

**Load repetition.** Loads, along with the environment, damage pavement over time. The standard model asserts that each individual load inflicts a certain amount of unrecoverable damage. This damage is cumulative over the life of the pavement and when it reaches some maximum value the pavement is considered to have reached the end of its useful service life.

**Traffic distribution.** On any given road, one direction typically carries more loads than the other. Furthermore, within this one direction, each lane carries a different portion of the loading. The outer most lanes often carries the most trucks and therefore is usually subjected to the heaviest loading.

**Vehicle speed.** In general, slower speeds and stop conditions allow a particular load to be applied to a given pavement area for a longer period of time resulting in greater damage. If mix design or structural design, have been inadequate, this behavior is sometimes evident at bus stops (where heavy buses stop and sit while loading/unloading passengers) and intersection approaches (where traffic stops and waits to pass through the intersection).

### 2.2 Load Quantification

Pavement structural design requires a quantification of all expected loads a pavement will encounter over its design life. This quantification is usually done in one of two ways:

- Equivalent single axle loads (ESALs)
- Load spectra

### 2.2.1 Equivalent single axle loads (ESALs)

This approach converts wheel loads of various magnitudes and repetitions ("mixed traffic") to an equivalent number of "standard" or "equivalent" loads based on the amount of damage they do to the pavement. The commonly used standard load is the 8.16t (18,000 lb) equivalent single axle load. Using the ESAL method, all loads (including multi-axle loads) are converted to an equivalent number of 8.16t (18,000 lb) single axle loads, which is then used for design. A "load equivalency factor" represents the equivalent number of ESALs for the given weight-axle combination. As a rule-of-thumb, the load equivalency of a particular load (and also the pavement damage imparted by a particular load) is roughly related to the load by a power of four (for reasonably strong pavement surfaces). For example, a 16.33t (36,000 lb) single axle load will cause about 16 times the damage as an 8.16t (18,000 lb) single axle load.

Table 3: Example of Load Equivalencies

Load	Number of ESALs
8.16t (18,000 lb) single axle	1.000
0.9t (2,000 lb.) single axle	0.0003
13.6t (30,000 lb) single axle	7.9
8.16t (18,000 lb) tandem axle	0.109
18.14t (40,000 lb) tandem axle	2.06

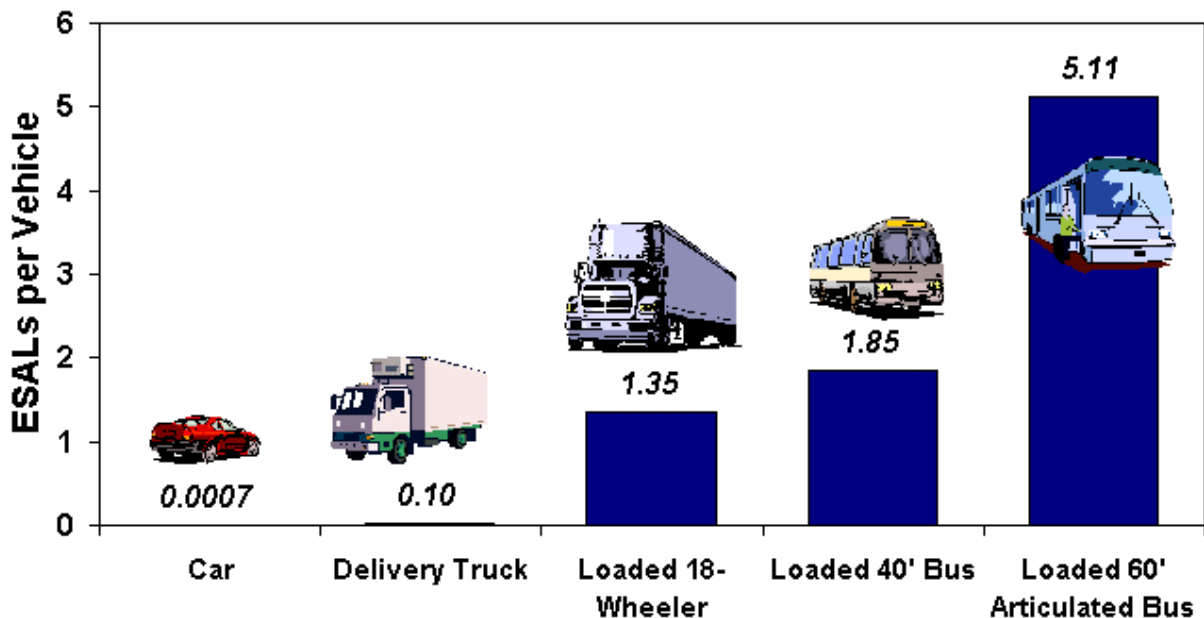


Figure 1: Some Typical Load Equivalency Factors

Table 3 shows some typical load equivalencies (note that spreading a load out over two closely spaced axles reduces the number of ESALs). Figure 1, using some approximations, shows some general vehicle load equivalencies - note that buses tend have high load

equivalency factors because although they may be lighter than a loaded 18-wheeler, they only have two or three axles instead of five.

### 2.2.2 Load spectra

This approach characterizes loads directly by number of axles, configuration and weight. It does not involve conversion to equivalent values. Structural design calculations using load spectra are generally more complex than those using ESALs because loading cannot be reduced to one equivalent number. In USA the load spectra will be an option for use in the new 2002 AASHTO *Design Guide*.

Both approaches use the same type and quality of data but the load spectra approach has the potential to be more accurate in its load characterization.

### 2.3 Stress in Motion (SIM)

A further aim is to increase the resolution of force measurement in such a way that the variation of contact pressure within the footprint of the tire can be measured in real time without disturbing the traffic flow. This should also offer the possibility of detecting vehicles in motion, which are endangering traffic safety due to tire pressures, which deviate significant from those specified.

For this purpose a multi-channel quartz sensor has been developed. The Advance WIM (A-WIM) Modulas sensor is dedicated for the force distribution measurement of the wheel “footprint” in the road pavement.

This sensor is a novel tool for the structural analysis of road pavements as well as for the measurement of dynamic wheel load influences onto the road foundation and within the soil. These promise to help optimising the road structural design methods and together with classical WIM systems, to improve pavement design further.

The dynamic measurement of wheel load distribution is essential not only in tire development for the assessment of force and pressure distribution within the footprint but also in road research for the investigation of factors which lead to excessive damage to pavements. There is growing evidence that actual tire-pavement contact stresses can be considerably higher than the traditional design values leading to pavements that are under designed. The prototype Stress in Motion (SIM) quartz sensor Modulas has been tested using the South African one-third scale Model Mobile Load Simulator, MMLS. The laboratory tests were designed to vary parameters such as temperature, speed, wheel path, pavement profile and tire pressure in a controlled environment in order to isolate the influence of these parameters.

The 32 channels of the Modulas sensor produce a considerable amount of raw data that had to be carefully analysed. The laboratory tests show that the Modulas promises to be an effective investigative tool as for the first time tire force distributions can be measured in real time with a high spatial resolution at highway velocities.

### 2.4 Variation of Tyre Pressure

These preliminary results also show that a significant difference in stress distribution under the tire can be seen for over/underinflated tyres. In such cases maximum vertical stresses can occur at tire edges that were sometimes more than 2 to 3 times the inflation pressure of the tyres. Velocity variation, Temperature variation, Lateral Drift, Pavement profile - As it is known that on the site there is a slight incline of 2.4% across the road profile, this part of the experiments were designed to duplicate this incline and evaluate the result on the resulting pavement stresses.

The traffic volume of heavy vehicles using the road network has been increasing steadily over the last decades, as is the trend for increasing individual axle loads. The weighing of road vehicle axles in motion (WIM) is getting more and more an important factor for the record and analysis of the traffic stream. This chapter described new applications of a special method for the measurement of force distributions under rolling wheels.

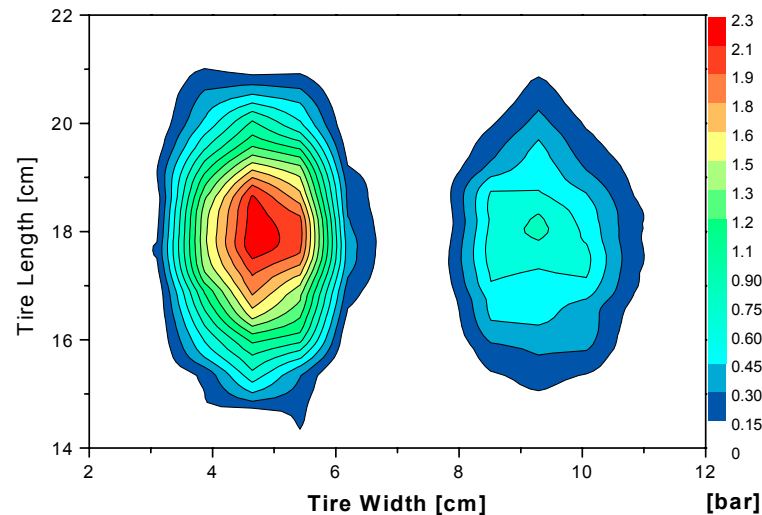


Figure 2: Isobar representation of contact pressure distributions: Examples of over- and under-inflated tyres

Results of the laboratory experiments with Modulas, show the sensor being a promising tool for pavement designers. These preliminary results also show that a significant difference in stress distribution under the tire can be seen for over/underinflated tires. In such cases maximum vertical stresses can occur at tire edges that were sometimes more than 2 to 3 times the inflation pressure of the tires.

### 3 CONDITIONS OF THE ROAD NETWORK

#### 3.1 Network monitoring

Road network monitoring forms an essential element of pavement management. Through periodic visual distress surveys, augmented by measurement of specific distress parameters such as the longitudinal profile, the condition of the network is followed over the years. Deterioration of the average condition of the whole network can indicate an inadequate maintenance budget. The condition of each individual section of the network can be used in a PMS (Pavement Management System) to give an indication of when maintenance might be required.

The road network monitoring consist following items:

- Inventory - length of section [m], cross profile of section (width, number of lanes), construction details (layer thickness, materials)
- Maintenance – rehabilitation history, maintenance history

Indicates frequency of measurements:

- Distress – manual or automated distress surveys
- Surface characteristics – texture, skid resistance
- Profile – longitudinal and transverse

- Deflection – falling weight or other type of deflectometer
- Availability – indicates whether monitoring data

### 3.2 Effects of wide single tyres and dual tyres

The main objective of the COST 334 action was to establish the relative effects of wide base single tyres and dual tyres assemblies in respect of road pavement damage, vehicle operating costs, vehicle safety and comfort and environment (particularly noise).

Wide base single tyres on heavy vehicles are not a recent innovation. Over the past ten years, as economic pressures on operators have increased, the adoption of wide base single tyres as fitments to heavy goods vehicles has become more widespread. They offer the vehicle operator lower unladen weights and, on the larger heavy goods vehicles, this can represent a significant payload advantage. The advantages of wide base single tyres have overcome the previous reservations of vehicle operators, and this has led to their very much wider use on the national and international fleets of heavy goods vehicles.

Studies of the potential of such tyre equipment to bring about structural wear in road pavements have indicated the possibility of increased wear. This has given rise to concern that the use of wide base single tyres does not adequately comply with the principle of cost recovery, which applies in many Member States to construction and maintenance costs for the national road network.

The question of the possible contribution to road wear of wide base single tyres has received considerable world-wide attention. Generally, however, reported work has been either based on the use of models of pavement response and response measurements, or has involved the use of limited experimental work in which direct comparisons with the wear caused by conventional dual wheel assemblies were made. Only one study is known (carried out in the USA) in which long term testing of a full-scale pavement has been used to compare the wear effects of the two tyre types. Unfortunately, this test was carried out on a pavement that is not typical of those used in Europe, and under conditions which make the translation of results to European conditions of truck weight and climate extremely difficult.

Against the possible effects on road wear, the use of wide base single tyres on heavy goods vehicles brings some clear advantages. In particular, their lower weight enables the multi-axle vehicle to carry significantly more payload than if it were equipped with dual wheels, and the reduced rolling resistance, with consequent improvements to fuel consumption, make the tyre attractive to vehicle operators.

Little is known of the possible effects on safety of vehicles equipped with wide base single tyres, and this aspect will need to be examined. The ride and handling (including braking) characteristics of such vehicles may be adversely or helpfully affected although, again, little is known on this at present. The fitting of wide base single tyres on vehicles designed to use them, for example, may lead to a wider wheel-wheel distance on an axle, conferring greater roll stability on that vehicle, with consequently reduced road wear. However, few if any experimentally driven results are available, and only limited modelling of the possibility has been undertaken.

Finally, it has been suggested that the use of wide base single tyres may have effects on noise emissions from the road/tyre surface, and that their use may lessen the increasing problem of tyre disposal. Again, these effects need to be quantified, so that informed overall judgements on the use of wide base single tyres can be made.

In addition to long term experimental testing of a wide range of pavement types for road wear effects, there is a strong need to work on the development of simple, but adequate, models of vehicle operating costs able to deal with tyre parameters. The use of techniques to evaluate overall effects on pavement construction and maintenance costs is also necessary, as is measurement of the effects of the use of wide base single tyres on noise emissions.

## 4 DEVELOPMENT AND HARMONISATION WITHIN EU

The base of coordination and harmonization itself involves reducing the administrative burden on partner countries, ensuring that the input of donors is coherent and avoiding unnecessary duplication.

There are three levels of content and three degrees of intensity in coordination. The content levels are:

- Policy, principles and priorities – harmonizing goals and activities
- Procedure – formal institutional rules and regulations (incl. financial control, auditing etc.)
- Practice – less formal than the procedures

The surface transport work programme proposes a set of research objectives which implement the content of the Gothenburg declaration of June 2001 and the Commission White Paper on European Transport Policy “European transport policy for 2010: time to decide”.

Objectives of research and development:

### Road Safety Strategies

- Accident analysis and injury analysis
- Driver safety training
- Road infrastructure safety
- Enforcement of traffic rules and drivers’ aptitude to drive
- Awareness campaigns and acceptability of measures

### Integrating Intelligent Transport Systems

- Electronic fee collection on roads
- Multi-modal real-time information system for people on the roads

### Implementation of Transport Pricing

- Cost of transport infrastructure use
- Optimal investment and charging
- Pricing demonstrations

Since 1984, European Community research and technological development activities have been defined and implemented by a series of multi annual Framework Programmes.

The Forum of European National Highway Research Laboratories (FEHRL) in 1992 put the WIM project at a high priority level in a list of 18 proposed topics for cooperative actions to be supported by the DGVII of the European Commission. The following development project have been managed:

### 4.1 COST Projects

COST 323 - Weigh in motion of road vehicles and WAVE project - Weigh in motion of axles and vehicles for Europe.

It was the main objective of the COST 323 and WAVE to promote the development and implementation of WIM systems and their applications throughout Europe. It was also necessary to harmonise and to explain the best practice for the users and vendors, as well as to facilitate the communication between them. The COST 323 Management Committee, as part of the COST Transport Action „WIM LOAD“, has produced the document: European WIM Specification. It gives general and detailed recommendations for site selection, installation, operation, calibration and assessments by application of WIM systems. The main objective of this work is to cover the need for a complete specification and harmonisation, covering both aspects: model approval and on site acceptance test and accuracy assessment, pending the publication of an official European Standard produced by CEN. It also provides a technical basis for such a standard – this is a “pre-Standardisation document”.



Other relating COST projects:  
 COST 324 Long term performance of road pavements  
 COST 334 Effects of wide single tyres and dual tyres

#### 4.2 Eureka Logchain Footprint Project

The European cooperative project Eureka Logchain Footprint aims to develop an innovative and cost effective method to identify road and rail vehicles by means of their "footprint" as characterized by dynamic load, noise, vibration and gaseous emissions induced by the vehicle. The goal is to relate this footprint to the cost of maintaining the infrastructure. The project has currently 27 partners from seven European countries with the U.K. providing overall project coordination.

Various phases of the project address a wide range of factors from monitoring and modelling to cost analysis. An important part of the project is monitoring of the vehicle infrastructure interaction and measuring the specific parameters listed above in a reliable, reproducible and costs effective manner. To this end two prototype Footprint stations, one on the road and one on the rail are planned. The rail Footprint station is located in Wadinxveen in the Netherlands. This is a fully functional Footprint station using fibre optic rail WIM, vibration and acoustic sensors.

The first road Footprint station will be built in Spring 2005 in Switzerland. This monitoring site is located on the major East-West artery A1 motorway between Zurich and Bern.

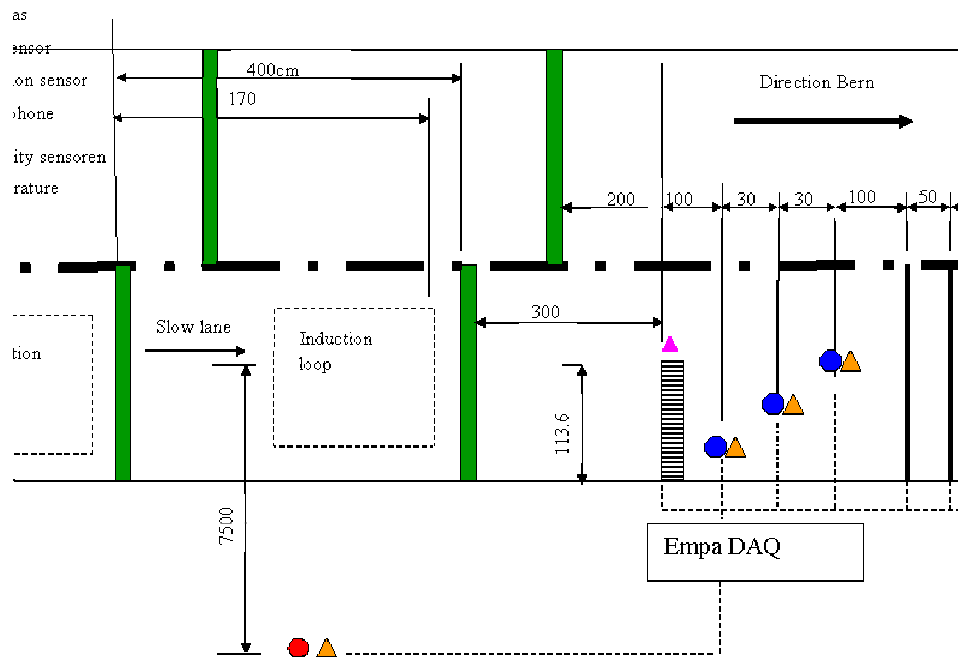


Figure 3: Footprint Monitoring Road Site in Switzerland

The need for traffic data is increasing with the development of heavy good vehicles. Road managers and authorities need to reduce the design, construction and maintenance costs of their infrastructure whilst maintaining the safety and quality of their road and bridge constructions. The harmonisation of traffic loads and legislations in Europe has produced a requirement for high quality pan-European Weigh-In-Motion networks and databases and a

European standard for WIM. Moreover, the increasing demand for environment protection and for fair competition between different transport modes has lead to requirement for more accurate data on axle and vehicle

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