Abstract
This paper gives a review of recent developments of Weigh-in-Motion in Europe, above all about the wider use of WIM for overloading enforcement. The output of recent projects, such as REMOVE, is reported. An overview of the current situation of WIM networks for enforcement in a number of European countries is given. Finally the perspectives of the standardisation of WIM in Europe, and the emerging WIM technologies for enforcement are briefly presented. The on-going FiWi project, a FEHRL initiative on WIM, is also shortly described.

Keywords: Weigh-in-Motion, WIM, Enforcement, Screening, Overload, Trucks, European Specification of WIM, Freight Transport, WIM Technology and Sensor.

Résumé
Cet article présente les développements récents du pesage en marche en Europe, notamment en ce qui concerne l’application de plus en plus fréquente pour la détection et le contrôle des surcharges. Les résultats de projets récents comme REMOVE sont rapportés. Un panorama des réseaux de stations de pesage en marche pour la détection et le contrôle des surcharges dans divers pays européens est donné. Enfin les perspectives de la normalisation européenne du pesage en marche et des nouvelles technologies pour le contrôle des surcharges sont esquissées. Le projet FiWi initié par le FEHRL sur le pesage en marche est présenté en bref.

Mots-clés: pesage en marche, détection, contrôle, surcharge, poids lourds, spécifications européennes du pesage en marche, transport de marchandises, technologies du pesage et capteurs.
1. Introduction

There have been considerable developments in the Weigh-in-Motion (WIM) industry in Europe in recent years. Developments have taken place in:

- **Hardware**: improvement of WIM-sensors durability,
- **Software**: development of new calculation algorithms for multiple sensor (MS-)WIM and bridge (B-)WIM,
- **Applications**: a wider use of WIM for enforcement of overloading.

WIM was initially developed in the 60’s and 70’s for applications in pavement, and then bridge engineering, assessment of traffic loads and damage induced to the infrastructure, e.g. fatigue. In the 80’s and early 90’s, the focus was on the development of better - more accurate, reliable and durable – sensors, and the research works were only carried out at National level, in UK by the TRL, in France by the LCPC, in Germany by the BAST and a manufacturer. Since the early 90’s, a series of WIM related European projects were carried out, involving a large number of EU member states and supported by the European Commission through the COST Transport and the Framework Programmes, which resulted in quick and significant steps forwards in the technologies and the implementation of WIM:

- the COST323 action (1993-1999) brought together the WIM users from across Europe and resulted in several improvements in technologies and in standards. The independent tests of the latest WIM sensors and systems in three countries, the development of European WIM Specification (COST323, 1999), the set-up of a pan-European database of WIM sites and systems, a multi-language glossary of terms, a series of reports on WIM needs and applications, and the start of a series of International WIM conferences were important steps ahead (Jacob et al., 2002);
- the WAVE research project (1996-1999), of the 4th Framework Programme, completed the work initiated in the COST323 action. This EU-funded project resulted in new algorithms for MS-WIM and B-WIM, WIM-data quality procedures, more results on the durability and behaviour of WIM sensors in harsh climate, and a prototype fiber optic WIM system (Jacob, 1999 and 2002);
- the Top-Trial project (2000-2002), a 5th Framework Programme project, focussed on the design, building and testing of a MS-WIM system under real highway conditions (CORDIS, 2002);
- the REMOVE project is briefly described in sections 2.2 and 2.3.

Since 2000, WIM technologies have become stabilized and mature. The combination with other ICT (Information and Communication Technologies) applications, such as digital imaging, vehicle identification and use of various databases, opens several new enforcement applications. WIM not only offers the potential for the enforcement agencies to significantly increase the number of truck checks, but it also enables free flow for non overloaded vehicles. A few EU member states already have some experience in using WIM for pre-selection of overloaded vehicles, e.g. the WIM-NL network in the Netherlands (Saan and Loo, 2002), and similar implementation of video-WIM networks in France (Marchadour and Jacob, 2008), UK and Germany. However these (pilot) projects are at National level while overloading is an international problem by nature. As a result there is a need for a European coordination. This coordinated strategy should incorporate not only relevant technical issues, but also operational and legal issues.
2. Requirements for enforcement

2.1 Overloading

Road freight transport by overloaded trucks creates a number of serious problems on Europe's road network. These include unfair competition, reduced safety and mobility, and considerable extra costs for additional maintenance/repair of the roads and bridges. As road transport by trucks increases, these problems become more severe. The problem of overloading is often caused by deliberate non-compliance, however in some cases the overloading is done unintentionally, e.g. when part of the truck load is removed, which may result in overloading of an axle due to a change in the distribution of weight on the vehicle.

Although the negative effects of overloading are well known, the exact figures are far less known. Some countries claim that about 15% of all trucks are overloaded, however this information often comes from enforcement agencies. Depending on the enforcement tools and procedure, the current overloading situation assessment may be over- or under-estimated, while the enforcement operation directly influences the amount of overloading. Moreover, nothing is known about the overloading situation when or where no enforcement is done.

When trying to calculate the costs of the negative effects of overloading, it becomes more difficult to find accurate and reliable figures. Only a rough estimation of the direct costs of the damage to the infrastructure is available in a few EU-countries. Figures about the costs (in Euros) of overloading on road safety, unfair competition and secondary effects of road damage (e.g. traffic jams) do not exist. But it does not mean that the problem does not exist!

2.2 The REMOVE Project

In the early 2000’s, a need for a new European WIM related project was recognised by European enforcement authorities. The aim was not to focus on technology but on the harmonised introduction of WIM technology in the enforcement procedures. In 2004 the DG-TREN of the European Commission (EC) agreed to launch the REMOVE project. Its objective was to present to the EC the operational, legal and technical requirements and a strategy (Figure 1) for a harmonised and interoperable deployment of WIM systems for enforcement of overloading throughout the EU. The transport industry, the ministries of transport and the enforcement agencies co-operated in the REMOVE project to develop new ways of enforcement that are acceptable for all involved parties, as well as to discuss more structural solutions to solve the problem of overloading in future. The REMOVE project developed a vision to deal with the problem of overloading in the future. An essential target is an increase in the compliance with loading regulations in the whole EU. Compliance can be achieved though a combination of:

- Enforcement and Prevention: since overloading is an international problem by nature, there should be a focus on cross-border enforcement. The key element in cross-border enforcement is the legal basis for data exchange; this involves data acceptance and data quality assurance. Instead of the current focus on enforcement alone, there should also be a focus on solving the underlying problems of overloading. There should be a system to separate the ‘fair’ companies from the ‘unfair’ ones, through monitoring the driver and truck load behaviour and company profiling. Therefore, a network of WIM systems could be used as a tool for screening the transport company behaviour.
Figure 1 – The REMOVE strategy.

- Harmonisation: from a legal, operational and technical point of view there is a strong need for harmonisation in order to create clear rules and a harmonised frame for the transport industry, and a more effective enforcement procedure for the government agencies. The harmonisation should cover the maximum load limits, the penalties when overloaded, the issue of liability and the specifications for WIM systems.
- Use of recent WIM technologies should be the basis of new enforcement procedures/strategies development. Applying WIM in an intelligent mix of ways should solve specific overloading problems. For cross-border enforcement it is essential to have international standards, for example the functional and technical specifications for WIM systems to be used for the different enforcement applications. Modern WIM and ICT technologies should be incorporated in the enforcement strategies.

2.3 REMOVE Recommendations

The main recommendations of the REMOVE project were:
- Harmonisation of the WIM system specifications as a EU-code of practice;
- Preparation of a set of technical specifications for High Speed (HS-)WIM systems to be used for direct enforcement of overloading;
- Harmonisation of penalties on overloading and if possible of the maximum load limits across member states;
- Identification of possibilities for introduction of a quality assurance programme such as the Australian Intelligent Access Programme (Baring and Koniditsiotis, 2008);
- Encouragement of the development of in-vehicle (on-board) weighing equipment.

3. Implementation of WIM for Enforcement

3.1 The Netherlands

With an area of 34,000 km² and 16 million inhabitants, the Netherlands has 125,000 km of roads. There are 3250 km of motorways controlled by the Department of Public Works (Rijkswaterstaat). (Inter-)national goods transportation by road is an important part of the Dutch economy; 173,000 trucks transport 600 million tonnes of freight annually. In 2000, the Ministry of Transport and Public Works started carrying out the project ‘Overloading’. Within this project Rijkswaterstaat works together with the Transport Inspectorate and the National Traffic Police to reduce the effects of overloading by heavy trucks. As part of this project a network of currently 8 WIM systems has been built (Figure 2).
These systems consist of two induction loops and two rows of piezo-quarz sensors per lane for weighing and vehicle classification. Digital cameras record the image of the whole vehicle and an image of the licence plate of overloaded trucks. The accuracy requirements are that 95% of all axle load measurements should be within ±15% when compared with the static axle loads. The network is maintained, calibrated and operated by Rijkswaterstaat, which also uses the WIM data for road design purposes. The traffic police use the WIM systems as a pre-selection tool for the static overload controls. The WIM data are also used for police control planning and to evaluate their effects. The Transport Inspectorate receives the WIM data and the digital pictures of all overloaded trucks. Using the licence plate number, the owner (transport company) is found and the data is stored in a data base per company. The data base is used to generate a ‘black-list’ of violating companies. These companies are visited by an inspector and their behaviour is monitored more closely. There are plans for a first pilot on international data exchange between Euro Control Route members.

An other part of the project ‘Overloading’ is the development of a WIM system for direct enforcement. For this separate research project a MS-WIM system has been built near the city of Arnhem. For the dynamic calibration of each of the 32 WIM sensors, a special calibration vehicle has been built. A total of 5 operational tests have been performed where the dynamic measurements of the MS-WIM were compared to static reference measurements. Because of a series of hardware problems the analysis of the measurement data suffered serious delays and many aspects still need to be investigated.

3.2 France

France is one of the largest EU country with 544,435 km² (+ 95,500 km² of oversea territories), and 60 million inhabitants. The population density is rather low (109 inhabitants/km²) compared to some other EU countries, e.g. the Netherlands, Germany, UK. The road network consists of: (i) 11,000 km of motorways, among them 8,200 are concessionnary, (ii) 9,000 km of National roads, (iii) 377,000 km of departmental roads, and (iv) 550,000 km of county (local) roads, i.e. a total of nearly 1 million of km. Currently 250,000 trucks on the road comprise 78% of freight traffic. In 2006, the road freight transport consisted of 2.18 billion tonnes and 198.8 billion tonne.km. The international road transit transport is rather high in eastern France (from the Benelux and Germany down to the Rhône valley, south of France, Italy and Spain), in northern France (between Paris and the Channel tunnel, Belgium and The Netherlands), and in the south-west on the A10 motorways from
Paris to Bordeaux and Spain. The overloading figures in 2002 (based on static measurements) were as follows: among 41,000 controlled trucks, 36.1% were overloaded, including 16.8% with more than 8% overload. However, the controls are mostly performed on presumed overloaded trucks, thus the overall rate of overload is expected to be much lower, i.e. around 10%. The national roads are equipped with the SIREDO network, which consists of 1500 counting stations (with silhouette and speed measurements), among them 150 WIM stations which currently records weight statistics (Rambeau et al., 1998).

In 2005, the Ministry of Transport (Department for Sea and Transport, DGMT) launched a call for tender, based on a detailed specification prepared with the CETE Est and the Laboratoire Central des Ponts et Chaussées (LCPC) to design and install a network of 10 to 40 video-WIM systems on National roads and motorways (Figure 3). The objective of this network is to screen the overloaded and over-speeding heavy vehicles, prior to the control area where enforcement is made by static or Low-Speed (LS-)WIM, and to record pictures of the presumed violators (truck and license plate number), to identify the most frequent violating companies, and to carry targeted controls by them (Marchadour and Jacob, 2008). The WIM systems are supplied by Sterela, a French company which won the call for tender, and use two piezo-ceramic strip sensors per lane, an inductive loop, a video camera, and in some case an additional automatic vehicle identification (AVI) video system to measure the mean speed over a few hundreds meters for over-speeding control and penalties for the speed limiter violation (Stanczyk et al., 2008). The first systems are now in operation since 2007.

Figure 3 – The new WIM network in France (2007-2009).

3.3 Slovenia

With its 20,000 km² Slovenia is one of the smallest countries of the European Union. It however plays an important role from the transport point of view as it is crossed by two of the heavily trafficked Trans European corridors, one going from South West to the North East of Europe, and another from the North West of Europe to Turkey and Greece. Slovenia’s 7000 km long state road network is equipped with around 600 mainly automatic traffic counters that provide up-to-date information about the traffic volumes. Traditionally, this data has also
been the main input for the ESAL (Equivalent Single Axle Load) method, which is used in
design and maintenance of pavements. As counting data cannot give any information about
real axle loads, especially about their overloading, in the year 2000 the Slovene Road
Administration decided to start acquiring the WIM data. The specification for the WIM
systems are set by the National Road Directorate for statistics on pavement loading and not by
the Traffic Police. The minimum specifications are COST323 class C(15) however many
WIM sites are actually in class B(10).

Figure 4 – The WIM-network in Slovenia.

Over the last 3 years a network of 30 WIM sites has been established to cover all major routes
of the main state road network (Figure 4). Four portable bridge WIM systems are used to
perform the 7-day measurements twice per year on each site. The results of weighing
exceeded some of the most pessimistic expectations. Over the years, the data of the Slovenian
WIM sites are used for other applications besides pavement loading, road maintenance and
new standards for road design. In order to have effective controls, the Slovenian police
department uses the SiWIM data to determine what areas and at what time they should have
controls. The police also uses WIM systems for pre-selection to make these more efficient
and less time consuming.

The new B-WIM generation provides measured information about structural behaviour of
bridges (influence lines, statistical load distribution and impact factors from normal traffic).
In Slovenia, these measurements are used in optimizing bridge safety assessment. Optimized
safety assessments can prove that many existing bridges are safe in their current conditions
and for their current loading, or can justify optimal rehabilitation measures, to avoid any
reduction of bridge posting and to save a lot of money. Due to the increasing volume of the
special transport in Slovenia, the Slovenian road district has also started using B-WIM data to
determine which roads are safe for special transports. The roads are checked for traffic
volume and the bridges along the way are tested for their support safety.

3.4 Other European Countries

United Kingdom: in 2005 the Weight and Safety Partnership (WASP) was started as a
cooperation between the Highways Agency (HA), the Vehicle and Operator Services Agency
(VOSA) and the Central Motorway Police Group (CMPG). The aim was to investigate and
evaluate the effectiveness of the combination of WIM systems, using piezo-polymer strip
sensors, with Automatic Number Plate Recognition (ANPR). VOSA uses the system as a pre-
screening tool for the overload controls. The system has a direct link with the UK vehicle database containing the individual permitted axle loads and gross weight limits. This connection and the ANPR data allow the vehicle’s permitted weights to be automatically compared with the WIM measurements. Non UK-registered vehicles are checked against the generic axle and gross vehicle limits. After a two year trial, VOSA assisted by the Highways Agency are currently rolling out a network of additional WIM systems (with ANPR).

In Sweden, the Swedish National Road Authority (Vägverket) has been using B-WIM systems since 2003 and has currently 4 systems operational on approximately 30 sites. There are 14 National sites, where measurements are performed once a year over a week. The data are used to generate an overview of the overall loading. There are also 14 Regional sites, that are used for various purposes depending on regional needs: to gather data for maintenance and rehabilitation measures, or to monitor loading behaviour. Finally, there are up to 4 R&D sites that are used for various research projects.

Hungary, has a central location in Europe with 4 major European transportation corridors running through the country. The highways are maintained and operated by the State Motorway Management Company, the national roads by the Hungarian Roads Management Company. Enforcement of overloading was the responsibility of Customs and the National Transport Authority. Customs checked all trucks entering the country while the NTA concentrated on the inland transports. As of December 2007 Hungary became part of the Schengen area, all border controls had to be stopped. The Hungarian Road Management Company has plans to construct a WIM network of 20-30 systems used for data-collection and pre-selection for overloading. The aim is to increase the efficiency of the enforcement operation and to reduce the damage caused by overloaded vehicles.

In Poland, the Directorate General for National Roads and Motorways (GDDKiA) is the government administration responsible for the operation and maintenance of the National road network. The General Inspectorate of Road Transport is responsible for the weight enforcement and most of the WIM systems operation. However some WIM stations are operated by customs while others are used for research purposes by the Technical University of Krakow.

In Switzerland, the Swiss Federal Roads Authority (ASTRA) operates eight WIM systems on the National road network for monitoring vehicle axle loads. The data of these WIM systems are used for road and bridge design, maintenance work planning, safety, economic purposes, transport studies, research and for other traffic related purposes. In addition, the WIM systems are also used by the police for overload controls planning and sometimes as a tool of pre-screening for heavy vehicle checks. The enforcement of overloading is the responsibility of the 26 individual regional (Cantonal) police agencies. The police also assists ASTRA to stop and statically weigh the trucks, and for the calibration of the WIM systems.

4. New WIM Perspectives for Enforcement

4.1 FiWi

Currently, the COST323 Specification is the de-facto European (and even a worldwide) pre-standard for WIM systems, for the last 10 years. Even though formally it is neither an official European nor an International standard, it is widely used as a reference in the testing and acceptance of WIM systems. While there have been considerable developments in the field of
WIM over the last 10 years, and the REMOVE project pointed out a strong need for harmonised European WIM Specification for enforcement applications, the FEHRL (Forum of European Highway Research Laboratories) initiated the FiWi project (FEHRL institutes WIM Initiative), over a 2-year period (2007-2009). Besides a general update of the COST323 Specification, some content will be added for B-WIM and WIM for direct enforcement. A preliminary questionnaire (PQ) procedure started with the CEN to transform the COST323 Specification into a European Standard.

Furthermore, the applications of WIM to traffic monitoring and safety as part of ITS, to infrastructure engineering and to enforcement will be more investigated. Another objective of the FiWi project is to facilitate peer reviews and exchanges of experiences in WIM activities throughout Europe. The FiWi partners (LCPC/FR, Rijkswaterstaat /NL, BAST/DE, UCD/IE, ZAG/SI, and CEDEX/SP, EMPA/CH) will form the kernel of the European group of the newly founded International Society for WIM (ISWIM). The FiWi project aims to create a platform where FEHRL members and WIM research institutes and users can share information on all WIM projects in Europe. It is planned to up-date and develop the COST323 database, by adding WIM data from several test and operational sites of European countries and to make them available for research and development activities.

4.2 Emerging Technologies for Enforcement

The next challenge of WIM technology is to provide reliable and accurate tools for direct and automatic enforcement of overloads, in the traffic flow, such as the speed enforcement by radars or video cameras. The two technologies which seems able to fulfil the requirements, i.e. an accuracy in class A(5) of the COST323 Specification, or ±5% for gross weights, ±8% for axle group loads, and ±10% for single axle loads, with a rather high level of confidence (i.e. 96 to 99%), are the MS-WIM if using road sensors, and the B-WIM.

Whatever the road sensor technology used and the strip sensor quality and performance, it was shown that, because of the dynamics induced by the road pavement profile, it will never be possible to meet the class A(5) tolerances with one or two sensors per lane. However, the research works carried out since the late 80’s on MS-WIM, and above all over the last 5 years, proved that MS-WIM arrays made of 8 to 16 sensors could provide such accurate results. But that requires highly efficient algorithms, accurate and reliable strip sensors, a powerful calibration procedure, and a detailed quality assurance chart. Theoretical works are still performed by the LCPC in France (Bouteldja et al., 2008), and experiments are in progress in France (Jacob et al., 2008) and in the Netherlands. The objective is to optimise the design and operation of such arrays and to develop operational systems.

The quick progresses made in B-WIM since the mid-90’s, mainly in Slovenia and Ireland, and the development of a commercial and operational system by CESTEL in Slovenia, opens new perspectives for overload enforcement. Tests of B-WIM systems carried out in Slovenia, Sweden and France, showed that an accuracy in class A(5) is accessible, above all for gross weights and axle group loads, and for some types of bridges. On-going research works and improvements of the SiWIM system would likely allow to meet the class A(5) requirements in the future. If so, B-WIM would provide a very useful alternative and complementary solution to MS-WIM, to be implemented where the appropriate bridge exists, with the great advantage of being almost undetectable by the drivers, and not requiring lane closure and traffic disruption for the installation and maintenance.
The last but not least issue to be resolved will be the certification or agreement of a high speed (HS-)WIM system by the legal metrology, at National level or by the OIML. Knowing the difficulties encountered and the delay to design the recommendation on LS-WIM systems (OIML, 2004 and 2006), that may require several more years. But the sooner it will start, the sooner it will be completed.

5. References