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WEIGH-IN-MOTION: RECENT DEVELOPMENTS IN EUROPE

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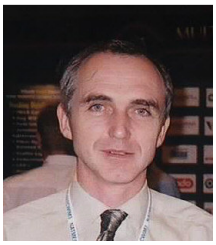

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Abstract

This paper provides a review of recent European developments in WIM. Pan-European and national projects are reported plus developments in sensor technologies and system design. Recent developments in multiple-sensor WIM systems are given particular attention. The coming of prototype fully-automatic overload systems is discussed and the technologies and legal framework necessary for their success. The commercialisation of Bridge WIM in Europe since the ICWIM3 is considered and the continued development of this technology towards almost maintenance-free systems. WIM applications are also discussed including pavement and bridge design and assessment.

Keywords: Weigh-in-Motion, WIM,

Résumé

Cet article donne un panorama des récents développements du pesage en marche en Europe. Il présente les principaux projets européens et nationaux et les développements technologiques concernant les capteurs et la conception des systèmes. Les travaux récents sur le pesage multi-capteur sont examinés plus particulièrement. L'introduction de systèmes prototypes pour automatiser le contrôle des surcharges est discuté, tant du point de vie des technologies à mettre en œuvre que du cadre légal nécessaire à leur usage. La commercialisation de systèmes de pesage par pont instrumentés en Europe a débuté depuis la conférence ICWIM3 et les développements se poursuivent pour tendre vers des systèmes ne nécessitant pratiquement pas de maintenance. Les applications du pesage en marche, notamment pour la conception et la vérification des chaussées et des ponts, sont aussi abordés.

Mots-clés: Pesage en marche

1. Introduction

There have been considerable developments in the Weigh-in-Motion industry in Europe in recent years. In the past, WIM sensors lacked durability and there was a lack of consistency in methods of assessing accuracy. The COST 323 action from 1993 to 1998, brought together WIM users from across Europe and resulted in several improvements:

- a report on the WIM needs of the transport industry,
- independently monitored tests of commercial and prototype WIM systems,
- a WIM standard with a standardised accuracy classification method (COST323, 1999),
- two WIM conferences for dissemination of research results and sharing of information on WIM developments (Jacob 1995; Jacob & OBrien 1998).

The final report for the COST 323 project has now been published (Jacob et al. 2002 & 2004).

The 4th Framework WAVE project, 1996 to 1999, complemented the activities of COST 323 (Jacob 1999 and Jacob 2002). This project funded research at a number of levels and resulted in significant advances in several areas:

- new algorithms to process the output from multiple-sensor WIM systems,
- significant advances in Bridge WIM technology, both in accuracy and in the range of bridge types through which it can be implemented,
- prototype database and WIM data quality assurance procedures,
- independent testing of WIM systems (overseen by the COST 323 group), including a test in cold climates,
- development of a fibre optic WIM sensor.

The 5th Framework TOP TRIAL project, 2000 to 2002, focussed more on the system architecture for a full scale trial of an automatic weight enforcement system utilising WIM sensor arrays:

- a semi-automatic weight enforcement system was constructed and operated,
- WIM sensor reliability and accuracy were investigated
- simulation techniques were developed to determine an optimal sensor layout for a multiple-sensor site,
- a cost-benefit analysis was carried out of alternative approaches to overload enforcement.

Since the 3rd International Conference on WIM, ICWIM3 (Jacob et al. 2002), the emphasis has shifted in Europe. There is increasing interest in semi-automatic systems for overload enforcement and a push towards fully automatic systems. Sensor design continues to progress and new technologies are still emerging. Bridge WIM has undergone considerable development and there has been a shift in focus from the laboratory into the field. There have been no pan-European WIM research projects in the past few years but there are a number of bilateral collaborations, and an on-going project on automatic weighing of trucks for enforcement: REMOVE (Requirements for EnforceMent of Overloaded Vehicles in Europe).

2. WIM for Pre-screening and Enforcement of Overloads

2.1 Video-WIM in the Netherlands

Some of the most significant recent developments in European Weigh-in-Motion have been the Dutch WIM-NL and WIM-Hand projects (van Doorn 2000, van Loo 2004). In WIM-NL (van Saan & van Loo 2002) pre-selection applications of WIM were constructed which utilise video images of overloaded trucks to assist their identification. The WIM system identifies overloaded trucks and generates a video image which is transmitted to personnel at a static weigh station downstream in the traffic. The measurements and the image are also sent to the Traffic Inspectorate for company profiling and preventive activities. Piezoquartz strip sensors are used for this application.

WIM-Hand is an abbreviation for "Weigh-in-Motion voor directe Handhaving" (direct enforcement) and its primary goal is to show that Weigh-in-Motion technology can be used for the automatic enforcement of overloaded vehicles. Problems with the hardware and the calibration of sensors in the multiple-sensor array have prevented the achievement of any reliable measurement results to date. To bridge the interval until fully automatic direct enforcement is possible, DWW have installed six operational video systems for pre-selection with an additional 2 systems in 2005 and there are plans to upgrade them to fully automatic enforcement systems in the future.

2.2 Overload Control Project in France using WIM

Since 1996 the Ground Transportation Division (DTT) of the French Ministry of Transport has supported R&D on: (i) Low-Speed (LS-)WIM, (ii) Multiple-Sensor (MS-)WIM, and (iii) Video-WIM. This work is carried out by the Laboratoire Central des Ponts et Chaussées (LCPC) and the CETE de l'Est, jointly with some manufacturers. The need for automatic systems for overload pre-screening and enforcement was identified because of the rapid increase in heavy goods vehicle density, a trend towards more overload cases because of strong competition in freight transport and a reduction in human resources for control, i.e., weighing officers and police staff (Marchadour, 1998).

A LS-WIM system was developed by a company and successfully tested in 1998 (Dolce-mascolo et al., 1998). The system met accuracy class A(4) according to the COST323 Specification and OIML class 10 (OIML, 2004). A certification procedure for this system is under completion by the French Legal Metrology authority, and an additional test was carried out in early December 2004, which proved that the system has slightly improved since 1998. It is expected that such a system may be used for enforcement instead of static wheel and axle scales in the near future.

Since 2001, the DTT has experimented with two WIM systems, associated with video and automatic vehicle plate recognition, in order to screen vehicles that are suspected of being overloaded or of speeding (Stanczyk and Marchadour, 2005). The DTT plans to implement in 2005-2007, a network of 20 to 40 Video-WIM systems linked to a telecommunication network (either the common telephone network, an ADSL network or a dedicated network, such as fibre optic on motorways). The WIM systems are to be installed on highways and motorways throughout France, close to enforcement areas. During enforcement periods, the system will send a picture of the suspected violators to the enforcement staff a few km downstream, and the vehicles will be stopped either at a toll station or using variable message

signs and police staff. In addition, the system will record pictures 24/7 of suspected violators, in protected and legally registered files, which will be used later by the DTT to focus control on the companies which accumulate most suspected violations. A European call for tender was issued in Summer 2004, and the contract for a first phase of at least 10 systems will be signed in Spring 2005. The LCPC and CETE de l'Est were appointed by the DTT to help with the specification of the whole system, to choose the required sites and later, to perform the acceptance tests of the systems. The specification does not require any particular technology for the WIM sensors, but the design of the system requires two WIM strip sensors per traffic lane.

2.3 Overview of Overload Control in Germany

LS-WIM systems are already approved (by the PTB) in Germany for enforcement in specific areas. Video-WIM systems are or will be used for accurate pre-screening of overloaded vehicles prior to a static weighing system or a LS-WIM system. The bending plates used in the past are now being replaced either by piezoquarz strip sensors or by other types of marketed sensors. The Federal Highway Research Institute (BAST) is investigating new technologies.

Since 2003, Germany decided to implement a toll system for heavy goods vehicles (above 12 tonnes for the authorised GVW), based on the mileage of each vehicle across the country. GPS and AVI systems, as well as electronic toll cards are part of the whole system. WIM systems will obviously be necessary to check and monitor the HGV's which are subject to this charge. However, until now it seems that the system is not fully operational.

2.4 European REMOVE project

The REMOVE project (van Loo and Henny, 2005), coordinated by the National Police Agency of the Netherlands (KPLD), is a 6th Framework project funded by the European Commission Transport and Energy directorate, DG/TREN. It started in February 2004 and is planned for 2 years. The partners are: Euro Control Route (ECR), TISPOL (European Association of Transport Police), the German Ministry of Transport, Building and Housing (BMVBM), the Dutch Ministry of Transport (DWW), the LCPC associated with the DTT (France), and the International Road Transport Union (IRU). The project will directly contribute to the introduction and dissemination across the EU states of new technologies related to the process of automatic weighing of trucks.

In the few EU countries, where WIM has already been used to aid overload enforcement, it appears to be extremely effective. Although a number of technical improvements still have to be made and a legal framework has to be drawn up, WIM system are clearly more than just a way to check practically unlimited numbers of trucks for overloading. The modern electronic vehicle recognition systems and communications networks make it possible to build entirely new enforcement models. In the near future these models can be based on intelligence gathering because of the huge number of measurements that are made. These measurements will allow the enforcement agencies to distinguish between legally compliant and non-compliant transport companies. The compliant companies will be hindered less by enforcement activities, whilst the non-compliant ones can be the focus of more intensive enforcement activity. In this way, the enforcement agencies can deploy their staff much more efficiently.

WIM systems, connected to a communications network could easily be deployed at an international level. For example, information about overloading offences which are committed abroad, can be sent to the member state where the transport company is registered. WIM systems, combined with new enforcement technologies should change the operational concepts of the enforcement agencies in the coming years. Harmonisation of such practices in Europe is also a focus.

3. Multiple-Sensor WIM

While LS-WIM is a significant improvement in efficiency over static weighing, the future evolution of enforcement efficiency will require High-Speed (HS-)WIM systems approved for overload control. This means that an accuracy class of A(5) according to the COST323 Specification must be definitively achieved. It is even likely that the required level of confidence will be higher than the minimum specified in the COST323 Specification, perhaps 98 to 99%. It means that for a given system and installation, instead of looking for the smallest confidence interval (δ_{min} in width) at a level of confidence of let say 95%, the approval will be given in a lower accuracy class (i.e. a larger δ or confidence interval width) but with a higher confidence.

Because of the dynamic effects induced in the trucks by the pavement profile, it has been shown['proven' is a bit strong] that no current pavement WIM system, using one or two sensors per lane, will be able to meet an accuracy class better than B(10) to C(15) on a very smooth pavement profile (Jacob and Dolcemascolo, 1998). However, there is considerable scope for accuracy improvement by combining several measurements of axle impact forces at different sections using a multiple-sensor WIM array. Force measurements are processed using simple averaging or more sophisticated algorithms, which can significantly reduce the inaccuracy of the static load estimation by WIM. Since the theoretical and experimental work done in the WAVE project (WP1.1), further investigations were carried out in France (Dolcemascolo et al., 2002; Labry et al. 2005a) and in Ireland using Neural Networks (Shamseldin et al. 2000; Black et al. 2002; González et al. 2002; González et al. 2003) and Functional Networks (González and O'Brien, 2005). New experimental programmes are planned in France and in the Netherlands. In the latter, a MS-WIM array of 16 rows of piezoquarz sensors has been installed on a motorway near Utrecht.

The critical problems to be solved in MS-WIM are mainly related to the individual sensor noise or inaccuracy. It was proven in the previous works and by simulations that with very accurate impact forces measurements and a number of sensors between 10 and 16, accuracy class A(5) can easily be met. Some accuracy improvement of piezoceramic strip sensors is expected if the lateral position of the wheels are measured and taken into account (Labry et al., 2005b). Afterwards, if the required accuracy is met, some additional issues will still have to be investigated and solved for legal applications and enforcement: (i) certification or approval of such HS-WIM systems by Legal Metrology Organisations, and (ii) reliability of the systems against violation or attempts to escape the control. For issue (i), the lack of International Standard approved by the OIML (the current OIML Recommendation's scope is limited to MS-WIM) will make it difficult to get approval for such HS-WIM systems. To ensure the reliability of HS-WIM based enforcement systems, it will be necessary to implement complementary traffic measurement tools, in order to identify vehicles trying to escape the control, e.g., by running between two adjacent traffic lanes, or partially on the emergency lane, or braking/accelerating on the sensors.

MS-WIM systems with less sensors, e.g., 4 to 8 per traffic lanes, may be useful for other applications requiring an accuracy such as B(10) to B+(7). The main choice for the users is to decide between: (i) fewer sensors (i.e., 1 or 2) of high quality and cost, or (ii) more sensors (MS-WIM) of lesser quality and cheaper. Because of the dynamic effects induced by the pavement roughness, (ii) is clearly the best solution for average road profile pavements.

4. Bridge WIM

In the WAVE project, the accuracy of Bridge WIM systems was considerably improved and tested on a range of bridge types in Ireland and Slovenia (McNulty & OBrien 2003; OBrien & Žnidarič 2001). In ICWIM3, tests in Sweden were also reported and new techniques for automatic calibration of the system without the need for expert knowledge in Structural Analysis (Quilligan et al. 2002, Žnidarič et al. 2002). Since ICWIM3, there have been over 70 commercial installations of Bridge WIM systems in Slovenia, Sweden and in the Netherlands. In addition, the effectiveness of Bridge WIM has been demonstrated in Canada, Austria, Poland and Croatia. The electronic systems and the software that runs and evaluates the measurements have improved considerably as has the user interface. For example, the SiWIM system developed by ZAG and CESTEL can be fully controlled from a remote office through a mobile telephone connection. It also automatically sends warnings to the control centre in the case of exceptional events and can be used with a video camera, with or without licence plate recognition, to control and pre-select overloaded vehicles.

There is ongoing work on Nothing-On-Road (NOR) Bridge WIM in an effort to get away from the safety and cost implications of axle-detecting sensors embedded or placed on the road surface. Following the original successful work on orthotropic (Dempsey et al., 1998) and short slab bridges (OBrien & Žnidarič 2001), considerable progress has been made on the extension of the NOR concept to other bridge types. The reliability of axle identification and axle spacing calculation has been increased to a level that NOR bridge WIM systems can now be used for regular measurement. In Slovenia, 20 bridges or around 50% of all installations in 2004 have been done in this way (Žnidarič et al. 2005). Bridge WIM is not been applied on bridges that would not previously have been contemplated, such as 30-m long beam-deck bridges. A new NOR Bridge WIM approach is reported in this conference (Dunne at al. 2005). This utilises wavelet techniques to transform the original strain signal in a way that highlights the effects of individual axles.

In France, an R&D project started in 2004, to be carried out by the LCPC for the DTT, with the objective to install and test Bridge WIM systems on several types of bridge (orthotropic decks, very short span bridges, multiple simply supported span bridges, slab or integral bridges). The SiWIM system, using the results of the WAVE project, will be installed and if necessary improved in cooperation with the Slovenian partners. The final goal is to include this technology in the pre-screening WIM system network described in section 2.2.

Bridge WIM systems are expected to be a suitable tool for pre-screening and enforcement of overloads, provided a convenient bridge for WIM is located near to the required site. Besides the improved accuracy (which already meets class A(5) for some bridges with very smooth pavement and the most advanced algorithms (Brozovič et al., 2005)), this system has other practical advantages: (i) it is impossible for a vehicle to avoid the WIM system if crossing the bridge, (ii) the system is not visible for the drivers, and much less exposed to vandalism than road sensor systems, (iii) the system may be installed and replaced without traffic disruption

and in good safety conditions, which is important for busy motorways and heavily trafficked highway. However, it may be more difficult to get a type approval or certification for such a system from a legal metrology organisation, for a direct enforcement application. The reason is that the bridge is part of the measuring system and, as each bridge is different from the others, it could require a case by case approval.

5. Application of WIM for Infrastructure, Road Safety and Environment

Applications of WIM in Europe are currently focussed primarily on the enforcement of overloaded vehicles, with the underlying Commission goal of ensuring fair competition between transport modes and transport companies. However, other applications are still important such as road safety, infrastructure and traditional applications to traffic monitoring and statistics.

In the late 1980's and early 1990's, a great deal of work was carried out in which WIM data from several European countries (Jacob et al., 1989) formed the basis for the Eurocode, EC1, Part 3 (Traffic Loads on Road Bridges). The design loads were assessed using statistical extrapolation of load effects (Flint and Jacob, 1996) while fatigue loads were calibrated in order to ensure that bridge lifetimes were in agreement with expected traffic conditions (Jacob and Kretz, 1996). Since this initial work, some countries used local traffic measurement to calibrate the so-called α-factors which allow increases or reductions in some load intensities to account for region-specific conditions (Orr & OBrien 1999; O'Connor & OBrien 1997). In the past 2-3 years, some verifications were carried out using new traffic data to check if recent increases in truck volumes and gross weights are affecting bridge safety, mainly in fatigue (Jacob and Labry, 2002). Such verification was required to transform the pre-standard (ENV) into a standard (EN). In the future, it will be necessary to perform periodical checks (e.g., every 5 to 10 years), because of the upward trend in the maximum truck GVW in Europe. In Scandinavia GVW's of up to 60 tonnes are allowed and in the Netherlands up to 50 tonnes. In France some trucks (e.g., timber haulage or container in combined rail and road transport) are allowed to carry 44 tonnes. Increases in the portion of freight carried by vehicles at the upper ends of these legal limits as well as illegally overloaded vehicles are hugely important factors in determining the characteristic traffic loading on bridges.

In recent years, the emphasis has shifted from the design of new bridges towards the assessment of existing bridges (Grave et al. 2000). A review of European highway structure assessment procedures was conducted through the COST 345 action. The resulting report on state-of-the-art procedures for the assessment of bridge traffic loading is given by OBrien et al. (2005). The implications of the accuracy of recorded WIM data and the duration of recording on the predicted load effect are assessed by O'Connor & OBrien (2005) along with the sensitivity of the extreme to the method of prediction. The effect of traffic evolution with time in terms of increased volumes of flow and weight limits are also explored.

There is some research ongoing on developing an improved understanding of the link between traffic loading and pavement deterioration (OBrien et al. 2004). However, there is a significant lack of experimental data. HDM-4 and the Swedish Pavement Management System study emphasises that is very difficult to measure and describe the complexity of the road surface and its characteristics. Further, it must be technically possible and practically feasible to measure the indicator.

With the evolution of the truck design, e.g., more axles, 4-axle bogies, smaller wheel diameter, tractor with double trailer, etc., it will be important to re-assess the pavement lifetime against fatigue and the effects of new traffic patterns. WIM data on European main routes will be an essential tool to detect such changes in loading patterns and link them with changes in the rate of pavement deterioration.

Finally, road safety and environmental impact became top priorities in the EU and in most of the member states in the late 1990's and remain so. Monitoring truck load and speed is important to ensure traffic safety. Gas emission and energy consumption are also to be considered. The debate is still open to decide if more relatively light trucks or fewer heavier trucks are the more efficient in environmental and safety terms to satisfy future transport demand, projected to grow by about 40% in Europe over a 10 year period. WIM data providing an accurate survey of the real loads carried by European trucks will be necessary to quantify the impact of heavy goods road transport on the safety and environment.

6. Conclusions

Recent European developments in WIM are reviewed. There has been a considerable shift in emphasis towards accurate pre-selection and automatic enforcement of overloaded trucks. Fully automatic enforcement has not yet happened but seems likely to come in the near future. This seems likely to come from multiple-sensor WIM and there has been considerable activity in the construction of pilot systems and the development of new algorithms for combining the outputs from the sensors. Durability of sensors has continued to cause problems but seems to be improving.

Bridge WIM is progressing well. With axle detectors on the road surface, it is achieving good and improving levels of accuracy. For applications that require less accuracy, Nothing On Road Bridge WIM systems are under development with clear implications for improved safety during installation and maintenance.

In addition to the pre-selection and high-speed enforcement of overload applications, there has been progress on the use of WIM for accurate assessment of bridge loading. Pavement assessment and design is still at an early stage and seems likely to take some further years.

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