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WAVE - A European Research Project on Weigh-in-Motion

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Abstract: WAVE (Weigh-in-motion of Axles and Vehicles for Europe) is a research project, part-funded by the European Commission, with the objective of improving the accuracy and performance of Weigh-in-Motion (WIM) technology. It has a budget of the order of $ 2 million and will run from mid 1996 to mid 1998. It has close links and a substantial overlap of membership with COST323, a pan-European group with representatives from about 20 countries which coordinates nationally funded activities relating to WIM. The principal objectives of WAVE are: (i) to improve the accuracy of WIM systems, (ii) to develop a prototype pan-European WIM database, (iii) to develop calibration and testing procedures for WIM system performance and accuracy, particularly for cold climates and (iv) to develop a prototype fibre optic WIM sensor.

1. INTRODUCTION

WAVE (**W**eigh-in-motion of **A**xles and **V**ehicles for **E**urope) is a pan European research project with the objective of improving the accuracy and performance of Weigh-in-Motion (WIM) systems. The research is being carried out by six full partner organisations, five associate partners and a number of other sub-contractors. The consortium, consisting primarily of national road research authorities, spans eleven countries from the arctic to the Mediterranean. It is lead by the French Road and Bridge Research Authority, Laboratoire Central des Ponts et Chausées (LCPC), and is part-funded by the European Commission. There are four principal objectives to the research:

1. **Accuracy**: Improvement of the accuracy of WIM systems
2. **Database**: Development of improved pan-European procedures for the checking, processing and storage of WIM data
3. **Cold climates/Calibration**: Verification of performance of WIM systems, particularly in sub-arctic and alpine climates
4. **Fibre optic WIM**: Development of fibre optic WIM technology

These objectives will be realised over a two-year period in 1996-98 through theoretical development, experimentation and full-scale field testing. The dissemination of results will be improved though close links with the European COST323 committee on Weigh-in-Motion of Road Vehicles (1). This committee has representatives from twenty countries from the European Union and Central/Eastern Europe.

2. HISTORY OF WAVE PROPOSAL

Considerable developments in WIM research have been taking place in Europe for many years, particularly in France and in the United Kingdom. In recent years the national road research authorities of the European Free Trade Association (EFTA) have acknowledged the need for a concerted approach on road infrastructure and have formed 'FEHRL', the **F**orum of **E**uropean **H**ighway **R**esearch **L**aboratories. This forum has agreed on a list of priority research areas and has lobbied the European Commission Transport Directorate to sponsor the research. Following the inclusion of WIM on the priority list, the European Commission agreed in 1993 to fund COST323 (1), a European action with the objective of promoting the research and development of WIM technology. Subsequently a call was issued by the Commission in the 4th Framework Programme/Specific Transport Programme (1996-98), for a full research programme on WIM. The WAVE consortium was the successful applicant.

2.1 COST323

The European COST programme does not fund significant research in itself but funds and facilitates cooperation between countries carrying out research at national level. The first full management committee meeting of COST323 was held in 1993 and the committee will continue in existence until after the conclusion of the WAVE project in 1998. The activities of the group, presented at the NATDAC '94 conference (1), include:

1. Collection and analysis of WIM needs in Europe.
2. Testing of proprietary and prototype WIM systems. An extensive test of eight WIM systems has recently been completed in Zurich (2). Further tests will be carried out in the future in lapland Sweden and on a French motorway, the A31 in eastern France between Metz and Nancy, which is one of the main north-south road links in Western Europe.
3. Preliminary work on the development of a European standard on WIM. This includes the definition of relevant terms and the translation of these into a range of European languages. A draft pre-standard will also be developed which may in the future result in an official European standard.
4. Agreement of mechanisms and protocols for a pan-European database of WIM sites and data.
5. Organisation of international conferences. The first European WIM conference was held in Switzerland in 1995 (3). A second is planned for Southern Europe in 1998.

2.2 Relationship between WAVE and COST323

In 1994, the European Commission issued a call for applications to the $10 billion Fourth Framework Research Programme. The specific Transport Programme was allocated $300 million, of which 11% was designated for road transport. One third of this amount, about $9 million, was allocated to road infrastructure. A substantial thematic part of this sub-programme included a request for research on WIM. The WAVE consortium applied to carry out this research and was successful. This consortium has a substantial overlap in its membership with that of COST323. While COST323 does not fund research in itself, it provides a very effective means of disseminating the results of research carried out at either national or European level. Thus, for example, COST323 will co-sponsor a cold climate test being carried out through WAVE in Sweden. Also, COST323 will organise a conference in 1998 to facilitate the publication of the results of WAVE. In addition it will provide a broader forum in which to secure agreement on standardisation of calibration procedures and database protocols which will be developed through WAVE.

3. PROPOSED RESEARCH

The WAVE project is divided into four work packages, which can briefly be described as (i) accuracy, (ii) database, (iii) cold climates/calibration and (iv) fibre optic WIM. These are described in turn in the following sections.

3.1 Accuracy

The purpose of the first work package is to develop WIM systems which can produce accurate and reliable data for static axle and gross vehicle weight. The specific target accuracy for axle weights is that 95 to 99% of results should have an error within ±10% or a root mean square error of about 4%. For gross vehicle weights, the target is that 95 to 99% of results should have an error within ±5%, or a root mean square error of about 2%.

Two techniques are being investigated which can be used either as alternatives or in combination. These are multiple sensor systems and bridge systems. Both techniques have already been studied and tested on a small scale in Europe and North America, but require significant further development in order to achieve the target levels of accuracy.

Multiple-sensor WIM: There is an upper limit on the accuracy of individual WIM strip sensors due to the effect of truck bounce. Research carried out under the OECD/DIVINE project (4) has shown that dynamic axle forces exceed the corresponding static weights by between 15% and 40% depending on the pavement eveness and the vehicle suspension. Regardless of the accuracy of strip sensors, they can only provide axle weight for one point in time. This problem can be overcome by using a number of low-cost strip sensors (capacitive or piezo-electric). The use of large base sensors (bending plates, weighing scales) only partially solves the problem by improving the intrinsic accuracy of wheel impact force measurement, but cannot eliminate the dynamic effect because it only measures the wheel impact during a short portion of the eigenperiod of vibration.

Spatial repeatability, i.e., a correlation between relative dynamic force and pavement profile, has been established at sites in the United Kingdom (5) and France (6). Knowledge of this phenomenon can be exploited in the design of arrays of WIM sensors, both for optimal sensor layout and for the calculation of a best estimate of the static axle weight from the measured dynamic weights.

The simple sensor averaging strategy devised in previous Anglo-French (7) research makes only limited use of the known models of vehicle dynamics, and of the known range of parameters for these models. The purpose of the new research on multiple sensor WIM will be to exploit knowledge of vehicle dynamics to the full in order to:

- improve the accuracy of weight estimates;
- minimise the number of sensors required in multiple-sensor arrays to achieve a specified accuracy;
- determine the optimal (uniform or non-uniform) sensor spacing;
- estimate from the sensor data other characteristics, such as resonance frequencies and vehicle suspension parameters.

Bridge WIM*:* The concept of using bridges as scales to weigh trucks in motion was developed by Moses and others in the 1970's (8). The method has considerable potential for accuracy as it allows measurement of impact forces over more than one eigenperiod. As bridges are large, a great number of sensor readings can be recorded during the time it takes for a truck to cross. Full exploitation of this information can be used to gain information on the dynamic behaviour of the truck whose axle weights are being sought. This in turn can be used to obtain a more accurate estimate of the static axle weights. Alternative strategies being investigated are the use of bridge sensors alone and the use of a combination of bridge and traditional pavement WIM sensors. A considerable research effort will also be expended in the development of more sophisticated dynamic models than those currently used.

Bridge systems may have some advantages over conventional WIM systems in terms of durability, particularly in sub-arctic and alpine climates. However, a major disadvantage is the problem of finding a suitable bridge at the desired location. In recognition of this, part of the work package concerns the testing of bridge WIM on a wide range of bridge types including concrete slabs, box culverts, arches and cable-stayed orthotropic steel decks. In addition, systems will be tested in a range of European climates. Bridges in Ireland, France, Slovenia, Germany and Sweden will be considered.

3.2 Database

Development of improved pan-European procedures for the checking, processing and storing of WIM data is an important objective of the WAVE project. In most European countries WIM data is being collected for different purposes. An increasing demand on WIM data at European level makes the exchangeability of WIM data between different countries an important issue. The principal task of the second work package of WAVE is the preparation of a prototype European WIM database. This is expected to be a source of information for all potential WIM-data users such as traffic engineers, road research laboratories and road or bridge designers.

The development of systems for ensuring the quality of data will be an important part of this work package. For this, results from the COST323 action may be used, particularly the preparatory work for the European Standardisation committee, CEN/TC226 containing European specifications for WIM. Quality parameters will be defined and procedures will be described for WIM system users to check, ensure and classify the quality of data. Experience gained from the American LTPP project (9) will be of great interest for this task.

It is envisaged that all countries providing WIM data for a European database will be capable of transferring their data in a standardised prescribed format. This means that, for example, a location code based on the European road numbering system will be provided. The introduction of such a format description will also stimulate WIM data exchange between countries in order to encourage integrated long term maintenance strategies for international transport routes.

3. 3 Cold Climates/Calibration

If WIM data is to be used at a pan-European level and particularly if it is to be used for future pan-European legistation and enforcement, it is essential that there be consistency in the accuracy of the results for all climates. It is also important that all regions of the continent have fair access to the technology. To ensure consistency of accuracy there is a need for standard methods of calibration and testing of WIM systems. To ensure that all regions have fair access, problems of both accuracy and durability in cold climates must be overcome. The third work package of WAVE thus contains two closely interrelated activities, namely, durability in cold climates and calibration/test procedures.

Durability in cold climates: A major test of existing and prototype WIM systems will be carried out in the harsh climate of northern Sweden. European WIM vendors will be invited to install their systems and tests will be carried out both under Summer and Winter conditions. The accuracy of the systems and their durability under conditions of snow and studded tyres will be assessed.

Calibration/Test Procedures: The purpose of the second part of this work package is to develop and specify calibration methods. In particular, such methods must cater for the sensitivity of WIM systems to temperature for the wide range that exists across Europe. Measurements will be carried out using preweighed and instrumented trucks at test sites near Lulea, in Northern Sweden close to the Finnish border, on the RN10 and A31 test sites in France and on the Abington site in the United Kingdom. Ideal properties of instrumented trucks will be specified with a view to the possible use of standardised instrumented vehicles or trailers across Europe.

3.4 Fibre Optic WIM

The simplest way to use optical fibres as sensors emerged during the 1970's when the intensity or amplitude of light passing through fibres was found to be proportional to applied strain. Based on this principle, some portable WIM systems were developed at Oak Ridge National Laboratory (Tenessee) which have recently been made available commercially in Canada.

An alternative approach is to exploit the spatial light energy distribution due to the arrangement of modes in a right section of a multi-mode fibre or to exploit polarization effects in single-mode fibres. The first of these has been investigated by the University of Liverpool in partnership with the United Kingdom Transport and Research Laboratory. The second, which exploits what was considered to be a polarizing effect due to an induced birefringence in single-mode fibres under loading, was shown to be feasible by Alcatel in partnership with LCPC in 1986. There are a number of advantages in the latter approach:

- high sensitivity with a range extending from pedestrian to heavy trucks with high accuracy (3%) and reliability,
- completeness of information,
- real-time response,
- response in digital form,
- no power source required along the roadway,
- immunity to lightning and electromagnetic interference,
- ease of installation.

Before 1980, due to the lack of technology, it was very difficult to exploit the optical phase from a given state of polarization in a fibre. The better understanding of this complex phenomenon available today has resulted in the availability of numerous components such as polarisation maintaining fibres, polarisers/depolarisers, polariser controlers, etc..

A single-mode fibre could be a WIM sensor by itself but, depending on the state of polarization of the light propagating within the core, the response to many parameters would be detected. In order to isolate the feature of interest from a perturbation generated by a tyre, a sensing structure must be developed and the corresponding optical link for sensor interrogation. This so-called sensing structure will be developed; specifically, a method will be developed for the encapsulation of the fibre in a material compatible in terms of Young's modulus. Also, it is felt by the consortium that the best way to increase sensitivity is to interrogate the sensor by reflection instead of direct transmission. That means that a mirror must be designed for location at the end of the sensing structure.

3. WAVE ADMINISTRATION

The WAVE partnership consists of a coordinating partner, five full partners and five associate partners as listed (with abbreviations) in Table 1. The associate partners report to the full partners as illustrated in Figure 1. This structure reflects, to some extent, the make-up of the teams which will carry out the four work packages. LCPC and CUED share responsibility for the Multiple sensor WIM part of the Accuracy work package. AKN and ETH also participate in this and two subcontractors, Golden River and the Transport Research Laboratory (United Kingdom) report to CUED. The Irish university, TCD, is responsible for the Bridge WIM part of the Accuracy work package. They are assisted by associate partners, TUM and ZAG and the French laboratory, LCPC, also participates.

Table 1 - Partners and Associate Partners

No.	Grade of Membership (full partner to which reporting)	Name of Organisation	Abbrev -iation	Country
1	Coordinating partner	Laboratoire Central des Ponts et Chaussees	LCPC	France
2	Full partner	Cambridge University Engineering Department	CUED	United Kingdom
3	Full partner	Trinity College Dublin	TCD	Ireland
4	Full partner	Road & Hydraulic Engineering Division	DWW	Holland
5	Full partner	Alcatel Kable Norge	AKN	Norway
6	Full partner	Swedish National Road Administration	SNRA	Sweden
7	Assoc. partner (4)	Belgium Road Research Centre	BRRC	Belgium
8	Assoc. partner (3)	Technische Universitat Munchen	TUM	Germany
9	Assoc. partner (6)	Technical Research Centre of Finland	VTT	Finland
10	Assoc. partner (6)	Swiss Federal Institute of Technology	ETH	Switzer-land
11	Assoc. partner (3)	National Building & Civil Engineering Institute, Slovenia	ZAG	Slovenia

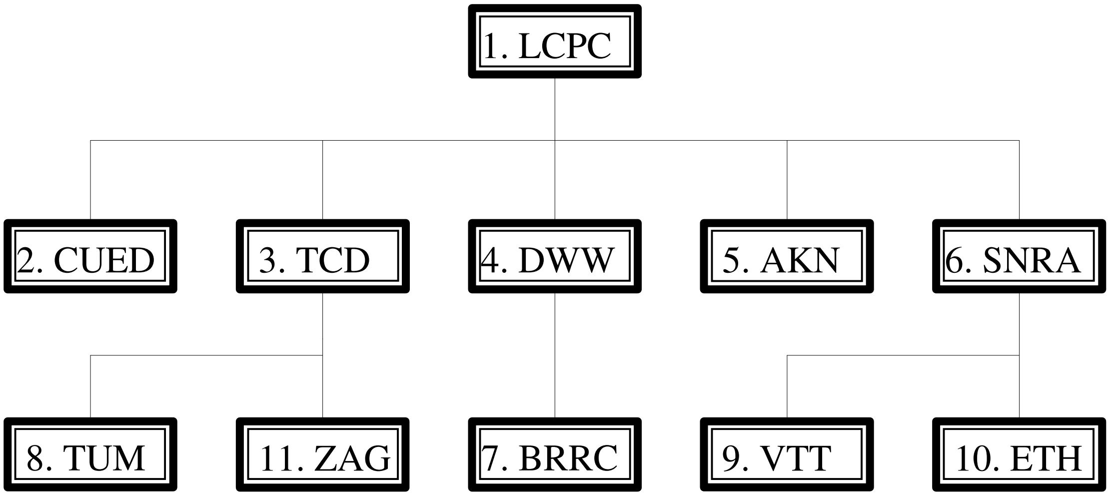

Figure 1 - Organisation chart for WAVE consortium

The Dutch authority, DWW is responsible for the second work package, Database, and they are assisted by the Belgian associate partner, BRRC. LCPC, SNRA and ZAG also participate in this work package which is of interest to many members of the consortium.

The Swedish road administration, SNRA, is responsible for the Cold climates part of the third work package. The Finnish and Swiss associate partners, VTT and ETH report to SNRA while AKN and TCD also participate. The Calibration part of this work package is coordinated by LCPC and VTT, and many members of the consortium participate - CUED, TCD, SNRA, BRRC and ETH.

The fourth work package, Fibre optic WIM, is shared between the LCPC and the Norwegian company, AKN. The partners are being assisted by one subcontractor, Applications Mathematiques et Logiciels.

Budget: The WAVE project is supported by the European Commission on a ‘shared cost’ basis. This means that non-university organisations must provide 50% of their total costs. Universities are 100% funded but on a marginal cost basis, i.e., no funding is provided for the time of permanent staff or for the use of existing equipment. Partners from Eastern Europe such as Slovenia are likely to be funded as soon as a special agreement is signed with the EU. Partners from countries outside the European Union such as Switzerland may partake in European research projects but are not funded by the commission. The total WAVE budget is of the order of $2 million of which the European commission will provide about 45%.

5. CONCLUSIONS

The WAVE research project on Weigh-in-Motion is described in this paper and the developments leading to the call by the European Commission for research on WIM are presented. This process started with the Forum of European Highway Research Laboratories, lead to COST323 and finally to WAVE. A detailed technical description is given of the four work packages of proposed research. Finally the complete partnership is listed and the structure of responsibilities within the elaborate consortium is described and illustrated.

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