

Output and Follow-up of the European Research Project, WAVE

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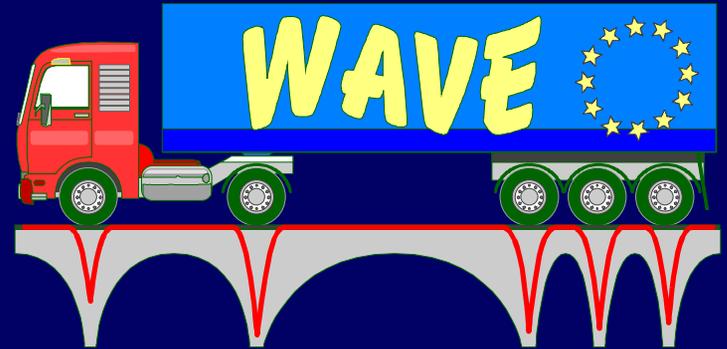
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What was WAVE?

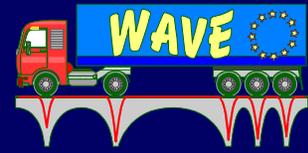
Weighing-in-motion of Axles and Vehicles for Europe



*European Research Project (RTD) with goal of
improving the accuracy and durability of WIM
systems (1996 - 1999)*

- ◆ 11 partners from 10 countries
- ◆ 6 research institutes, 4 universities, 1 company

Context of WAVE Project



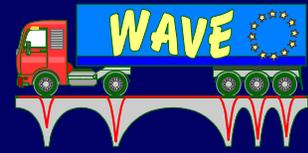
◆ **Enforcement**

- **Tendency towards heavier and larger trucks, many of them illegally overloaded**
- **Need for consistency across Europe in legal limits and in degree to which **limits are enforced****

◆ **Road Pricing**

- **Charges by weight of axle/truck**
- **Shadow tolls**

Origins of WAVE Project



◆ FEHRL

- Forum of European Highway Research Laboratories
- Agreed list of Priority Research Topics

◆ COST 323 (1993 - 1998)

- European Commission Co-ordinated and Facilitated Nationally Funded Research on WIM

◆ WAVE

- 4th Framework Research Programme

Summary of COST 323



- ◆ **WIM Needs and Requirements**
- ◆ **Glossary and definition of WIM terms in ten languages**
- ◆ **European Standard on WIM**
- ◆ **Field Trials (Switz-93, France-96+97-98, Sweden-97-98)**
- ◆ **Database (WIM sites + stats)**
- ◆ **Two International Conferences (*proceedings*)**
 - 1995: Zurich, Switzerland (ICWIM1)
 - 1998: Lisbon, Portugal (ICWIM2)
- ◆ **Final Report of COST 323 (*book available*)**

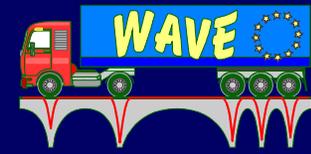
The COST group recognised the need for more WIM research. This gave rise to the WAVE project

◆ ***Relationship between COST 323 & WAVE***

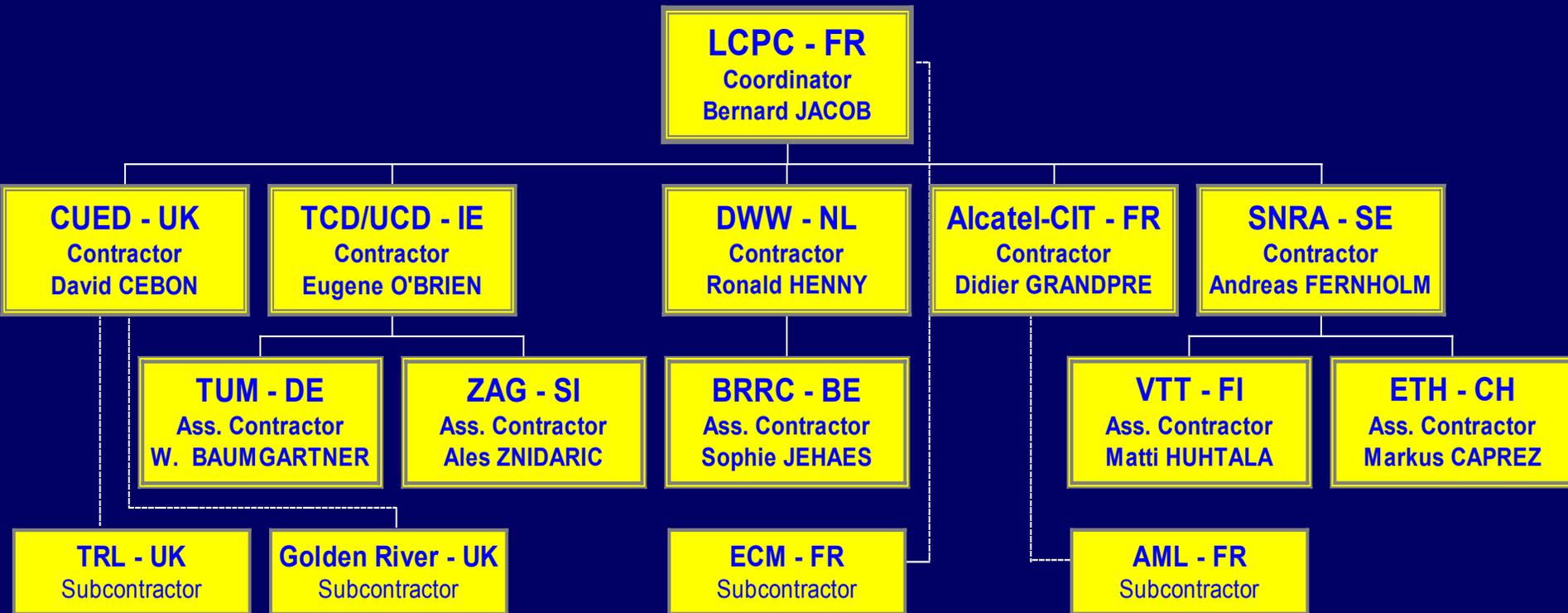
- **COST 323 only Funded Travel Costs while, in WAVE, the European Commission provided about 50% of the budget**
- **Substantial Overlap of Membership**
- **Common Chairperson**

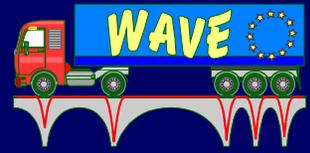
◆ ***Shared Activities***

- **Field trials/Database/Calibration**



The WAVE Partners

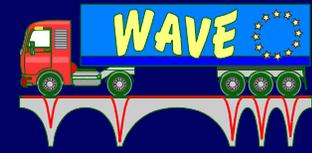




Objectives of WAVE

- ◆ **Improved accuracy through arrays of multiple sensors**
- ◆ **Improved accuracy and durability of Bridge WIM through more sophisticated algorithms + Free of Axle Detector (FAD) Systems (Nothing on the Road Surface)**
- ◆ **Common Database Formats to facilitate exchange of data and Quality Assurance system**
- ◆ **Field Trials for Durability 100 miles South of Arctic Circle (frost heave, studded tires, de-icing salt)**
- ◆ **Improved calibration procedures to allow for dynamics of moving truck**
- ◆ **New mono-mode fiber-optic sensor**

WAVE Resources



Budget : € 1.5 million
of which € 0.75 mill from EU

Personnel
67%

20 person-years:
- 15 senior
scientists/research
engineers
- 25 PhD students

- ◆ 2 Multiple-Sensor arrays
- ◆ Instrumented trucks + hundreds of pre-weighted trucks
- ◆ Several instrumented bridges

Other costs
7%

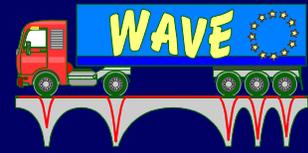
Travel
10%

Computer
3%

Consumable
8%

Equipment
5%

WAVE Work Packages



◆ WP1. Accurate estimation of weights

- ❧ WP1.1. Multiple Sensor WIM
- ❧ WP 1.2. Bridge WIM

◆ WP2. Quality, management and exchange of WIM data

- ❧ WP2.1. WIM data QA
- ❧ WP2.2. WIM data format and database structures

◆ WP3. Calibration and Durability

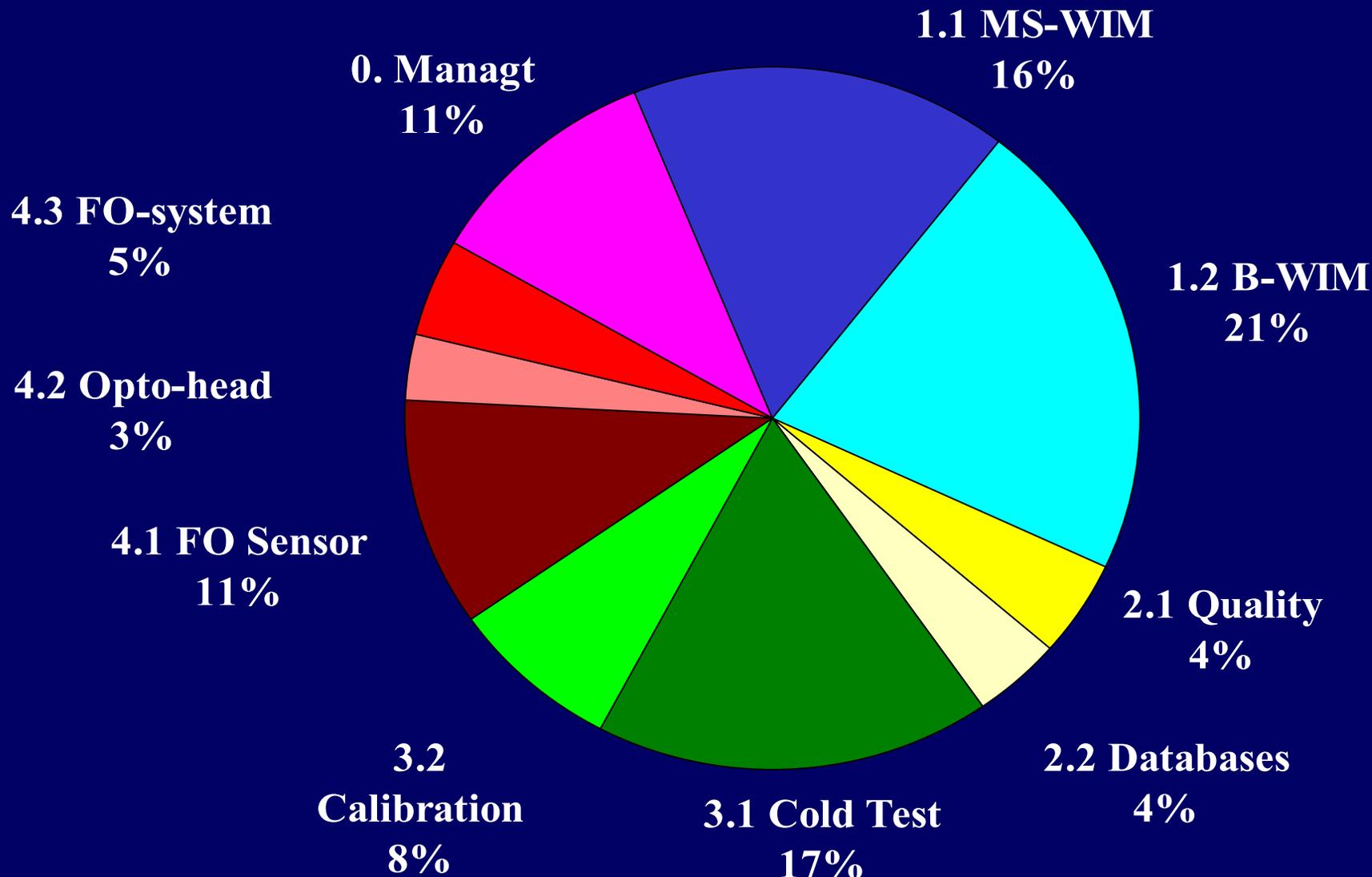
- ❧ WP3.1. Durability of WIM systems in cold climates
- ❧ WP3.2. Calibration of WIM systems

◆ WP4. Fiber-Optic WIM systems

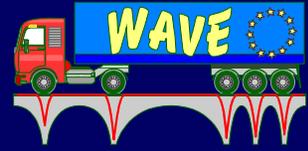
- ❧ WP4.1. Sensor Design
- ❧ WP4.2. Opto-electronic Head
- ❧ WP4.3. Data Acquisition and Processing Unit



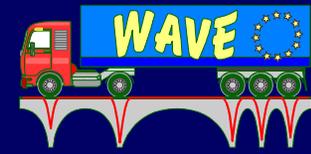
WAVE Budget by Work Package



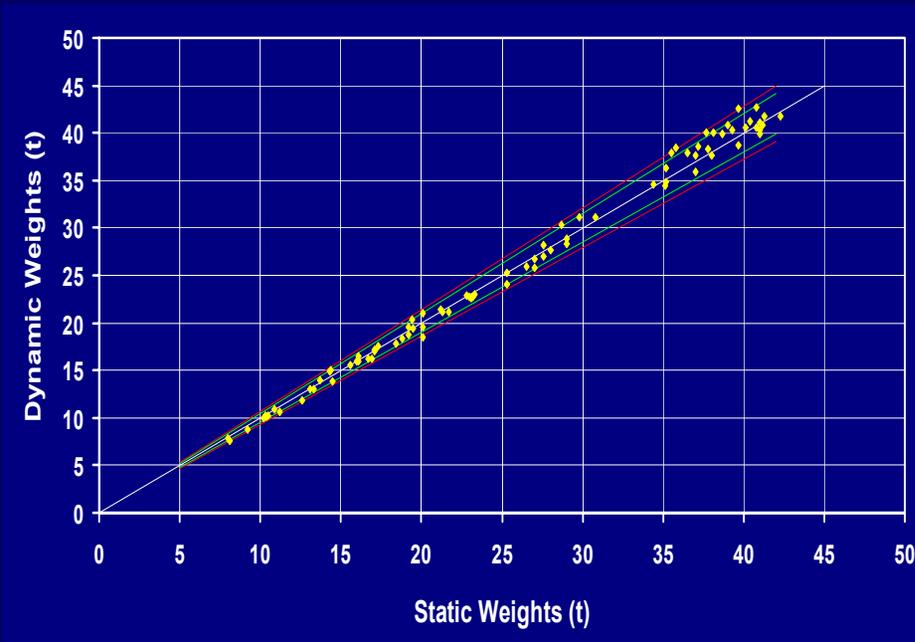
Technical Outputs - Improved Accuracy through Multiple-Sensor WIM (WP 1.1)



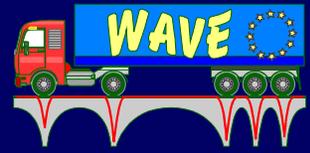
- ◆ Two new theories/ algorithms
 - Signal reconstruction (sampling, trigonometric polynomial decomposition, mechanical vehicle model) - LCPC
 - Maximum Likelihood estimation (2 sine wave model, probabilistic approach) - CUED
- ◆ Experiments
 - Trappes & Metz (F)
 - Abingdon (UK)



Technical Outputs - Improved Accuracy through Multiple-Sensor WIM (cont.)



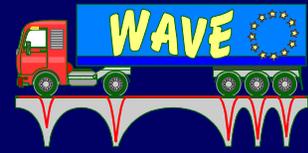
- ◆ Improvement in the accuracy of static weight/load estimation: simple average / new theories: B+(7)/A(5)



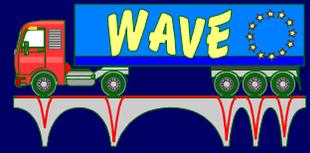
Technical Outputs - Calibration (WP 3.2)

- ◆ Review of the existing calibration methods
- ◆ Issues of automatic self-calibration:
good/poor
- ◆ Use of an instrumented truck (VTT)
 - useful for MS-WIM systems calibration, repeatability to be checked
- ◆ New findings: calibration by axle rank
 - bias/axle rank for all types of WIM sensors

Technical Outputs - Data Management (WP 2)



- ◆ **Quality assurance system**
 - multiple-criteria (site, pavement, environment, sensors)
 - up-dating process, rating system, coherence tests
 - still to be implemented on a large scale
- ◆ **Implementation in the European WIM database**
 - + users' tools



Technical Outputs - Durability in Cold Climates (WP 3.1)

- ◆ Durability and accuracy of commercial and prototype WIM systems in cold climates
- ◆ 2 tests: Luleå - Sweden, St Gotthard & St Bernardino - Swiss Alps
- ◆ Data analysis: BRRC (Belgium), VTT (Finland), ETH (Switzerland)
- ◆ Durability: no failure in Sweden (but loss of accuracy), one in Switzerland
- ◆ Accuracy: new accurate sensors, some sensitivity to temperature, prototype improved...

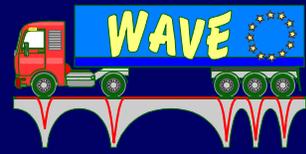
Technical Outputs - Durability in Cold Climates (cont.)



Northern Sweden, 100 miles South of Arctic Circle in Winter

Swiss Alps



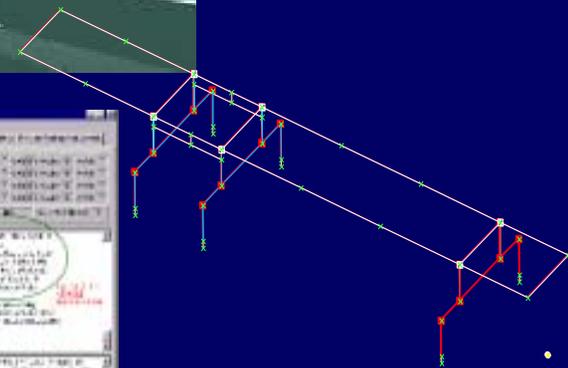
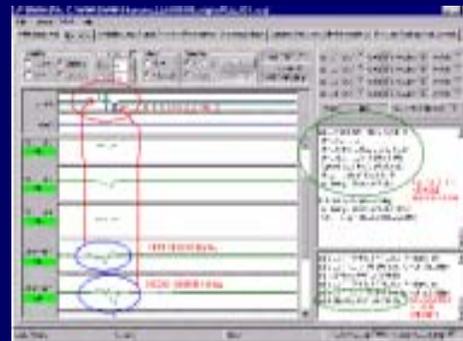
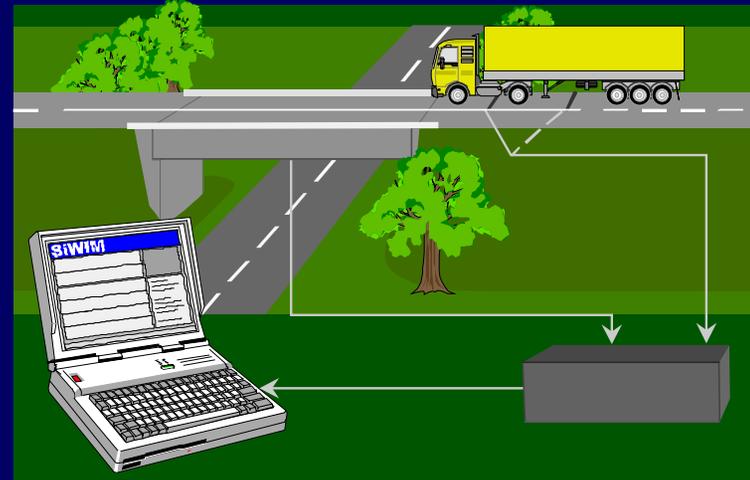


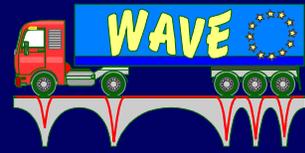
Technical Outputs - Bridge WIM (WP 1.2)

◆ Concept of Bridge WIM

◆ Objectives

- Dynamics of the Truck Crossing Event
- Prototype software **SiWIM**
- New Approaches and Algorithms
- Durability: FAD Systems
- Testing the Accuracy



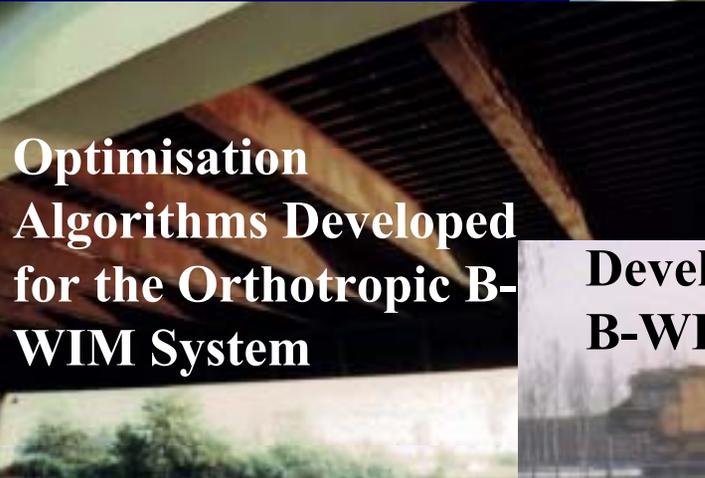


Technical Outputs - Bridge WIM (cont.)

◆ Accuracy Testing



Combined B-WIM and Pavement WIM System



Optimisation Algorithms Developed for the Orthotropic B-WIM System

Development of a Dynamic B-WIM Algorithm



Luleå, S - B(10) accuracy

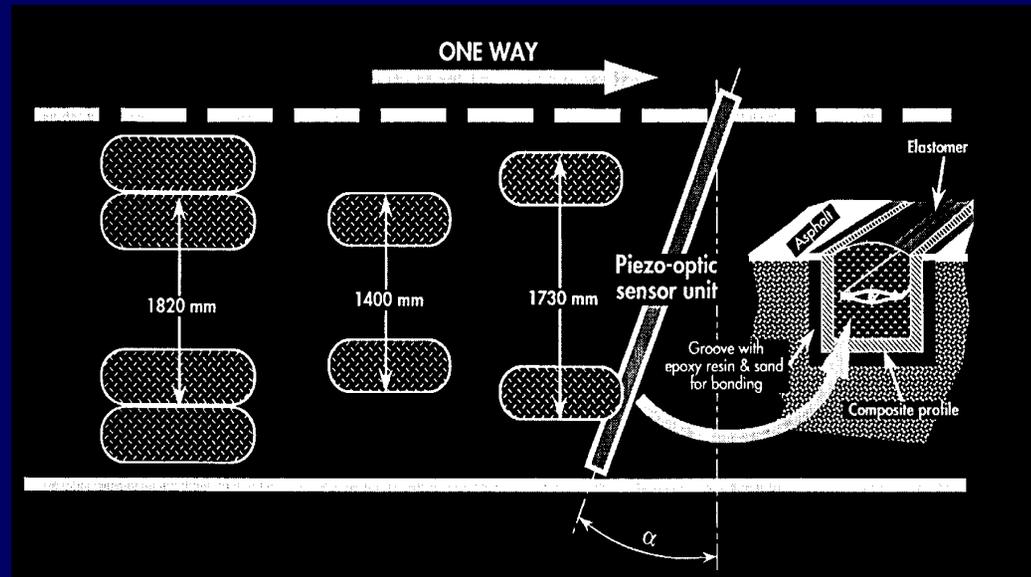
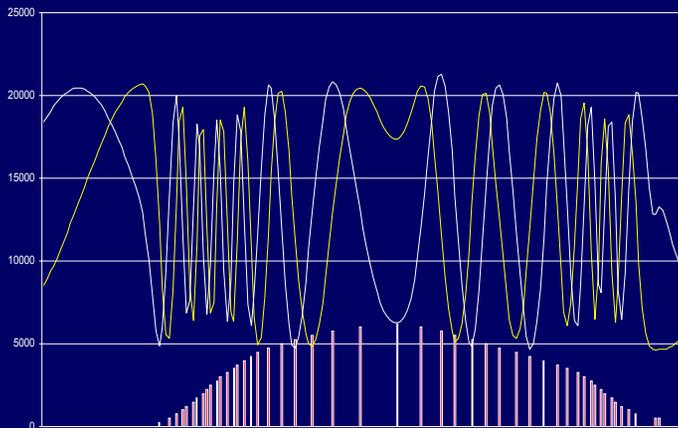


Multiple-Sensor Static B-WIM Algorithm

- Slovenia, France, Sweden
- Wide range of bridge *types*

Technical Outputs - Fiber Optic WIM (WP 4)

- ◆ Sensor : new design (1997), mono-mode fibre + metal ribbon + resin bar
- ◆ Optoelectronic head : analyses the modification of a polarised incident light beam (phase, fringes)
- ◆ Software : fringe counting & analysis, data collection and file organisation
- ◆ Prototype :



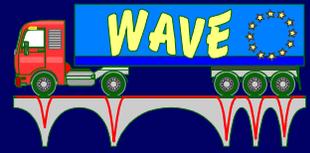
Technical Outputs - Fiber Optic WIM (cont.)

◆ Preliminary tests:

- sensor = good sensitivity and homogeneity in lab
- first results in a car park



- ## ◆ Advantages: high sensitivity, quasi-static, low speed & high-speed, insensitive to temperature, more parameters to be measured



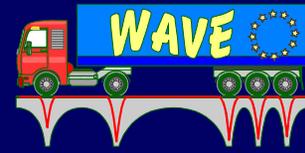
Follow-up - Multiple-Sensor WIM

- ◆ Expected to replace static weigh stations for direct enforcement in the future
 - more cost-effective; all trucks checked
 - avoidance will become difficult
 - ◆ Will require high accuracy + reliability
 - 95% - 99% of GVW's to be within 5% of exact static value
 - 95% - 99% of axle weights to be within 8% - 10%
- *class A(5) of the European COST 323 Specs*



Follow-up - Multiple-Sensor WIM (cont.)

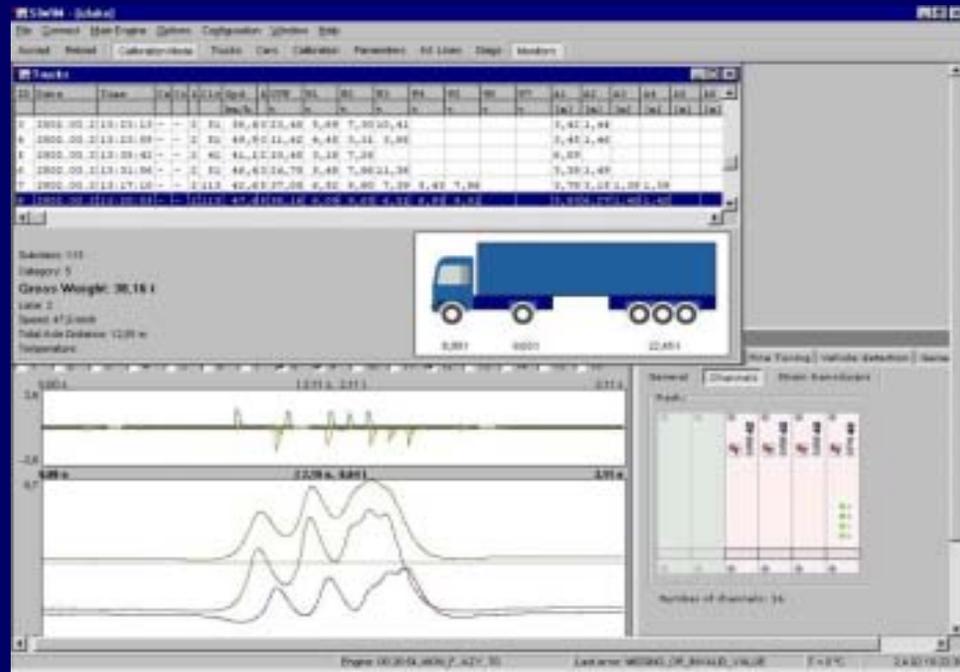
- ◆ 3 European countries still active in developing this technology
 - France : sophisticated computer simulations of trucks travelling over arrays to assess sensitivity of algorithms to sensor noise, etc.. Major field trial planned
 - Netherlands : array of 16 piezo-quartz sensors
 - Germany : “Top Trial” project, major field trial using “staggered multiple measurements”
 - Algorithms developed in WAVE will be used



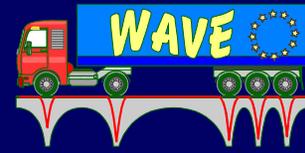
Follow-up - Bridge WIM

- ◆ SiWIM developed rapidly since WAVE
 - Redesigned and tested on 25 more bridges
 - Permanent and portable systems are now on sale
 - Cellular phone link (GSM)
 - Automatic calibration (no bridge expertise needed)

User-friendly interface



Follow-up - Bridge WIM (cont.)



- ◆ New Free-of-Axle-Detector (FAD) Systems
 - No sensor on road surface
 - Research in Sweden and Implementation in Slovenia
- ◆ KTH university (Stockholm) and University College Dublin
 - Developed a 'matrix method' to automatically calibrate (optimal solution)
 - Handle presence of multiple vehicles on bridge
 - Tackling errors due to variations in transverse location of trucks
 - Expect Class A(5) system in future



Follow-up - Database, Quality Assurance, Calibration

- ◆ Maintenance support sought from WERD (Western European Road Directors) and FEHRL (Forum of European Highway Research Laboratories)
 - No decision has been taken to date to support a European WIM database
- ◆ QA System to be implemented by users and data managers
- ◆ Dynamic Calibration Tools (instrumented trucks) to be developed & implemented



Dissemination of WAVE and COST323

- ◆ Future Implementation of MS-WIM Systems
- ◆ Marketing of B-WIM *by CESTEL (Slovenia)*
- ◆ Knowledge on Accuracy and Durability of WIM Systems for users + European Specs
- ◆ Future of Enforcement by WIM depends on :
 - Type approval by legal metrology organisations
 - Accuracy of individual sensors in array
 - Cost (installation and maintenance)



Conclusions

- ◆ WAVE + COST 323
 - Most existing technologies tested in independent comparative field trials
- ◆ Developing and prototype technologies
 - Further developed
 - Tested in laboratories and in the field
- ◆ Major advances in ...
 - Accuracy + Durability
 - Data processing and use
- ◆ Wide European Partnership + initiation of ICWIM's