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Weigh-in-motion of Road Vehicles for Europe (WAVE)

Report of Work Package 2

A Data Quality Assurance System for the European Wim-Database

Road and Hydraulic Engineering Division

Ministry of Transport, Public Works and Water management

December 2000

THE PROJECT

'WAVE' (**W**eigh-in-motion of **A**xles and **V**ehicles for **E**urope) is a research and development project of the fourth Framework Programme (Transport). Concerned with the weighing in motion of road vehicles, the project ended in June 1999 after two and a half years of steady work. Thanks to an integrated programme with a fruitful collaboration between the partners, and complementary contributions from the participating organisations, significant scientific and technical progress was made and very many results were achieved.

1. Origin of the project

During the COST 323 action (WIM-LOAD, 1993-98), part of the activities of COST Transport, it emerged that further research on WIM was necessary to address the latest requirements of road managers and decision makers. In 1994, the 4th Framework Programme of the European Commission was presented, with a specific "Road Transport" programme. Part of the latter was entitled "Road infrastructure" and a task of this was "Monitoring of factors affecting pavements and structures to support existing and future harmonisation legislation in respect of axle and vehicle weights" (task 7-4/27).

To address this task, a proposal for a large research project, 'WAVE' (**W**eigh-in-motion of **A**xles and **V**ehicles for **E**urope) was submitted to the Commission by a consortium of 11 partners from 10 countries, following the first call in March 1995. A majority of the partners were already participants in the COST 323 action. After a positive review by the experts and a negotiation phase in Autumn 1995, the project began in September 1996, after a 6 month delay for administrative reasons.

2. Objectives

The objective of the 'WAVE' project was to effect a significant step forward for those responsible for road networks, through the following actions :

1.1. Improve the capacity of conventional WIM systems to accurately estimate static loads from measurements of dynamic impact forces applied by axles, through use of arrays of sensors whose combined results can allow for the dynamic interaction between vehicle and pavement.

1.2. Develop and improve the functioning and accuracy of bridge-based WIM systems through more sophisticated vehicle/bridge interaction modelling and data processing.

2. Develop common data structures, formats and quality assurance procedures to facilitate the exchange and comparison of WIM data throughout Europe, to increase confidence in such data and to provide reliable management information to decision makers.

3.1. Perform tests of WIM systems to assess their durability and performance in various climatic conditions, particularly in cold regions where pavements deform and are weaker during the thaw and sensors are susceptible to studded tyres and de-icing salt.

3.2. Develop standardised calibration methods and procedures by improving existing methods and extending their applicability to all European climates and types of WIM system.

4. Develop and implement a new WIM technology, based on an innovative fibre optic sensor which has considerable potential in terms of quality and the extent of information provided and its insensitivity to harsh climatic conditions.

This project constituted a strategic policy initiative to confirm the Europe's leadership in WIM. It led to the development of new technologies such as advanced multiple sensor and bridge WIM systems, a quality assurance procedure to be implemented in a pan-European database, data about the behaviour of WIM systems in harsh environments, an improvement in calibration procedures and the development of a new European optic-fibre WIM technology. That will help road and transport decision makers.

3. Project organisation and means

The consortium involved 6 Contractors and 5 Associate Contractors:

Coordinator: Laboratoire Central des Ponts et Chaussées - LCPC - France

Contractors

Cambridge University Engineering Department - CUED - United Kingdom
Trinity College Dublin - TCD - Ireland
Road and Hydraulic Engineering Division - DWW - The Netherlands
Alcatel Contracting - ALCO (9/96-5/98) / Alcatel CIT Saintes (6/98-6/99) - France
Swedish National Road Administration - SNRA - Sweden

Associated Contractors

Belgian Road Research Centre - BRRC - Belgium
Technische Universitaet Muenchen - TUM - Germany
Technical Research Centre of Finland - VTT - Finland
Swiss Federal Institute of Technology - ETH - Switzerland
Slovenian National Building and Civil Engineering Institute - ZAG - Slovenia

All together, more than 15 senior scientists and engineers, 25 Ph.D. students, post-doctoral or young engineers or researchers, and many technicians were involved in WAVE. Some subcontractors were SME (Small or Medium Enterprises), manufacturers and/or vendors of WIM systems or services; they were therefore self-motivated and interested in the output and deliverables of the project.

The project was planned for 24 months, from September 1996. A 9 month extension was subsequently accepted by DGVII, which lead to a project completion date of June 1999.

The complete project was organised in 4 main research areas, each of which was divided into two or three parts to give a total of nine work packages (WPs). The WPs were sub-divided into tasks. Each task consisted of work with a specific deliverable or output to be used in another task. Each specific WP covered one of the main objectives of the project and a basic need in Europe. The four main research areas were consistent areas, but had relationships between them. Each WP worked towards providing more efficient and accurate WIM systems and more reliable traffic load data.

The detailed organisation of the WPs is described below:

WP1. Accurate estimation of static weights using WIM systems

WP1.1. Multiple Sensor WIM (MS-WIM) - *leader: CUED / co-leader: LROP/LCPC*

a. New and improved theories
b. Validation using experimental data
c. Tests of MS-WIM systems
d. Specifications and legal issues

WP 1.2. Bridge WIM systems (B-WIM) - *leader: TCD*

a. Increased Accuracy for Typical Bridges
b. Extension of B-WIM to Orthotropic Decks
c. Extension of B-WIM to Other Bridges
d. Dynamic Analysis for Typical Bridges
e. Calibration

WP2. Quality, management and exchange of WIM data - *leader: DWW*

WP2.1. WIM data quality assurance

a. Analysis of existing quality systems
b. Site quality
c. System quality
d. Calibration procedures
e. Data quality

WP2.2. WIM data format and database structures

a. Submitted data format
b. Harmonisation procedure
c. Description of two database levels
d. Database management and maintenance

WP3. Consistency of Accuracy and Durability

WP3.1. Durability of WIM systems in cold climates - *leader: SNRA*

0. Preparatory work in advance of the project start
a. Reporting previous experience on the subject matter
b. Inviting WIM manufacturers to the test
c. Final decision on test site localisation
d. Site preparation
e. WIM installation
f. First summer test
g. Winter test
h. Second summer test
i. Random traffic test
j. Final report

WP3.2. Calibration of WIM systems - *leader: VTT*

a. State of the art report
b. Test of calibration devices and procedures
c. Specification of the calibration procedures

WP4. Optical fibre WIM systems, technology for the future - *leader: LCPC*

WP4.1. Sensor Design

a. Feasibility
b. Characterisation and testing
c. Calibration
d. Mathematical model (1)

WP4.2. Optoelectronic Head

a. Design
b. Multiple sensor head
c. Long-term performance
d. Prototype improvements

WP4.3. Data Acquisition and Processing Unit

a. Data acquisition and treatment
b. Mathematical model (2)
c. Validation and Report

A total budget of 1.5 million Euros was allocated to the WAVE project, of which 0.75 million Euros was provided by the European Commission. The total time spent on the project was nearly 30,000 man-hours, i.e. 20 man-years. The personnel cost represents 69% of the total budget. A mid-term seminar was organised in September 1997 in Delft, The Netherlands (WAVE, 1997) and a Final Symposium in Paris (May 1999), in order to widely disseminate the results of the project. In addition, much of the results were presented at the Second European Conference on WIM organised through the COST 323 action. A Web site was initially built by LCPC and is now merged with the European WIM web site built by the COST 323 action and hosted by ZAG (http://www.zag.si/wim/). A CD-ROM was prepared (edited by the BRRC) to present all the reports and output of the project.

Several large testing facilities or bridge and road test sites were used in the project. Two road sections were instrumented with multiple-sensor arrays, in the UK and France, for testing MS-WIM systems. For the calibration of these arrays, instrumented lorries and pre-weighed lorries were used. Several bridges of different type were instrumented in France, Germany, Sweden, Slovenia and Ireland to develop and test B-WIM systems. For WP3.1 in Sweden, a road section of 0.5 km was instrumented with five WIM systems, and a static weighing area with a large weigh-bridge was used.

4. Project output

New theories, models, algorithms, and procedures have been generated, prototypes built, and field tests performed. New prospects have been opened up for weighing using multiple sensors and instrumented bridges, an innovative technology has been developed using optical fibres and optronics, and there have been significant advances in the calibration of the systems and in the quality and management of weigh-in-motion data. Experiments on roads fitted with sensors and on instrumented bridges have yielded highly valuable quantitative information on the durability, performance, and precision of many types of weigh-in-motion system.

As happens in most active and innovative research projects, many questions have been answered and others asked, opening up new prospects. The scope of weigh-in-motion has been expanded to encompass new needs in the checking of vehicle weights, thanks to a substantial improvement of the levels of precision, and in the design and management of road infrastructure, thanks to new approaches to the instrumentation of roads and bridges.

In addition to performing the research and attaining the project's objectives, the consortium has attached special importance to dissemination of the knowledge and results acquired, both within the scientific community and to the users and industrial builders of the systems. The fallout from such a project is almost as much a matter of "making known" as of "know-how".

Overall results of the project are presented in the General Project Report, published by the LCPC. Detailed results of each WP are presented in each WP's report, which are published by the WP leader's organisations.

Report on the WP 2

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Final report

WAVE -WP 2

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1. OBJECTIVES

In most European countries Weigh In Motion equipment is in use to collect Weigh-in-Motion (WIM) data for one ore more purposes. An increasing demand on WIM data on European level makes the exchangeability of WIM data between different countries an important issue. Collection of WIM data is and will be done on a variety of concepts in different countries, thus a very important issue is to transform the available data to an European format. Due to the various measuring methods and site specifications there is a need for quality parameters to classify the submitted WIM data.

The work done in Work Package two (WP2) of the project WAVE is the preparation of a quality assurance system (QA) and tools to enable users to retrieve data for different applications. The European WIM-site database extended with WIM data, prepared in the COST-323 action will be used basis. The database will be a source of information for users such as traffic, road and bridge engineers, road research laboratories, road managers and authorities.

The information and data in the European database need to be well defined and dependable so that policy makers and decision makers can make use of it. Each provider of data is responsible for the quality of the delivered information and data to be used in the quality classification as prepared in 'WAVE'. But this quality must be known by the users, as well as the accuracy and reliability of the data. That is an essential criterion for future use of these data. The QA system not only aims to ensure the quality of the data, but also to inform the users about the actual value of this information.

The prepared WIM database will not be fully automated in collecting data from WIM systems in all countries. There are several reasons for setting this restriction:

That would require formal and legal agreement of all the parties.

- preparation of such a system is very expensive,
- it would require an amount of work not campatible with this project and direct involvemenet of national executives

Thus it is impossible in the duration of 'WAVE' to set up the final product. But the essential task devoted to this project is to prepare the background and the procedures in order to enable database implementation soon after the project achievement.

The objectives of WP2 were divided in two parts:

The main objectives of WP were

1. The development of a quality system that takes into account the wide range of system types, applications and environmental situations in Europe. For this part of the work, results from the COST-323 was be used, in particular the preparation work for the CEN/TC226 committee, containing European specifications for weighing-in-motion. The most current knowledge was gathered from the cold environment (WP3.1) the calibration of WIM-sys systems (WP4.2). Quality parameters will be defined and procedures will be described to classify the data.

2. to organise the database and develop tools which enables users to easily get detailed or aggregated data, as well statistics and indicators about the traffic loads on the European roads.

The proposal for an European quality assurance procedure requires that the data will be labelled in way that easily classifies the quality of the data. The basic principle is that the provider of the data as well the user does not need to know and understand the technical details of the used methods to provide information or to collect information from the database.

note: It is stated that in all the WP2 that the accuracy of WIM-data is defined with respect to the static weights estimation by WIM systems. Only in some particular scientific cases that may not be true, but these cases do not deal with the general use of WIM data.

2. ORGANISATION OF THE WORK

In order to collect all ingredients for a sufficient and consistent quality assurance system first an inventory was made of existing procedures and standards. The quality assurance starts at very low level of sensors and equipment, up to checks on statistical data. In particular the test procedures on statistical data were to be analysed. The inventory was done by ZAG, LCPC and DWW and reported in chapter 4. The inventory made clear that a minimum of procedures was available. One official standard the ASTM-198 was available, the FHWA-LTPP data quality assurance (proposed) system was investigated and French SIREDO network, a national wide traffic data acquisition and WIM network installed on the national roads. Further investigations led to the conclusion that networks with integrated QA-systems are not operational.

In number of working group meetings the basic approach was discussed taking the information as described for the European WIM-database by the COST-323 action as basis. The wide range of applications and initial quality of information made it a difficult task to fulfil the initial tasks. Especially the minimum information available about measuring environments and effects of factors.

The approach chosen was the following:

-inventory of the main influence factors, as described in chapter 5 (5.2), by all partners, and define quality as a function of bias and standard deviation (DWW).

-describe coherence tests for the European database. Data provided to the European Database will be tested on their content and on their values. Although the responsibility of the data quality belongs to the supplier, a number of tests have to be done to minimise the possibility of wrong information This work was done by LCPC, and described in chapter 6

-find the information required for QA-procedures and describe the necessary parameters not available from the database. This process is described in chapter 7, and was done by DWW, including prediction of effects of critical parameters.

-qualify the used calibration procedures. The QA procedures should take into account the calibration procedure, frequency of re-calibration, date of last calibration or check, if an statistical checking procedure is active. This was done by BRRC. A description is presented in chapter 8.

-to qualify the influence factors by means of an experimental method. This method was introduced and described by DWW (chapter 9).

The work of WP2 was expected to be strongly supported by the other WP's of the project by means of written procedures to be included in the quality assurance plan. During the project it became clear that the partners involved had up to date access the latest information from these work packages. The possible contribution from the other WP's was less then expected.

User tools and Quality Assurance implementation in database was not achieved. The reason for that was that requirement for different application were discussed in the COST-323 action but did lead to clear definitions for the following applications: road/traffic management, pavement, bridge, enforcement.

A preliminary model of the EU-WIM-database is prepared under the COST-323 action. The QA system and the user tools developed in WP2 were not implemented in this database. The concept of the QA-assurance system as discussed in this report need to be fed with more experience. It was discovered that the basic knowledge available was less then expected. Secondly the EU-database was presented as an low budget example, to show the possibilities of a European database of WIM-data. The database need to rebuild order to add the required information for the QA tools. For such an action the recourses need to be available. In the implementation and dissemination plan in chapter 11 ideas and actions are presented to initiate activities in this field.

3. INTRODUCTION

Weigh in Motion measurements can be performed for multiple purposes, such as statistical studies for improvement of pavement managing systems, road transport analyses, inventory of overloading of road vehicles, bridge loading and pre-selection of vehicles for enforcement [1]. For most applications statistical information of aggregated data is required. To quantify (calculate) the significance of changes in statistical data collected from one WIM site, or to compare statistical data from different locations (sites) information on accuracy and the quality of the measured data and the statistics is required.

Since in the European WIM database statistical information from different providers will be collected, the accuracy of the data provided to the European WIM database can vary. Not only due to use of different systems, maintenance strategies or calibration systems, but also due to different accuracy requirements set by the responsible organism owns the system and/or uses the data..

The main issue of the Workpackage 2 of the WAVE project is to provide a system that easily can be used by suppliers of WIM data to label their data. The user of the aggregated information will be informed about the potential quality of the provided data by some basic parameters. These parameters contain as well information on the system, its environment as well as its calibration status.

It can be divided in the following elements:

1. Sensor

The accuracy of measurements of the sensor in combination with its detector and the durability of both.

2. Site/environment

The smoothness of the mounted sensor in the road, alignment of the road, as well pavement characteristics play an important role in the potency of a site to generate accurate WIM-data. Since the dynamic impact force applied to the road by an axle driving at speed is not easy to measure, for WIM systems in general the static axle loads are being used as reference. The dynamic component of the axle load depends interaction between road profile, deflection etc. and the suspension characteristics. In general a WIM-sites will be chosen in a way that the dynamic component is minimal. The alignment will normally not change during lifetime of the WIM-system, other things like rutting and evenness will change in time. So characterising a WIM site at time of installation is desired, but not enough.

3. Calibration

After installation most systems are being calibrated using a relatively simple test. Also more advanced calibration procedures can be used. The knowledge that a certain WIM system is for example calibrated and tested extensively, using advanced statistical analyses of tests results, is not a guaranty that data provided two years later are reliable. So, with any set of data it is necessary to know the 'calibration status' of the system during data collection.

In most European countries except France WIM is done not very extensively. Most systems are directly under responsibility of the organism that uses the data. This means that information about the road quality and the 'calibration status' is available very easily. When data are provided by different suppliers to a large European database the need for information about the quality of the information increases.

Although it is not the scope of WP2 to provide a complete quality system, in chapter 2 useful information is collected on sensor and system level to insure the quality of WIM-systems, and so to lay a basis for the quality of data provided by the WIM-system.

4. Sensor and equipment quality

To which extend a sensor is capable to provide a signal referring to the impact force applied by a wheel, or set of wheels belonging to one axle, of a vehicle moving at speed (dynamic load) is the basis of the result of WIM-measurements.

Depending on the sensor type different tests can be done before and after installation. As far as known there are not many countries using structural acceptance tests before sensor installation. In the draft of the 'European Specification on Weigh-in-motion of road vehicles [2] under the Chapter Sensor Acceptance and Installation some methods are described. Manufacturers often test all their sensors before selling. To investigate the potential accuracy of the WIM -system after installation ore information is required.

The process of assuring quality of information from dynamic weighing devices starts with the site selection procedures, through choice of equipment, installation procedures, data transmission and collection, calibration and maintenance, until the presentation of statistics processed from data collected on different sites. For each part of this process a level of QA is required, depending on the requirements of the end user, and in practice, a result of compromise between technical and organisational requirements and financial recourses.

In the most optimal situation the QA procedures are developed for each part of the process and balanced in accordance with the requirements of the end user. In practice until now this is not the followed procedure. In each quality assurance system under development existing systems and procedures has to be taken into account.

In Europe a wide range of weighing devices are in use, for different applications and with different levels of quality control. Within the COST-323 project a WIM-site database has been developed, extended with two levels of WIM-data (statistics and detailed data) in order to present the possibility of in integrated source of information in the area of vehicle /axle weight related traffic data.

The database in principle is open for all WIM-data provided by different organisations with divers background. Due to this philosophy the quality i.e. the accuracy of the WIM-info can be of any level.

4. INVENTORY OF EXISTING DATA QUALITY SYSTEMS

4.1 Introduction

Investigation in and outside Europe learned that no automatic data quality assurance system is in use. Only one official standard concerning Weigh In Motion is available since 1990, the ASTM E1318-90 [3]. This standard describes Weigh In Motion, contains relevant terminology and classification of WIM-systems related to their application. Performance and user requirements are described and acceptance and calibration tests are described. This standard is very useful but concentrates on the installation, acceptance and calibration of equipment rather then on quality assurance of data in general.

In some cases some structural manual checking method on WIM-data is in use (FR and US), or an automatic system is in preparation. In this chapter the used or prepared systems, as well automatic and manual, are being presented and discussed.

4.2 ASTM

The Standard Specification for Highway Weigh-In-Motion Systems with user Requirements and test Method [3] is the first official document containing procedures and tests to increase quality of WIM-data. It contains a chapter terminology in which Weigh In Motion is defined as:' the process of estimating a moving vehicle's gross weight and the portion of that weight that is carries by each wheel, axle, or axle group, or combination threreof, by measurement and analysis of dynamic vehicle tire forces'. The specification covers all aspects of WIM, such as reference measurements, calibration and test procedures, site requirements, data contents and performance (accuracy) requirements. A summary is presented in the next paragraphs.

4.2.1 Classification

Four types of WIM-systems are classified, in order to meet the needs of the users for intended applications:

Type I

The type is system can be defined as the most complete high speed WIM-system: it should be able to record four lanes and cover a speed range from 16-113 km/h. It produces the following items: wheel load, axle load, axle-group load, gross vehicle weight, speed, axle distances, vehicle class, site identification code, lane and travel direction, data and passage time, vehicle record number, wheelbase (frontmost to rearmost axle), ESAL (equivalent standard axle load) en violation code. Also some minimum hourly statistics are defined and a feature to provide maximum wheel, axle, axle group loads and vehicle weight limits for overload detection should be made.

Type II

This type is identical to type I except the provision of wheel loads

Type III

This type is defined to be applicable for preselection of overloaded vehicles and/or axles at weigh-enforcement stations. It operates at speed from 24 to 80 km/h. Vehicle class, wheelbase and ESAL are not recorded. The system should estimate acceleration while the vehicle passes the system. Of course limits for axle and vehicle loads can be entered.

Type IV

Type IV system are defined as slow speed WIM-systems (LSWIM) for enforcement purposes and should work in a speed range from 0 to 16 km/h. Lane and travel direction, vehicle class, wheelbase and ESAL ore not required

4.2.2 Performance and user requirements

In the performance requirements a accuracy per type of system is defined in % tolerance for 95% probability of conformity. An example for type I is presented in Table 1

Function	Type I
Wheel load	+/- 25 %
Axle load	+/- 20 %
Axle-group load	+/- 15 %
Gross-vehicle weight	+/- 15 %

Table 1: Example of performance requirement for a type I system (ASTM E1318)

Two vehicle classification systems are defined, base on axle space patterns. Also formats for parameters are prescribed.

In the user requirements aspects the quality of the WIM-site is defined buy means of maximum, slope, curvature, evenness. Also aspects power supply are mentioned.

4.2.3 Test method for WIM system performance.

A test method for evaluating the performance of each type of WIM system is presented. Procedures are given for acceptance testing of any new type of WIM-system and on-site calibration at the time of system installation (initial calibration) or when site conditions have changed.

The acceptance test for type I and II systems consist of multiple runs of two test vehicles at minimum and maximum speed specified by the user and 51 vehicles selected from the traffic stream. The site for performing the test should be approved by both the vendor and the user. The apparatus to be used for reference static measurements is also specified.

If, after performing the tests, more then 5 % of the calculated differences for any applicable data item exceeds the specific tolerance, the WIM-system is declared inaccurate.

This method gives a reasonable indication of the performance of a system, however, when a system passes the test it is not a statistical proof that all readings will fall within the specified tolerances.

4.3 LTTP (US)

In the United States the collection of WIM-data has grown exponentially the last years because of two reasons:

1. the traffic data requirements for the Long Term Pavement Performance Project (LTPP), and,

2. the increased Federal Highway Administration (FHWA) emphasis on the use of accurate truck weight and volume information for planning, programming, and design purposes.

For the LTPP test sites continuous WIM-data collection was preferable, but also AVC with portable (temporary) WIM collection was accepted. Since every State Highway Agency (SHA) is free so select their own equipment vendor, equipment type and data collection time table, there is a basic similarity with the European situation. The necessity to develop an automated quality assurance process arose hen the LTPP program started to generate enormous quantities of WIM data and the funding and staffing levels in most SHAs decreased. Until now data were checked manually. The data quality assurance described in the reference document [3} concerns both Automatic Vehicle Counting (AVC) data, as well as WIM-data. A short description of the developed quality assurance system is presented in this document, in order to evaluate the concept with respect to the design of an European WIM-database.

Before going into the quality assurance system prepared for the WIM-data within the LTPP-program some information on the database structure is required.

4.3.1 Structure of the LTPP traffic-database.

The database structure of the LTPP Traffic Database contains 5 levels of information, shortly described as follows:

Level 1:Primary Loading Estimates

Data for pavement researchers, mainly containing traffic loading information, without extensive information on vehicle types and seasonal variation.

Level 2:Annual Traffic estimates

Same as 1, but including vehicle type information

Level 3:Daily traffic Estimates

Primary database for in-depth analysis, containing daily traffic data. This level requires user to be reasonable familiar with traffic data, and analysing methods

Level 4:Detailed Raw Traffic Data

Highly desegregated data also containing individual truck weight data (axle loads and axle distances), and hourly statistics.

Level 5:Supporting data

Data from sites not providing continuos information for level 3 or 4. In fact it can contain every information from counting of WIM actions. The first matrix in this level is a matrix with available data.

Data on level 5,4 and 3 are processed weekly, monthly or semi-annually at the RCOD, and at the end of one year summarised to lever 2 and 1.

Data passed the quality assurance procedures as described below are entered to levels 3 and 4.

4.3.2 The LTPP quality assurance procedure

Conceptual Design

As stated before the FHWA has no control over the equipment, so a method has been developed to examine the data provided by the software/hardware of the vendors, that is:

- independent of the used system (vendor/manufacturer)
- independent of the type of sensors
- can be used by any SHA participating in the LTPP and,
- can be applied consistently to all submitted data.

The designed quality assurance system computes a variety of summary traffic variables from the traffic data submitted by the SHAs, and tests these variables against known or expected values. Submitted data that fall outside these ranges are considered "questionable' and are subject to further review. In fact they are flagged as questionable until a valid explanation for the found abnormality is given by the SHA. If these traffic conditions are expected to be repeated at that site the target values and/or ranges can be adjusted. In fact this system only detects malfunctioning equipment.

Preliminary Checks

Prior to calculation of summary statistics a series of simplistic checks is carried out. They are developed by FHWA and adopted by the LTPP. These test scan the data to asses they are complete. They determine among other items that:

- dates are valid;

- site identifiers on the data record match those of the LTPP site for which they were submitted;
- numeric fields do not contain alphabetic characters;
- direction and lane identifiers match known lane and direction information on that site;
- all data for a day have been submitted.
- The spacing between tandem on tractors (type 3S2) fall within a given tolerance. (if not the speed calculation is not accurate and can cause inaccurate axle load calculation (in case of strip sensors, using integration of signal over time)

If data do not pass these tests they are send back with reason to the SHA. If large number of record fail, all data are send back. Accepted data are subject to further tests.

WIM-data checks

Some tests are carried out on weight data in order to identify calibration drift. This drift is a serious problem in the US, caused by lack of sufficient resources to routinely monitor the calibration coefficients and the costs to perform manual checking methods.

The performed tests are based on the gross weight distribution of a certain type of vehicle. (5-axle, tractor semi-trailer). (fully) Loaded as well as empty this vehicle type has a gross weight within certain boundaries. These type of vehicles make up 80 percent of the truck fleet so on most locations it is easy to achieve a reasonable sample size. The quality assurance test examines the frequency distribution of gross weights of these type of trucks. It determines if peak values occur at the expected location in the curve. The initial expected values are bases on two sets of information:

- the gross vehicle weight frequency curve immediately after calibration of the WIM system
- the known characteristics of a specific truck type

The height of the peaks are less important then the location of the peaks.

The height of the peaks can change due to economic conditions. The following checks are performed:

- the first peak (empty vehicles) is expected to be stable over time. Drift of this peak will rather be caused by calibration drift then by change of average weight of empty vehicles.
- the second (loaded) peak is expected to be at or slightly below the legal limit. If the peak is above the legal limit it is likely that the scale calibration is not correct.

-The allowed range of the loaded peak is within rather wide boundaries because many commodities have a loaded peak below the maximum allowable limit.

These tests on weight data are performed on data from each single lane because calibration drift or sensor failure can be restricted to one lane.

Another check is based on the assumption that the percentage of overloaded trucks is limited.

It is mentioned that on specific sites other truck weight conditions can be used when careful review shows that these conditions do take place. Of course the setting of parameters can be modified on basis of carefully checked data.

Questionable data are not discarded, but flagged. The responsible SHA is asked to examine the data. If a careful check of calibration and operation indicates that the frequency distribution is correct the data are accepted, and the expected frequency distribution values are changed.

Vehicle classification data checks.

In the LTPP also some checks on vehicle classification data are performed. These test are more difficult because the vehicle classification varies more form site to site then the load distribution of the 'reference' vehicle. These tests also are carried out per lane. A variety of variables are checked, as there are:

- number of hours without traffic per day is limited
- detection of (temporarily) equipment failure, for example due to power failure, data transmission error of lightening strikes.
- traffic volume at 13:00 should be greater than at 1:00 at night. By this the setting of the time clock is checked (in US many clocks are not set to use 24 hours).
- daily traffic volumes for key vehicle classes should be within specified ranges. This is done by day of the week and season. The rages are broad and analysis imprecise, but enables to determine sensor problems, such as 'ghost axles'.
- percentage of truck within each truck category should be within specified ranges for each day. The same as before.
- number of vehicles not classified or classified but not weighed is limited. This data can be caused by vehicles changing lane, and should not exceed a maximum. If more of these errors occur it indication malfunctioning of sensors and further investigation is necessary.

The error detection codes provided by the software of most vendors is very useful. For the LTPP-program standardised data submittal formats are required, and thus vendors reports on system errors are not used automatically.

When one ore more of these data checks exceeds the parameters set for that site, a message is printed, indicating which rule was exceeded and when. These data are automatically extracted from the data, together with the data from the day before and the day after. By this the investigation time to search for the 'suspicious' data is minimised.

In order to perform all checks, for each site a parameter file is maintained. The values can be adjusted and modified per site which allows a wide variation in expected values and ranges. The following scheme illustrates the dataflow concerning the quality assurance system.

Initially the QA is performed by regional contractors for LTPP (the Regional Co-ordinating Offices). Questionable data are send back to SHA who has the responsibility to determine whether a system failure has occurred or whether the measurements are valid. If the measurements are valid and not different from 'normal' due to temporarily circumstances such as for example. extreme weather, special events, road maintenance activities or accidents, both the SHA and RCOC have the ability to change the assurance parameters file for that site.

Later on the LTPP plans to have the quality assurance process occur at the SHA level.

4.4 Cete de l'Est

In the QA-procedures developed by Cete de l'Est two levels can be distinguished, a 'low level' procedure which basically checks whether the sensors and first line electronics are functioning well, and a 'high level' procedure that controls the calculated statistics.

4.4.1 Verification of sensor functioning.

To verify if the sensors perform well, the WIM-system every day creates a file in which some parameters reflecting the proper functioning of the sensors are stored. This file is continuously checked by software.

In the following these parameters are mentioned and their function is described

1. Maximum registered scale factor of the sensors (4 columns, for 4 sensors)

The scale factor indicates the maximum registered axle load.

There is malfunctioning if this value is:

- very high, because there is a risk of wrong weight indications of light vehicles
- very low, because there is a risk of limiting the axle load at the indicated value
- blocked on one value; in this case the sensor can be broken, or the automatic calibration system not performing well.

In all cases of a wrong scale factor, the operator has to adjust the weight detectors at distance.

2 Number of registered vehicles of the day.

This value permits to verify the proper functioning of the induction loops. Large discrepancies with comparable day indicates that a loop detector is not functioning properly. In this case the operator replaces the loop detector on the site.

3. Number of heavy vehicles

The number of heavy vehicles is used to verify the functioning of the Piezo-electric cables and the vehicle classification procedure of the WIM-System

4. Date and hour

This values enables the operator to check the clock of the computer.

5. Status of the station (functioning)

The last column indicates the functioning of the WIM-system. If it is "0" it is functioning well; if this value is "1", one of the parameters in another file is modified. In this file, accessible by the command "N" are stored:

- start and end dates of the 'bad sector'
- the software resets done by an operator
- the functioning of the loop detector and piëzo-detector. In case of malfunctioning a message is generated.

4.4.2 Verification of statistical information.

Tests on the coherence of the content of (statistical) files

In the weighing system different statistical files are produced. A program called MAR-TINE automatically verifies the content of different statistical files based on the same datafiles.

For example:

Hourly traffic flow

The software verifies if the sum of hourly traffic flow for one day in a statistical file is equal to the one in another statistical file

Monthly traffic flow

The software verifies if the monthly traffic flow is the same for in different statistical files containing for example, flow of heavy vehicles, speeds, weights and overweighs.

Tests on the validity of data

The monthly statistical files are checked manually by means of comparison with other monthly files (reference same month one year before, or former or next month). By this checks the operator checks on pre-defined indicators to reject a complete monthly file.

Rejections of this files are very rare, and are in general done on files from stations which have a broken piezo-electric sensor.

The operator validates the data in files which respect the following limits:

- the total vehicle flow and the flow of 5 axle heavy vehicles are exceeding +/- 20% of the report of months of the same type
- average speed of small cars and 5 axle heavy vehicles is more then +/- 5 % of the report of one year together

- average weights of each vehicle category is +/- 5% of the report of one year together
- percentages of overloading per vehicle type
- verification of the % of overloading and rejection in case of important deviation
- hourly and daily number over overloaded vehicles: rejection if the results per traffic direction are not balanced
- average number of axles per heavy vehicle: +/- 10% of the report of one year together.

5. CONCEPT OF THE QA-SYSTEM

5.1 Introduction.

The aim of the QA-system for the European WIM-database is to provide the user with information on the quality of the information.

There are different issues:

- consistency of the information
- accuracy of the measurements

The consistence of the information is important; the information, presented from the database, (both the general information on the site as well as the WIM-data) should be clear and well defined. Errors or mistakes should be found automatically by the system. These part of the QA-procedure consist of coherence tests on the information and data provided to the database and is presented in chapter 3.

The accuracy of the measurement (the basis of the WIM-data) is very important. In the most preferable situation the accuracy of the WIM- measurements is regularly checked and expressed in a statistical way like proposed in the COST-323 Specifications. All information from the database should be consistent and checked before presented in order to minimise the possibility of providing unreliable information.

In the European WIM-database, as developed within the COST-323 project information from different WIM-sites is collected. The installation of these sites was done under different circumstances and for a wide range of applications. These, as well as the different recourses and technical staff available to maintain these sites and collect the data, play a role in the quality of the available information.

However the best way to express the accuracy of available WIM-data is by means of statistics based on regular checks as proposed in the COST-323 specifications this kind of information is not always available. The QA-system should provide the user with information about the expected quality of the available data, as much as possible, by means of one ore more QA-parameters.

The QA-parameters are indicators based on information about the weighing equipment, pavement and other parameters. The principle of the system is as follows:

- The supplier of the data fills a sheet with required information
- This information is automatically proceeded by the QA-tool
- Quality indicators are calculated
- The quality indicators are related to the WIM-data

When WIM-data is red from the database the quality parameters are presented.

This approach has the following advantages:

- the supplier only fulfils a sheet with information as far as available;
- neither the supplier nor the customer needs to understand all details of the quality parameters calculation;
- the quality parameters calculation is centralised and under the responsibility of the database manager. Implementation of new calculation methods due to better understanding of influence factors, can easily and efficiently be done;

users are informed about the (relative) quality of the data, without being overloaded with complex or too technical details.

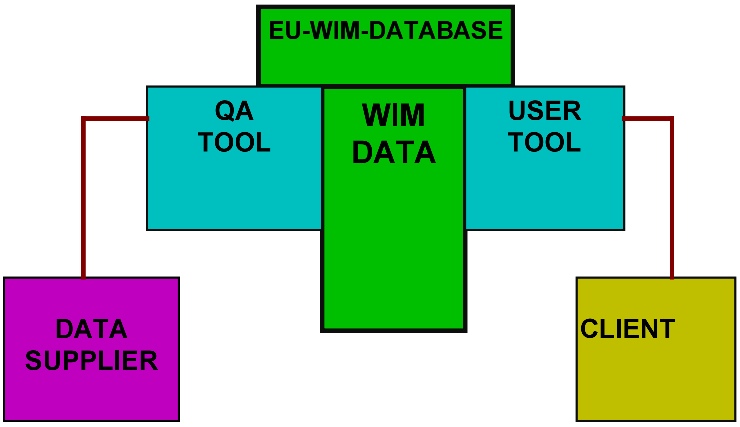

Figure 1: Database and tools

5.2 WIM accuracy influence factors

High Speed Weigh In Motion measurements are carried out under real traffic conditions, by measuring the impact force of passing axles by means of one or more sensors. The potential of installed WIM-systems to produce accurate WIM-measurements is to large extend depending on the definition of the used reference. Generally spoken the static weights of vehicles or static loads of axles are used as reference. These weight or loads are often measured by static weighing devices approved for enforcement activities such as weigh-bridges or (build-in or portable) axle weighers using different techniques. The actual accuracy of dynamic weighing devices can only be obtained by using a dynamic reference weight, for example by using an instrumented vehicle from which the momentary wheel loads can be measured (for example by strain gauges on the axles) .

For some type of weighing techniques the accuracy of the measuring device itself can be obtained in laboratory by static tests. Other systems require dynamic tests. In this case the dynamic tests are used to test if the sensor is homogeneously sensible to applied forces.

When a WIM-system is installed, the road or bridge construction can become an integral part of the measuring device. (For Bridge WIM the environment (the bridge) is in fact the basic part of the sensor). This means that the performance of the WIM system after installation in most cases differs from the ‘original’ performance of the sensor itself. Often, the accuracy of the WIM-system as a whole is taken into account, including the sensor, the measuring environment, the hardware and the software and is expressed in relation to the static weights of axles. The main sources of differences between the WIM-measurement and the static reference can be divided into two groups:

1. Dynamic versus static weight

WIM-systems in general are used to predict static axle and vehicle weights, by performing a (or more) momentary measurement of the impact force applied by the wheels of an axle of a moving vehicle. The vertical forces generated by a moving wheel on a road surface consist of two components:

- the static component which can be defined as the force applied by the axle on a flat surface when the vehicle is stationary.
- the dynamic component which can be defined as the result of the interaction of the vehicle and the pavement due to the fact that the vehicle is moving.

This means that generally spoken the reference value is another parameter (static load) then the measured parameter (sample(s) of the dynamic load);

2. Measurement environment

Under this header all influences not directly related to the actual measurement of force applied to the sensor by the wheel are considered, such as

- direct impact of climatic factors, such as temperature, humidity, snow, frost etc.
- road alignment and profile
- pavement behaviour (for example. deflection)

In figure 2 all influence factors playing a role in assessing the static weight of a vehicle (axle) by means of a dynamic weighing.

In practice the isolated sensor accuracy is combined with the measurement environment. [5]

In the draft specifications from COST-323 [2] general requirements for WIM-sites are advised according the alignment of the road, and 3 classes for WIM sites are defined, based on pavement characteristics. These requirements and classes are defined in order to choose a site for installation of a WIM-system.

The QA-procedures to be defined for the European WIM-database aim to indicate the quality of WIM-data coming from a particular site. To be able to do this it is necessary do define the required information and indicate the cross-relations as mentioned before.

In the QA system these pavement characteristics and environmental parameters are used as an input to estimate the level of confidence of the data. The QA system has to take in account real or expected values and these values have to be updated. Missing information has to be dealt with and for some values a quotation for evolution of these values in time has to be defined. Important is the relation between different measuring methods for the same parameter, for example evenness or deflection. For each parameter the most common used measuring method in Europe will be chosen as basis.

5.3 Conceptual design

Figure 2 shows in a concise way the teamwork between the set of factors influencing the dynamic measurement of the weight of a vehicle. All these factors can play an important role when establishing the accuracy of a WIM system. The goal is a to get an idea about the accuracy of the measurement. Stated in another way assume that a large set of date has been gathered, all coming from the same vehicle under the same conditions, how well does the batch of data describe the real weight of the vehicle. Figure 2 shows this in a graphical way. The normal distribution is the distribution of an individual measurement. This graph shows a significant *Bias*, that is a difference between the real weight and the mean of the measurements. Secondly it shows that there exists scatter between the measurements coming from on the same phenomenon.

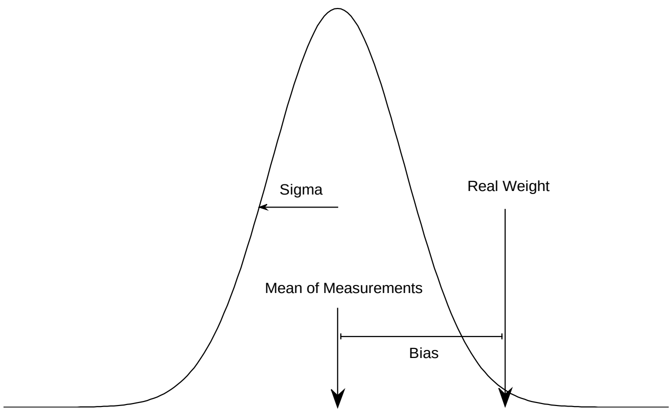

Figure 2. Distribution of individual measurements

The difference between real value (θ) and the distribution of individual measurements (mean=μ, sd=σ) can be written as,

$$MSE = E\left[(X_i - \theta)^2\right] = (\mu - \theta)^2 + \sigma^2$$

The term (μ-θ) is the bias. This bias can disappear if a correct calibration is performed. Assuming this has been done studying the variance σ^2 is sufficient. The distribution as shown in Figure 2 results from an experiment in which the same vehicle is asked to ride over the same sensor in the same way again and again and again. Since there will always be variation in the way this is done, e.g. i) not exactly the same speed ii) vehicle behaviour will vary iii) sensor reaction will not exactly be the same and so on and so forth.

Accuracy is defined as follows[6]

A system has an accuracy of at least order δ if a lower confidence interval (α=0.95) for the fraction of observations falling between [Ws-δ;Ws+δ], Ws being the real static weight, is at least 0.95.

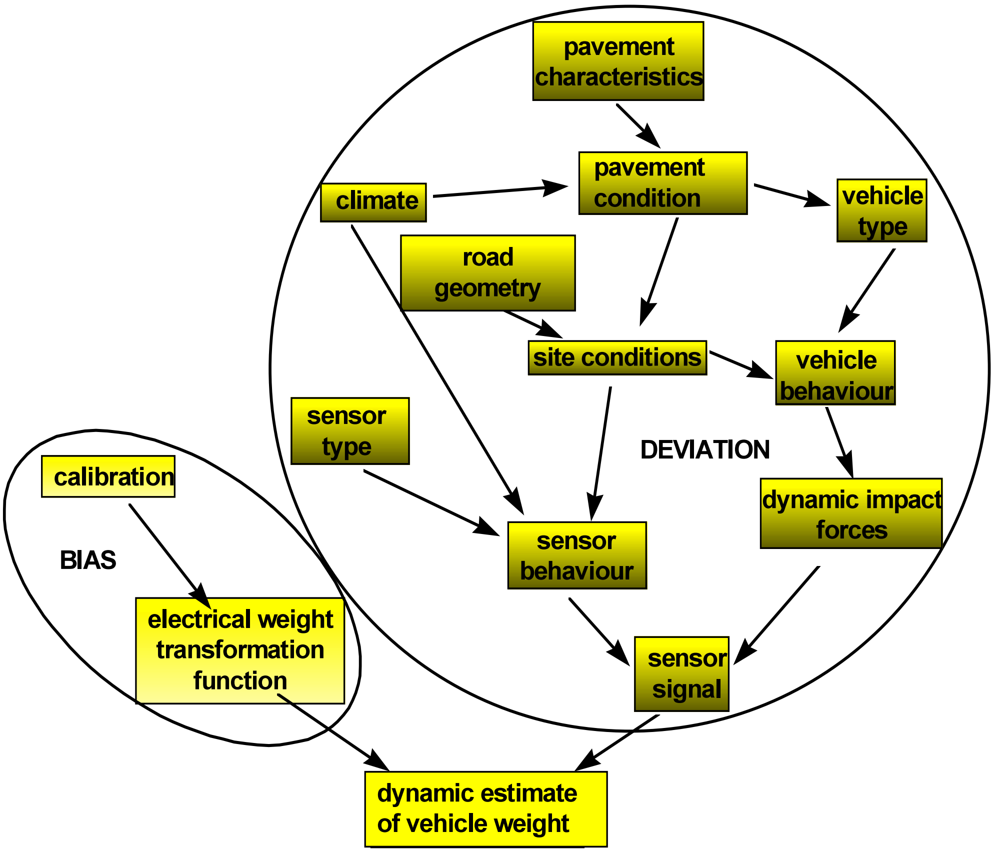

Figure 3. Influence diagram for dynamic weighing

The second interesting issue here is the question how the variance or standard deviation varies as a function of different input factors. Figure 3 shows some factors that have only arrows pointing away from them and not to towards them. Such factors are called *exogeneneous* factors.

The accuracy can only be calculated if real data (WIM data & reference data (static weights)) is available. In case this information is not available it would be preferable if the accuracy can be predicted by means of another method.

One way of dealing with situations were no objective measurements are available is to use subjective measurements instead.

Figure **4** shows this in a graphical way. The square in the top of shows the objective situation where bias and standard deviation are known based on a large number of data.

Using the definition of accuracy an quality level can be derived. This is the basic of the concept of the classification proposed in the COST-323 specification.

The second square shows the subjective analogy. The bias has been replaced by 'the calibration method'. This provides a rough indication of the bias probably present. The column entrance of this second square has been replace by a subjective classification of standard deviation in terms like Bad (--),…., Excellent (++).

This way a subjective way of determining measurement accuracy can be found. Using a new definition 'subjective Quality' can be calculated as a function of 'subjective measurement accuracy' and 'calibration method'.

As the measurement accuracy is depending on different factors the first thing to do is to define the most important factors and then to estimate the and influence of these factors. In chapter 6 two methods are described to achieve this.

In chapter 8 the qualification of calibration procedures is described.

The second aspect as it has been mentioned in the list above is concerned with the influence of several main factors on standard deviation/ measurement accuracy. The aim of this study is to build a subjective model for measurement quality, as depicted in the second square of figure 4.

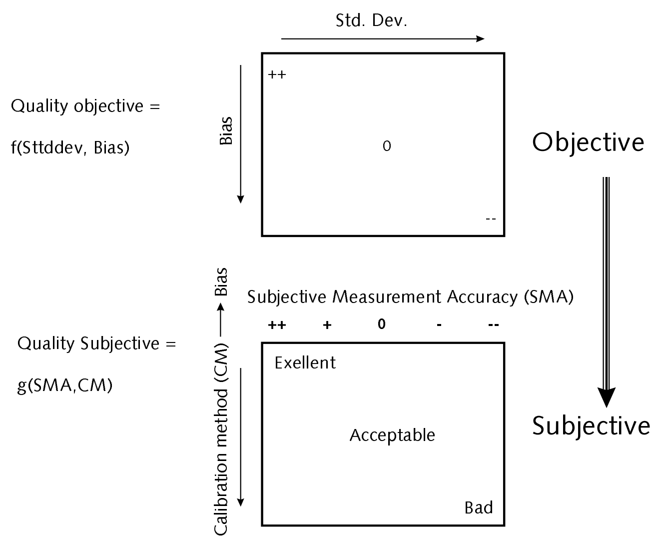

Figure 4. The relation between an objective and subjective model

6. COHERENCE TESTS

6.1 Introduction

This chapter contains a description of coherence test for the EU-WIM-database. The database contains several levels of information for each part. Level 1 and 2 of part II are presented in Table 2 and Table 3.

Data provided to the European Database will be tested on their content and on their values. Although the responsibility of the data quality belongs to the supplier, a number of tests have to be done to minimise the possibility of false information. First the extensibility of coherence was discussed. Then the actual test procedures were defined. The following types of tests can be distinguished:

- checking the information in specific files or fields
- coherence between statistics from one site to another, or from one period to another.
- comparison of samples and/or parameters with target values, based on experience

The coherence tests are described in accordance with their appearance in the database; in part 1 and part 2.

6.2 Part II, level 1

Field N°1 ‘Data site number’: The test has to check that two (more) different sites can’t have the same data site number. For one country, the ‘data site number‘ must be sequencious (ex: FR 0001, FR 0002 , FR 0003 …) This number is not provided by the manager of the database, but internal by the database.

Field N°3 ‘Country’: choice of official abbreviation of EU-countries

Field N°6 ‘Type of road’ choice of road type

Field N°9 ‘Number of equipped lanes’: This field must be between 1 and 4 if field N°13 ‘WIM site on both directions’ equals ‘NO’ otherwise Filed 9 is between 1 and 8.

Field N°12 ‘First date of installation’ and Field N°12 bis ‘Last date of installation’ : the ‘Last date of installation’ must be greater than the ‘First date of installation’. The ‘Last date of installation’ must be lower than the date of the day.

Field N°15 ‘total traffic’: this field must be lower the 300 000 vehicles per day.

Field N°36 ‘Date’: this date must be greater than the ‘last date of installation’ and lower the date of the day.

N°	Data	Comments		N°	Data	Comments
1	**Data site number**					
2	**Site number**			28	**Recorded data 1**	ex : Axle load
3	**Country**			29	**Recorded data 2**	ex : Total weight
4	**Department**	(part of Country)		30	**Recorded data 3**	ex : Classification
5	**District**			31	**Recorded data 4**	ex : Speed
6	**Type of road**	(motorway , Main express highway...)		32	**Recorded data 5**	ex : Counting
7	**Road number**	ex: A6		33	**Recorded data 6**	ex : distance/axle
8	**Number of lanes**			34	**Main use**	ex : Pavement studies
9	**Number of equipped lanes**			35	**Other use**	ex : Testing and research
10	**Quality of pavement**	1 :excellent 2 : good 3 : medium		36	**Calibration method**	ex : Automatic with characteristics vehicles
11	**Precise location (km+m)**	ex : km 15,25		37	**Date (updating)**	ex : 03/02/1997
12	**First and last date of installation**	ex : 03/02/1996 05/02/1996		38	**Fulfilled by**	ex : M. Smith
13	**WIM sites on both directions**	Yes/No		39	**Other type of weight sensor**	ex :1 Piezoceramic bar and 1 Capacitive mat
14	**Manager of WIM system**	Organisation in charge of the WIM system		40	**Memo field**	ex : 1 Piezoceramic at km 15,28 and 1 Capacitive mat at km 15,29
15	**Total traffic (veh/day - 2 directions)**	ex : 24000				
16	**Comments**					
17	**Type of weight sensor**	ex : capacitive strip				
18	**Removable ?**	Yes or No				
19	**Numb/lane (17)**	Number per lane				
20	**Sensor Manufacturer**					
21	**Electronic Manufacturer**					
22	**Type of other sensors**	ex : Inductive loop				
23	**Numb/lane (22)**	Number per lane				
24	**Time of work**	ex : continuously				
25	**Power supply**	ex : 12v DC //220v AC				
26	**Data transmitting on site**	ex : yes 2400 bauds				
27	**Processing on site**	ex : yes (software) or no				

Table 2: Structure of PART II of the EU-WIM database from COST-323, level 1

6.3 Part II, level 2.

The first type of tests either logical test (as seen for part I) or either comparison of the computed values (mean, std ..) to reference values

Field N°2 'Period number': (Do you mean the actual year. Then it is not correct (0001) first month of year 2000) it must be between 0000 an 9912) . First two digits > 80 or < 20, second pair < 13.

Filed N°3 'Period of reference length' : this field must be smaller to Filed N°5 'End of measurement' minus the field 4 'Start of the measurement'. (is it possible to calculate with dates??)

Filed N°7 'Traffic flow (all vehicles)' : this field must be lower than 300000 vehicles per day

Field N° 8 'Traffic flow (HV)' : this field must be lower than 99999 vehicles per day and lower than field 7

Field N°9 '% of HV' : this field must be lower to 100%.

Field N°10 'all vehicle speed' : The mean Values must be between 20 and 120km/h and the standard deviation (STD) lower then 60k/h

Field N°11 'HV's speed' : same test as field 10

Field N°12 'Vehicle spacing' : The mean Values must be greater than 5m

Field N°13 'HV's spacing' : The mean Values must be greater than 10m

Field N°14 'All axle load' : The mean Values must be between 2 and 15 tonnes and the standard deviation (STD) lower than 15 tonnes

Field N°15 'Single axle load' : same test as field 14

Field N°16 'Axle of tandem load' : same test as field 14

Field N°17 'Axle of tridem load' : same test as field 14

Field N°18 'Axle group (tandem load)' : The mean Values must be between 4 and 25 tonnes and the standard deviation (STD) lower than 10 tonnes

Field N°19 ‘Axle group (tridem load)’ : The mean Values must be between 6 and 30 tonnes and the standard deviation (STD) lower than 15 tonnes

Field N°20 ‘Axle group load’ : The mean Values must be between 4 and 30 tonnes and the standard deviation (STD) lower than 15 tonnes

Field N°21 ‘gross weight’ : The mean Values must be between 5 and 40 tonnes and the standard deviation (STD) lower than 20 tonnes

Field N°22 ‘Number of axle per HV’ : The mean Values must be between 2 and 6 and the standard deviation (STD) lower than 3

Field N°23 to N°30 (percentage of silhouette) must have values between 0 and 100%.

In addition, the sum of the field N°24 to 29 (percentage of HV silhouette) must be equal to field 9 (% of HV’s) with a tolerance of 5%.

Afterward, The mean GW value (Field N°21) divided by field 22 (Number of axle per HV) must be equal to field 14 (All axle mean weight value) with a tolerance of 5%.

Afterward, The mean Axle of tandem load value (Field N°16) multiplied by 2 must be equal to field 18 (Axle tandem load weight value) with a tolerance of 5%.

Afterward, The mean Axle of tridem load value (Field N°17) multiplied by 3 must be equal to field 19 (Axle tridem load weight value) with a tolerance of 5%.

Thanks to the knowledge of fields 24 to 30 and because the number of axle for each silhouette is known, it is possible to compute a weighed average for the estimation of the number of axles per HV (field 19). The difference between the computed and the filed value must not be greater than 5%.

The second type of internal coherence tests are based on statistical tests. They should be applied to the following field:

Traffic flow

HV’s speed, car’s speed

Load (Gross weight, axle load etc…)

% of vehicle per silhouette

N°	Data	Value	Mean	Comments
1	**Data site number**	x		Same as in the WIM sites database (part I)
2	**Period number**	x		coded: year/N° (e.g. 9703 = 1997, 3rd period)
3	**Period of reference length**	x		in number of days (1)
4	**Start of measurement**	x		date, to be completed if the measurement are not continuously recorded over the year (1) in the format dd/mm/yyyy
5	**End of measurement**	x		idem
		(2)	Mean	Comments
6	**N° of lane/direction**	x		L1 to Ln (lanes), D1 or D2 (direction), A (all)
7	**Traffic flow (all vehicles)**	x		in vehicles/day
8	**Traffic flow (HV's only)**	x		in HV's/day
9	**% of HV's**	x		= 100 * (line 7) / (line 6)
10	**all vehicle speed**	x	x	computed on all vehicles population (km/h)
11	**HV's speed**	x	x	computed on on the population of HV's (km/h)
12	**Vehicle spacing**	x	x	all vehicles, computed on all the population (m)
13	**HV's spacing**	x	x	computed on on the population of HV's (m)
14	**All axle load**	x	x	computed on all axles taken individually (kN)
15	**Single axle load**	x	x	computed on single axles population (kN)
16	**Axle of tandem load**	x	x	computed on all axles belonging to a tandem (kN)
17	**Axle of tridem load**	x	x	computed on all axles belonging to a tridem (kN)
18	**Axle group (tandem) load**	x	x	computed on tandem population (kN)
19	**Axle group (tridem) load**	x	x	computed on tridem population (kN)
20	**Axle group load**	x	x	computed on all axle groups population (kN)
21	**Gross weight**	x	x	computed on all HV's population (kN)
22	**Number of axles/HV**	x	x	idem
23	**% of vehicles/silhouette 1**	x		computed on all vehicles population
24	**% of vehicles / silhouette 2**	x		idem
25	**% of vehicles / silhouette 3**	x		idem
26	**% of vehicles / silhouette 4**	x		idem
27	**% of vehicles / silhouette 5**	x		idem
28	**% of vehicles / silhouette 6**	x		idem
29	**% of vehicles / silhouette 7**	x		idem
30	**% of vehicles / silhouette 8**	x		idem
31	**Aggressivity - single axles**	x		
32	**Aggressivity - tandem axles**	x		
33	**Aggressivity - tridem axles**	x		
34	**Aggressivity - all axles**	x		
35	**Aggressivity per lorry**	x		
36	**Method of aggressivity calculation**	x		As referenced in the database brochure

Table 3: Structure of PART II of the EU-WIM-database from COST-323, level 2.

To be significant, tests should be applied only if aggregated data statistics are computed with data collected over 7 days or more. Moreover, shorter time periods may be accepted.

The statistics relative to 2 periods can be compared only if :

the lengths of these two period are the same (at least 7 days) or similar

the are representative of the same period of the year or of homogenous period

(For example, if data are collected at a site over more than 270 days, the relative aggregated data are considered to be representative of the year. If the data are collected over the same period (270 days) for several years, the statistics can be compared).

Mean values will be compared using the test of the equality between the mean of 2 samples.

Variance values are compared using the test of the equality of the variance of two samples (F-test will be used).

Concerning the "% of vehicle per silhouette", the khi-squared test (which is a non parametric test) will be used in order to compared the histograms of silhouette relative to the different periods.

In the statistical test (α risk) is by default 5%. In some case, another values is specified.

The significance level is 5% if statistics computed over 7 days.

The significance level is 2% if statistics computed over 1 year.

Between 7 days and 1 year, the significance level value is 3%.

7. REQUIRED INFORMATION FOR QA-PROCEDURES

7.1 Introduction

In this part the coherence test are not under consideration but the input from site and environment to the quality of WIM-information. The eventual effect on the performance of electronics and software is not under consideration. The reason is that that this is mainly depending on the maintenance policy of the system owner and can also be a financial or practical considerations and, besides that, has to large extend effect on the durability of the system, rather then its accuracy related to a specific data collection period.

First the available data is discussed and then the required additional information

7.2 Data available in the database

In the European database as developed within the COST-323 action information about the system and the environment is collected as useful information to characterise the site and the WIM-information. Some of the information can also be used in the QA system. Table 2 shows the information in the first level of the database (part II).

The information in Table 2 presented with a grey background can be of interest for the QA system however there are some remarks to be made:

- Field N°10: *'Quality of pavement'.* You have three choices (1,2 or 3) according the COST 323 specifications.

The first problem with this field regarding the QA-system is that it is presented as a static value, related to the site. In reality it is a temporary situation which will change in time. It would be better to use here the term ‘Quality of the pavement at date of installation’, because that is the function of the classification in the specifications. The quality of pavement can be 1, but for how long? For QA-procedure also the measuring date of the different pavement parameters is required in order to take into account the expected deterioration, related to the climatic conditions and pavement type. Then the quality of the pavement is linked to one measuring period.

- Field N°15: *‘Total traffic’*

The total traffic flow can be of interest for different issues such as the expected increase of rutting over time and the possible advantage of the use of automatic calibration systems based on traffic parameters. For both issues more detailed information is required, possibly being collected from the second level of the database.

- Field N°17: *'Type of weight sensor'*. In this field you have the choice between the following possibilities:

- Piezoceramic nude cable
- Piezoceramic bar/strip
- Piezopolymer nude cable
- Piezopolymer bar/strip
- Capacitive strip
- Capacitive mat
- Optic fibre strip
- Optic fibre mat
- Bending plate strain gauges
- Load cells plates
- Instrumented bridge (B-WIM)
- To be added:
-Quartz sensor
- Sub pavement beam sensor (prototype installed in Lulea, WP3.1)

Note: optic fibres: relation and sensitivity to parameters not based on experience.

- Field N°36: *'Calibration method'.* In this field you have the choice between the following possibilities:

  - Automatic with characteristics vehicles
  - Pre-weighed vehicles
  - Instrumented vehicle
  - Automatic + pre-weighted vehicles
  - Automatic + temperature correction
  - Pre-weighted vehicle + Temperature correction
  - Automatic + Pre-weighed vehicle + Temperature correction

An important issue is the judging of the calibration method in terms of expected quality of the data. Basically the calibration is only used to correct the bias, and in addition it can provide information about the accuracy (deviation). This subject is discussed in chapter 8: Qualification of calibration procedures

7.3 Additional information required for QA-procedure

To calculate, by any system, an indicator of the reasonable expected quality of the WIM data additional information is required.

	Data	Choices	Values
1	**Climate**	1 sea 2 land 3 (sub)tropical 4 cold	
2	**curvature**		in m (radius)
3	**transverse slope**		in %
4	**longitudinal slope**		in %
5	**last junction/crossing/merging road**		in m upstream
6	**type of pavement**	1. concrete (rigid) 2. semi-rigid 3. all bitumen 4. flexible	
7	**Deflection**		in 10^{-2} mm
8	**longitudinal evenness**		IRI in m/km
9	**transverse evenness**		rutting in mm (3 m beam)
10	**Bridgetype and/or span length**	in case of Bridge WIM	(m)

Table 4: Additional information required

1. Climate.

If the climate is to be taken into account the influence subjects should be clearly defined.

- Cold climate

The deflection of asphalt pavements in strongly related to temperature. In cold climate regions a frozen depth of 2 meters is not unusual as there is no snow to insulate from the coldness. The stiffness increases with decreasing road-temperatures and effects the interaction with the vehicle. Extreme cold environments (for example minus -20 ºC) also effects the dynamic behaviour of vehicles. The stiffness of shock absorbers increased when temperature decreases.

Also the use of studded tires and snow ploughs can be considered

- Sea climate: high humidity, moderate temperature changes

- Land climate: wide range of temperatures seasonal, but also daily,
- Sub-tropical: hot and humid

2. Curvature

The curvature can cause dynamic effects because of steering action, and effects the distribution of loads on the two wheels of one axle. When the radius of curvature exceeds the advised minimum in the COST-specs, no influence will be taken into account. If the radius is smaller there can be some dynamics introduced.

3. Transverse slope

Most sensor types use measurements of two tires (left and Right) at once or sum up two measurements of left and right tire. Even if only one side of the vehicle is measured, (in case of standard configuration of capacitive mat f.e.) the calibration will partly compensate the effect of the transverse slope. One critical point is that the effect on the left-right load distribution initiated by the transverse slope is depending on the position of the point of gravity. Due to this an effect on the standard deviation of the axle loads can be expected because the point of gravity varies between vehicles.

This parameter is also important when you want to evaluate the loading of trucks with respect to the left-right balance, which is a specific research request and thus will not be taken into account.

Tranverse slope

Probably in case of extreme transverse slope (f.e. > 4%) some effect should be presumed. A simple calculation based on figure 1, assuming:

Transverse slope of 4 % (α= 2,3°)

wheel base = 2,3 m

points of gravity 1 m and 3 m above pavement

d= 2m. sin α = 8 cm

Increase of Rl:

0,08/ (2,3m x cos α) = 0,035 = 3,5%

Theoretically the effect will be some more because of suspensions. It can be concluded that due to differences in point of gravity the effect on the error of measurement is approximately 1 % per %.

4. and 5. Longitudinal slope and distance to last junction.

The combination of 4 and 5 can say something about the expected dynamics due to acceleration. Literature on this issue is welcome in order to quantify the effect. However is seems clear that the effect is depending on the vehicle type.

Longitudinal slope and distance to last junction

Taking into account the acceleration of heavy vehicles, in relation to the slope [7] the following schedule can be produced.

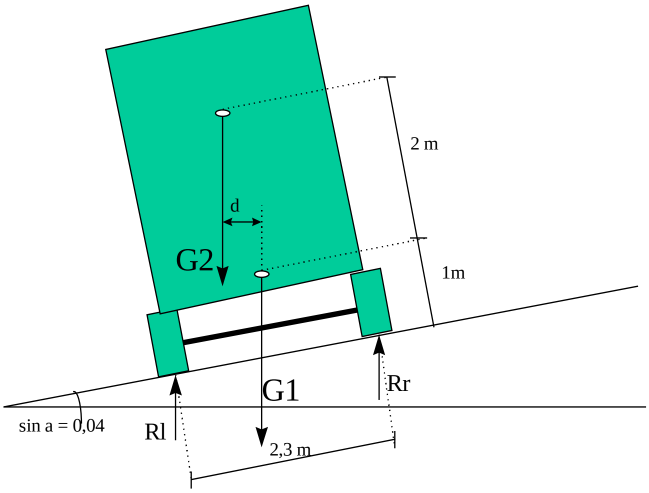

Figure 5: Effect of different points of gravity on the left-right distribution of wheel loads.

	Slope in %											
dist. (m)	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
<200	X	O	O	O	O	O	O	O	O	O	O	O
200-400	X	O	O	O	O	O	O	O	O	O	O	O
400-600	X	X	O	O	O	O	O	O	O	O	O	O
600-800	X	X	X	X	O	O	O	O	O	O	O	X
800 -1000	X	X	X	X	X	O	O	O	O	O	X	X
1000-1200	X	X	X	X	X	X	O	O	O	X	X	X
1200-1400	X	X	X	X	X	X	O	O	O	X	X	X
1400-1600	X	X	X	X	X	X	O	O	X	X	X	X
1600-1800	X	X	X	X	X	X	O	O	X	X	X	X
>1800	X	X	X	X	X	X	X	X	X	X	X	X

X= no effect due acceleration expected

O= effect due to acceleration expected

in grey: intermediate area, some effect expected

Table 5 : Expected acceleration related to slope and distance to last junction

The maximum speed is set at 80 km/h.

When the slope is increasing the length effect decreases. The reason for this is that the loaded vehicles do not reach the maximum speed.

It seems logical that there only two possibilities: acceleration or no acceleration. This is the case when only one vehicle is considered. In order to take into account the effect on the population an area intermediate is introduced with some expected effect (in grey)

6. Type of pavement

In the table only 4 types of pavement are mentioned, in accordance with the WIM-specs, the COST-324 and PARIS project[8]. For site identification this can be sufficient. The question is if this also the case for the QA-procedures, especially when the expected deterioration in time is concerned.

The pavement types with their specific properties are [8]:

concrete (rigid)

All concrete pavements are considered, as long as the concrete is used to provide the strength of the pavement: unreinforced, reinforced and continuously reinforced concrete pavements. Also concrete pavements with a bituminous top layer are considered as concrete pavement.

semi-rigid

A semi-rigid pavement consist of a relatively this bituminous top layer and a base course providing the structural strength. The base course can for example consists of sand-cement or lean concrete.

all bitumen

An all bitumen pavement consists of a bituminous pavement on an unbound natural base

In this type of pavement the bituminous layer provides structural strength of the pavement. When the thickness of the bituminous layer is slightly reduced because of e relatively stiff base course (granular materials for example with binding components, such as crushed concrete), the pavement is still considered as all bitumen pavement.

flexible

A flexible pavement is a pavement with a bituminous upper layer and an unbound granular base course layer providing the strength of the pavement. or example cemented ,

7. Deflection

A wheel passing over a pavement will cause deflection of the road surface. This deflection can have an effect on the output of the sensors. Some type of sensors will generate a signal just because of the bending of the sensor. In case of a direct relation between the applied force and the deflection this effect can be compensated by calibration. For bituminous pavements, i.e. the ‘all bitumen’ and ‘flexible pavements’, the E-modules of the pavement is related to the temperature of the material and thus on the deflection level caused by a (standard) axle passage. In such case an effect on the accuracy of the measurement can be is expected for some types of sensors.

The deflection of the pavement also can have an effect on the durability of sensors, or the durability of the mounting of the supporting frame or the sensor. Cracking of the pavement and the epoxy resin supporting the sensor or the sensor frame is a well known phenomena

In the QA system the effect on the durability of the system is not taken into account.

8 Longitudinal evenness.

The longitudinal evenness, or better the road profile is directly effecting the behaviour of the moving vehicle and responsible for the initiation of the main part of the dynamic component of the axle-load. Of course the interaction of the vehicle (suspension system and shock absorbers, mass and vehicle dimensions) are of major importance. If a vehicle is moving on a smooth surface some dynamics will be generated by the vehicle because of unbalance in parts of vehicle (engine, wheels, tires, axles) but under normal circumstances the evenness related dynamic component will be critical.

In the COST-323 specifications [3] the longitudinal evenness of pavement roughness is expressed in IRI, because this is the most widely used parameter.

Longitudinal evenness

In order to indicate the effect of the longitudinal evenness on the expected accuracy of WIM-data some literature is available. From this literature a raw expected relation can be extracted.

The effect of the road profile on the dynamic component of the axle load is depending strongly on the vehicle speed, the type of suspension and the vehicle weight (loaded / empty).

In general WIM system are used to measure the weights of heavy vehicles driving at speed and thus the background of indicative effects on accuracy of data is based on the following assumptions:

- heavy vehicles are considered
- travelling at high speed (60-100 km/u)

In [9] a quarter vehicle model is used to simulate the vehicle behaviour on pavements with different roughness (steel -springs) . For each pavement the possible range of maximum and minimum dynamic component of the wheel load is calculated for different speeds.

The roughness of the road is expressed in PSI (Present Serviceability Index) and not in IRI.

In [10](the little book of Profiling) the relation between IRI and PSI is indirectly expressed:

The PSI is a prediction of the present serviceability rating (PSR), which originally was defined as ''the ability of a specific section of pavement to serve high speed, high volume, mixed traffic in its existing condition'' and rates on a scale from 5 (very good pavement) to 0 (very poor). Later (in the 80^{th}) the profile index 'Ride Number' (RN) was introduced as an estimate of the Mean Panel Rating and on a similar scale to PSI (0-5). The correlation between these two parameters is has a STD of 0.29 and R^2 of 0,85, so

$$MPR \approx PSI \approx RN$$

The profile Index (PI) which is used for the RN analyses relates to RN by:

$$RN = 5e^{-160(PI)}$$

The relation between PI and IRI is presented in Figure 6

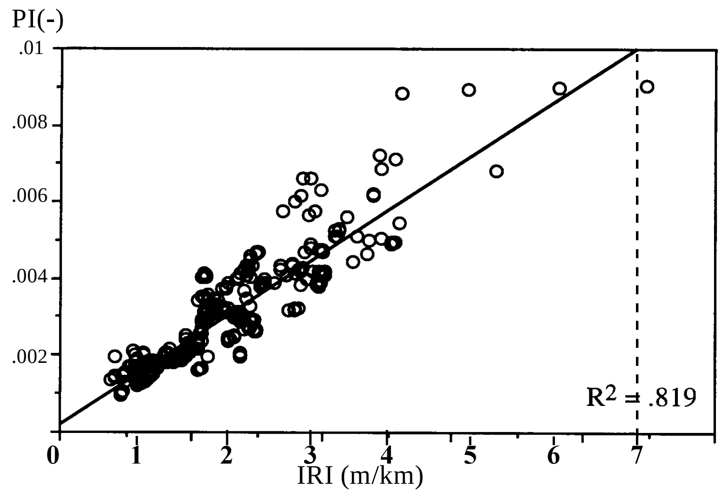

Figure 6: Relation IRI-PI

Assuming a linear relation between PI and IRI, the relation between IRI and PSI can be expressed as:

$$IRI = -4{,}375 \ln(RN/5)$$

Now the results from [9] can be expressed in IRI:

A row indication of error on Dynamic load coefficient and IRI can be made now.

IRI (m/km) range	DLC (%) (steel)
1-1,6	6-14
1,6-3	14-25
3-4	25-40

Table 6: Relation IRI-DLC ([9]Caprez)

In [11] the relation between DLC and IRI is measured for different vehicle weights and speeds for two vehicles. In the range of 60-100km/u the following ranges were found for the DLC for different IRI.

IRI (m/km) range	DLC (%) steel	DLC (%) air
1	7-9	3-5
3	15-17	7-12
5	23-26	9-16

Table 7: **Relation IRI-DLC ([11]Jacob)**

It is clear that air suspension has a positive effect on the DLC however it is known that the condition of the dampers is of great importance.

In general can be concluded that :

on a smooth road surface (IRI= 1) a DLC in the order of 5-8 has to be taken into account, ranging up to 20-40% for a rough pavement (IRI=5).

9 Transverse evenness

The transverse evenness of the road surface is generally expressed in the rut depth. The rutting in the pavement does theoretically spoken not directly effect the axle load by introducing dynamic effects. The effect of rutting on the WIM-measurements are depending on the sensor type. If a stiff sensor or a stiff support frame is placed in the

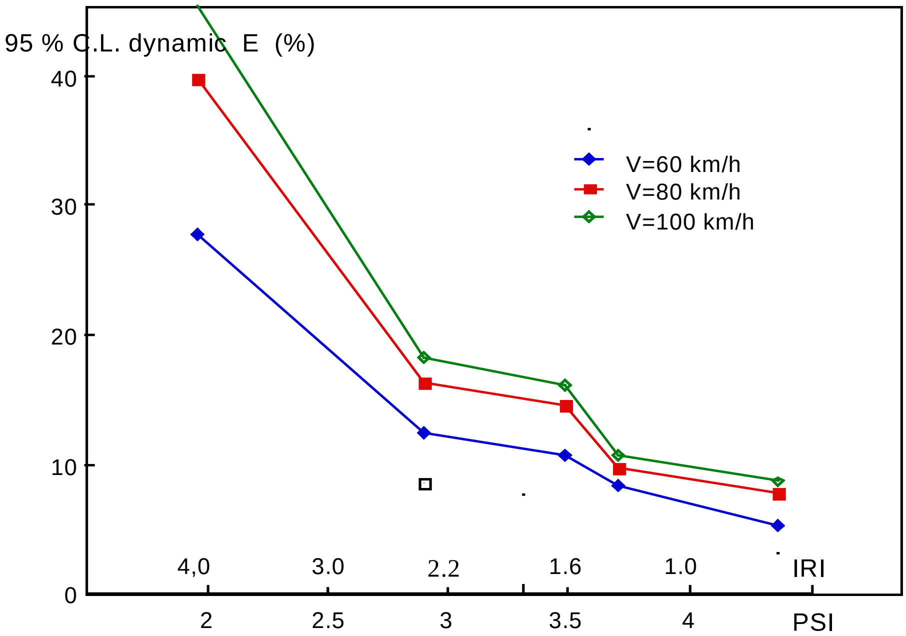

Figure 7. Relation DLC and IRI

pavement and rutting is introduced a dynamic impact will be introduced when the tire hits the frame. If the sensor is flexible it can follow the pavement by bending. In this case no dynamic impact is introduced due to the rutting.

It is expected that for 2,3,4 and 5 the effect on the WIM-data is independent to the type of sensor, is directly related to the dynamic behaviour of the vehicle.

8. QUALIFICATION OF CALIBRATION PROCEDURES

8.1 Introduction

In chapter 5 is explained that the expected possible bias, in the subjective method to indicate the quality of measurements is a result of the used calibration method. In order to classify the used calibration procedure the most important factors in the calibration process have to be provided by the data-supplier by means of questions. In this chapter the different issues are presented and modified, and the classification process is described

Some other remarks with respect to the QA-procedures:

- calibration with instrumented vehicle is only used for research activities, maybe in future for MS-WIM.
- temperature correction only to compensate the first order effect of temperature i.e. the correction of sensor output to the sensor output by a standard temperature. The question is if this information is useful because it is an integral part of the sensor/system. It can be expected that the system manager is not aware of this details.
- more important is the correction of second order temperature effect, i.e. the impact of deflection of the pavement on the sensor output, which in general is not done.

Five elements are described in 8.2. and the required information is presented and coded for each element. In chapter 8.3 the decision process in presented.

8.2 Elements of calibration

In the calibration process 5 important elements are defined to build the calibration part of the QA procedure:

(I) Automatic calibration on axle load
(II) Knowledge of the factors involved in the automatic calibration
(III) Knowledge of the traffic composition
(IV) Frequency of the calibration
(V) Test plan used

8.2.1 Automatic calibration on axle load

Automatic calibration can as well be an advantage as a disadvantage. The information that automatic calibration is active does not automatically include a positive effect.

An automatic calibration aims to avoid a bias and thus allows to increase the accuracy when the reference value is the static load. The purpose is to compare the measurement to a reference value if the measured vehicle is recognise as a reference vehicles (usually, in function of its silhouette or number of axles, its gross weight and its first axle load). This comparison gives the calibration factor which is applied to all vehicles.

To apply a good automatic calibration, the knowledge of the traffic composition on the site is necessary to define the target class and load values. Is seems not realistic to take into account all factors responsible for the effect of automatic calibration (used method, standard deviation of pre-set values in real traffic, with respect to the frequency of this particular parameter etc.) see also 8.2.3

Depending on the type of weighing sensor and on the type of climate, a temperature compensation is required. By example, piezo-sensors need one without climate condition and during extreme climate (very cold or very hot), bending plate needs also one.

Of course an automatic calibration is a continuous comparison between reference values and measured values, nevertheless, a drift could still appear in the sensors output if, for example, the traffic composition or the average vehicle weights are changing or if (temporarily) the population of reference vehicles is small. This is why a frequent verification of the automatic calibration system is necessary.

Question: Is there an automatic calibration ?

Answers	Code
Yes	I-1
No	I-2

Table 8: Automatic calibration available?

8.2.2 Knowledge of the factors involved in the automatic calibration

To install the automatic calibration, the target (or reference) vehicle(s) and some information about its(their) weight(s) need to be known, for increasing the efficiency of this method.

Also, some sensors need a temperature compensation, for all or some particular (extreme ones) climatic conditions.

It is impossible to list all the automatic calibration factors, this is why the question has to be general and some factors could be listed as an example.

In the QA-procedure, we will assume that if several factors are needed and if the customer answers “Yes”, then it means all the factors are known and tested.

We can assume that, if they know the factors, they know also the composition of the traffic to prepare adequate test plan for the initial and regular calibration checks. If not, the question (III) must be answered and the decision chart becomes figure 2.

Question: Do you know and do you check the factors involved in the automatic calibration ?

Answers	Code
Yes	II-1
No	II-2

Table 9: Automatic calibration factors checked?

8.2.3 Knowledge of the traffic composition

Without an automatic calibration, the system evolves during the time and gets, after a certain time, some drift or bias due to an ageing of the sensor and/or of the pavement.

Without an automatic calibration, the test frequency must be as higher as possible, surely less than one year. To increase the quality and thus the confidence to the experiment, the test vehicles need to be chosen in respect to the traffic composition on the site. Without knowing the traffic, some test plans (TP1 and TP2) are the same and some others will see their confidence decreasing (TP4).

The traffic composition determination does not need a high accuracy or a big number of classes. Something like that will be enough: cars, 2-axles, 3-axles, 4-axles with a tandem, 4-axles without a tandem, 5- and 6-axles with a tridem, 5- and 6-axles without a tridem, more than 6 axles.

An idea about the mean and the dispersion of the first axle load and of the gross weight could be a useful information to chose the test plan or the automatic calibration factors.

Question: Do you know the traffic distribution on the site ?

Answers	Code
Yes	III-1
No	III-2

Table 10: Traffic composition known?

8.2.4 Frequency of the calibration

Whatever the type of calibration (automatic or manual), if there is no check of the drift or of some traffic variation on the site, after some times (the duration depends on the calibration type, on the sensor type and on the intrinsic sensor accuracy (or on the intrinsic resistance to the lost of calibration)), the sensor loses its calibration.

Depending on the application, on the climatic conditions and/or on the financial conditions, the frequency will be higher or lower. If the sensor is sensitive to the season variations, the frequency must be linked to the season shift. If the pavement deteriorates very quickly or if there is an important variation in the traffic distribution then the frequency will be higher.

Nevertheless, without any initial calibration, the confidence to the data has to be very small (near to zero). The first (or initial) calibration allows to take care of the real sensor installation on the site and of the real traffic on the site. At the sensor installation if there is no initial calibration, the first calibration during the sensor life is considered as an initial calibration.

The use of an automatic calibration allows to decrease slightly the frequency.

Question: What is the frequency of the calibration ?

Answers	Code
Calibration after less than 6 months	IV-1
Calibration between 6 and 18 months	IV-2
Calibration after more then 18 months	IV-3
No (initial) calibration	IV-4

Table 11: Frequency of calibration.

8.2.5 Test plan used

The best calibration (manual one or check of the automatic one) will be based on the sample closest to the normal traffic flow distribution.

If the calibration is based on a type of vehicle non representative of the traffic flow, the sensor gets a high accuracy to measure and recognise such a type of vehicle and disregards mostly of the traffic flow.

This is particularly true if the calibration is done with light 2-axles lorries and if the most common type of vehicles in the traffic is an heavy 5-axles semi-trailer. In this example, two problems occur:

- The first one is linked to the load of axles: doing the calibration on light loads gives an incertitude on the heaviest ones (we have to pay attention that this problem is not directly linked to the gross weight but well on the axle loads as a sensor is measuring an axle loads and not a gross weight).
- The second problem is linked to the type of axles: two single axles and a group of axles (tandem or tridem) do not react in the same way to the dynamic effects, due to the link between the axles in the second axle type (this is not directly linked to the number of axles, a 4-axles road train without tandem axle gives the same information as a 2-axles lorry.

The probability of using a test plan based on instrumented vehicle is really small and could be forgiven, in particular if we are speaking about normal applications of WIM. The use of an instrumented vehicle is necessary to study some scientific aspects like the repeatability. Also, in this case, the reference value is not more the static load but the impact force. Actually, most of the WIM applications are linked to the static weight, this is why such a calibration method is not recommended for normal applications.

This method requires no automatic calibration (which is surely based on the static weight) and no knowledge of the traffic.

Due to the price and the difficulties to apply this calibration (only a few vehicles in the world are available), a frequency of five years is enough.

For all these different explanations, the instrumented vehicle test plans are cancelled from the proposal.

Question: Which calibration test plan do you apply ?

(choose the closest one to your real test plan)

Answers	Code
One test vehicle (singular type, light or without group of axles vehicle) and at least 7 runs without speed condition	V-1
One test vehicle (normal type, heavy or with group of axles vehicle) and at least 7 runs without speed condition	V-2
V-1 + V-2 (at least 7 runs per test vehicle without speed condition)	V-3
static post or pre-weighed vehicles from the traffic flow (at least 25 vehicles that represent the traffic distribution)	V-4
V-1 + V-4	V-5
V-2 + V-4	V-6
V-3 + V-4	V-7

Table 12: Calibration plan

8.3 Decision process

The confidence in the calibration process i.e. the level of confidence in unbiased data is depending on the combination of answers on the presented questions. Table 12 shows all possible combinations, using the codes from tables 7-11, and an interpretation of these combinations in terms of - an +. Roughly can be concluded that combinations resulting in +/- are acceptable general statistics, and ++ is required when individual data are used, for example as pre-selection of overloaded axles or vehicles.

Frequency of calibration (IV)				< 6 months (IV-1)							6-18 months (IV-2)						
Test plan no. (V)				V-1	V-2	V-3	V-4	V-5	V-6	V-7	V-1	V-2	V-3	V-4	V-5	V-6	V-7
	Yes	Factors	yes (II-1)	+/-	+/-	+	+	++	++	++	-	-	+/-	+/-	+	+	++
auto.	(I-1)	Known (II)	No(II-2)	--	--	-	-	+/-	+/-	++	--	--	-	-	-	+/-	+/-
cal. (I)	No	Traffic	yes (III-1)	+/-	+/-	+	+	++	++	++	-	-	-	+/-	+/-	+/-	+
	(I-2)	Known (III)	no(III-2)	--	--	-	-	+/-	+/-	+	--	--	-	-	-	-	+/-

Frequency of calibration				> 18 months (IV-3)							not regular (IV-4)						
Test plan no.				V-1	V-2	V-3	V-4	V-5	V-6	V-7	V-1	V-2	V-3	V-4	V-5	V-6	V-7
	Yes	Factors	yes (II-1)	--	--	-	-	+/-	+/-	+	--	--	--	-	-	-	+/-
auto.	(I-1)	Known (II)	no (II-2)	--	--	--	-	-	+/-	+/-	--	--	--	--	-	-	-
cal. (I)	No	Traffic	yes (III-1)	--	--	-	-	+/-	+/-	+/-	--	--	--	-	-	-	+/-
	(I-2)	Known (III)	no (III-2)	--	--	--	--	-	-	+/-	--	--	--	--	-	-	-

Table 13 Decision process calibration procedures

9. QUALIFICATION OF INFLUENCE FACTORS

9.1 Introduction

Factors effecting the results of weigh in motion measurements are presented in chapter 5.3, especially when static weights of vehicles are the reference value. The effect of the different influence factors is difficult to quantify, especially due the interaction between the different factors, and also depending on the type of system and the environment. Investigation of this issue led to the conclusion that no scientific basis for a qualification system is available. In chapter 5 is explained that, if objective measurement are not available to quantify the influence of different factors, subjective measurements can be used instead. This method is called the experimental method and uses experts opinions. In chapter 9.2 this method is explained. The design of the experiment and the questionnaire for the specific problem of WIM is reported in chapter 9.3. The results of the experiment are presented in chapter 9.4.

9.2 Experimental method

An experiment is a method that can be used for quantifying the relation between an output factor (accuracy) and several input factors as mentioned in chapter 5.2. For a given value of these input factors (pavement characteristic, ….., vehicle type) measure the dynamic weight often enough to be able to calculate the spread in the measurements. Do this for several other combinations of the input factors. Use the results to derive the empirical relation,

$$S_{ijklm} = f(PC_i, Cl_j, ST_k, RG_l, VT_m)$$

Where S_{ijklm} is the estimated accuracy using: Pavement characteristic i (PC_i), Climate j (Cl_j), Sensor type k (ST_k), Road Geometry l (RG_l) and Vehicle Type (VT_m). Calibration is assumed to take care of the bias and is therefore not included in the model.

Such an experiment is however not possible! It is not possible to vary factors like Climate, Road Geometry. Nor is it possible to vary the factor ‘pavement characteristics’ rather quickly. Another way that can be used to catch this kind of information is by using a simulation model. Literature only describes results obtained this way for a restricted number of situations. The third way is to perform a subjective experiment i.e. an experiment using a set of judges that can rate the accuracy into a number of five, say, classes.

Let’s assume that the potential accuracy of a WIM system based on a number of site factors can be classified as Excellent, Good or Acceptable. More classes can be added if necessary. Such a dependent variable is called an ordinal variable. An ordinal variable is a variable that is categorical and ordered. One way of describing the relation between the ordinal variable and the set of independent variables (e.g. rutting, deflection and evenness) is,

(1)

$$\Pr\{Accuracy_j = i\} = \Pr\{\kappa_{i-1} < \beta_1 x_{1j} + \ldots + \beta_k x_{kj} + u_j < \kappa_i\}$$

where u_j is a random variable. One estimates the coefficients β_1, β_2, …, β_k along with the cut points κ_1, κ_2, …, κ_{I-1}, where I is the number of possible outcomes. In this κ_0 is taken as $-\infty$ and κ_I as $+\infty$.

A simple example will probably clarify the method. Suppose that we have asked 25 judges after their opinion on the influence of rutting and evenness on the quality of a WIM system. Assume, by the way, that these two variables are the only variables influencing the quality. The results are shown in Table 14.

Nr	tting m-beam)	ness IRI-index	Frequencies		
			Acceptabl e	ood	Excellen t
1	4	1.3	15	7	3
2	4	4	8	12	5
3	7	1.3	4	10	11
4	7	4	2	8	15

Table 14: Fictitious data for 25 judges.

Statistical analysis of these data shows that the probability of a given outcome for a new combination of rutting and evenness can be calculated as,

(11)

$$\Pr\{Accuracy = i\} = \frac{1}{1+\exp(-\kappa_i + f(R,E))} - \frac{1}{1+\exp(-\kappa_{i-1} + f(R,E))}$$

where;

f(R,E)=0.62*Rutting+0.31*Evenness

$\kappa_0 = -\infty$, $\kappa_1 = 3.14$, $\kappa_2 = 5.07$ and $\kappa_3 = +\infty$.

These results are completely obtained from the data from Table 14! Using this formula it is for instance possible to calculate, for an arbitrarily combination of rutting and evenness, the *probability* that the outcome, and thus a WIM-system, will be ‘excellent’, ‘good’ or ‘acceptable’. Using these probabilities a measure of quality can be defined. Let’s assume that we are interested in the results for rutting R=5 and evenness equal to 3. Using the equation above, results are displayed in Table 14.

		Pr(Accuracy=.)		
R	E	Ac.	Gd.	Ex.
5	3	0.29	0.45	0.26

Table 15: Probabilities for R=5 and E=3

As a final measure of Quality various possibilities can be listed. A very obvious one would be the class that has the largest probability. Use of the median class could be a good alternative. Perhaps a criterion can be defined that uses the entire distribution over the classes instead of a single measure. The first two methods point towards a quality that can be described as Good.

9.3 Experimental Design and Questionnaire

In order to keep the size of the questionnaire within acceptable limits all sensors have been classified into three types: strip, plate- and bridgesensor. For each type the most important factors affecting the measurement accuracy have been selected and interaction between some parameters are defined.

All sensor types are divided in three groups:

1. Strip sensors: all sensors with a relatively small width, smaller then the length of a freight vehicle wheel print (ca. 30 cm).

2.Plate sensors: all sensors having a width larger then the length of a freight vehicle wheel print (ca. 30 cm). In the questionnaire is assumed one plate covering half the lane width. The effects of two plates per lane are calculated from the questionnaire.

3. Bridge sensor: a bridge that is used as measuring device by measuring strains caused by passing vehicles. Several groups are considered:

1. Stiff: concrete slab bridges, box girder
2. Moderate: slab and composite
3. Flexible: orthotropic deck and other steel structures.

Wood and stone bridges are excluded.

For each sensor type the factor assumed to have a major impact on measurement accuracy are displayed in table 16.

Figure 8: Sensor types

For each factor an interval (min, max), that has been chosen for its practical relevance, is shown. The factors together with there levels and interactions determine the size of the experiment (=questionnaire).

Strip sensors

Factorname	min level	max level	unit
A. IRI	1	5	m/km
B. FWD-Defl	300	600	μm
C. Acceleration	No	Yes	-
D. Curve	0.5	1.5	km
E. ΔT-pavement	20	50	dgrs

Plate sensors

Factorname	min level	max level	unit
A. IRI	1	5	m/km
F. Rutting	3	12	mm
C. Acceleration	No	Yes	-
G. T-slope	2	4	%
D. Curve	0.5	1.5	km
E. ΔT-pavement	20	50	dgrs

Bridge sensors

Factorname	min level	max level	unit
A. IRI	1	5	m/km
C. Acceleration	No	Yes	-
H. Bridge-type	Stiff	Flex.	-
E. Span	<8	>=8	m

Table 16 : levels for the factors assuming to be influencing measurement accuracy.

Factor explanation:

IRI [m/km]: International Roughness Index

The most common used expression for description of roughness. 1 is a very smooth pavement, while 5 is extremely rough

Defl.[µm]:

Deflection reference: FWD (falling weight deflectometer measurements, carried out with Dynatest 8000 apparatus, with a test load of 50 kN, and a reference temperature of 20 °C

Speed variation [-]:

Speed variations are induced close to crossing or junction nearby upstream or downstream. The acceleration has only two levels: Yes or NO. Yes means that the main (heavy)vehicle population is at varying speed (unstabelised), NO means that under normal traffic conditions (the speed is almost constant on the site).

Radius of curvature [km]:

The curve has influence on the vehicle behaviour, i.e. dynamic behaviour due to steering corrections, and distribution of weight on left and right side of the vehicle.

ΔT [^{o}C]:

This means short term temperature fluctuation of pavement.(within one day) and not seasonal effects. Temperature changes of 50° C are realistic values for bituminous pavements

Rut depth [mm]:

Maximum rutting in one lane, measurement related to a 3 m beam

For Bridge only

Longitudinal stiffness :

- S: stiff : concrete slab; box girder
- F: orthotropic deck and others steel structure

For moderate stiff bridges effects are calculated from S and F

Interactions

The following interactions are assumed to be present:

Sensortype	Interactions
Strip	-pavement * Deflection
Plate	Curve* T-slope
Bridge	-

Table 17: Interactions of parameters

If all factors are varied on two levels the following experiments are feasible:

Sensortype	factors	-way interactions	e
Strip	5	1	)=8
Plate	6	1	)=8
Bridge	4	-	)=8

Table 18: Size of the experiment.

The response variable is an indication of the accuracy of a measurement system by choosing one of the categories (bad, poor, acceptable, good, excellent)

At least 20 judges per questionnaire are to be preferred.

9.4 Results of experiment

The response on the questionnaires was very low. Only 10 answers were received, while the questionnaire on bridge sensors has been filled in only once! Despite this small amount of results a statistical analysis has been performed. There are two reasons for this,

1/ it can give a reasonably good indication about whether this *approach* can be used or not,

2/ if the respondents are more or less consistent with each other a first rough indication about the relation between WIM measurement accuracy and the factors varied can be given.

Data. Table 19 and Table 20 show in an aggregated way the results of the strip- and plate-sensor questionnaires. The bridge-sensor will not be analysed due to the single response received. Each table can be divided into two sub-tables. The left side shows the factors varied while the right side displays the results received. Each cell entry shows the number of respondents that categorised the situation as indicated by the column label.

A	B	C	D	E	Response classes				
					Bad	Poor	Accep.	Good	xcellent
1	300	N	1.5	50	-	-	2	6	2
5	300	N	.5	20	3	4	3	-	
1	600	N	.5	50	1	3	4	2	-
5	600	N	1.5	20	4	3	3	-	-
1	300	Y	1.5	20	-	-	5	2	3
5	300	Y	.5	50	6	3	1	-	-
1	600	Y	.5	20	-	4	4	2	-
5	600	Y	1.5	50	8	1	1	-	-

Table 19: Results Questionnaire for strip-sensors. (A: IRI, B: Deflection, C: Acceleration, D: Curve, E: ΔT)

A	B	C	D	E	F	Response classes				
						Bad	Poor	Accep.	ood	xcellent
.5	1	N	12	50	4	1	7	2	-	-
1.	1	N	3	20	4	-	2	4	2	2
.5	5	N	3	50	2	3	4	3	-	-
1.5	5	N	12	20	2	4	5	1	-	-
.5	1	Y	12	50	2	1	2	7	-	-
1.5	1	Y	3	20	2	-	2	4	4	-
.5	5	Y	3	50	4	2	7	1	-	-
1.5	5	Y	12	20	4	9	1	-	-	-

Table 20: Results Questionnaire for plate-sensors. (A: Curve, B: IRI, -: Acceleration, D: Rutting, E: ΔT, F:T-slope)

Analysis. Section 4 described a method by which the data from Table 19 and Table 20 can be analysed. It models the probability of a particular outcome as a function of the factors A, B,… as,

$$\Pr\{Accuracy_j = i\} = \Pr\{\kappa_{i-1} < \beta_1 x_{1j} + \ldots + \beta_k x_{kj} + u_j < \kappa_i\}$$

where u_j is a random variable. One estimates the coefficients β_1, β_2, …, β_k along with the cut points κ_1, κ_2, …, κ_{I-1}, where I is the number of possible outcomes. In this κ_0 is taken as $-\infty$ and κ_I as $+\infty$.

Using the logit-function as an intermediate this relation can be written as,

$$\Pr\{Accuracy = i\} = \frac{1}{1+\exp(-\kappa_i + X'B)} - \frac{1}{1+\exp(-\kappa_{i-1} + X'B)}$$

In our case the following code has been used,

i	Response Class
1	Bad
2	Poor
3	Acceptable
4	Good
5	Excellent

Statistical analysis of the data in Table 19 and Table 20 using this model delivers the results as shown in table 21 and table 22.

Strip Sensors, X'B = -1.86*a-0.78*b-0.42*c+0.54*d
κ_1=-1.81, κ_2=-0.19, κ_3=2.43, κ_4=4.47
Where a: =(IRI-3)/2, b:=(Defl-450)/150, d:=2*(Curve-1) c=-1 if acceleration =N and c=+1 if acceleration =YES

Table 21 Results for strip Sensors.

Plate Sensors, X'B = -1.66*b-1.07*d-0.48*e-0.49*f
κ_1=-1.88, κ_2=0.86, κ_3=3.46, κ_4=5.16
Where a:=2*(Curve-1), b: =(IRI-3)/2, d:=(Rutt-7.5)/4.5, e:=(Tslope-3), c=-1 if acceleration =N and c=+1 if acceleration =YES

Table 22 Results for plate Sensors

As an example, the probability that a WIM system using a strip-sensor will be classified as Good given, IRI=1, Defl=500, No Acceleration and a Curve of size 1 is estimated as,

a=(IRI-3)/2=(1-3)/2=-1

b=(Defl-450)/150=(500-450)/150=0.33

c=-1 since Acceleration is "No".

d=2*(Curve-1)=2*(1-1)=0

κ_3=2.43, κ_4=4.47

X'B=-1.86*(-1)-0.78*0.33-0.42*(-1)+0.54*0=2.02

and thus,

$$\Pr(Accuracy = Good) = \Pr(i = 4) = \frac{1}{1 + \exp(-4.47 + 2.02)} - \frac{1}{1 + \exp(-2.43 + 2.02)} = 0.92 - 0.60 = 0.$$

Conclusions. Several interesting conclusions can be drawn from Table 21 and Table 22. One of the most essential ones is that the method used is one that seems to work well, even with so few as 10 responses! In order to get even better results it is important to convince latent respondents of the importance of their co-operation. Specific conclusions for strip- and line sensors are;

Strip Sensors:

- The influence of the factor ΔT can not be proven using the data.
- The coefficient of Curve is positive while all other coefficients are negative. This means that whatever the probability being calculated, Pr(Accuracy=Bad),.., Pr(Accuracy=excellent), this probability increases if the factor Curve is increased and decreases if any of the other factors is increased.

Plate Sensors:

- The influence of the factors Curve and Acceleration can not be proven using the data.
- All coefficients of X'B are negative, meaning that that whatever the probability being calculated, Pr(Accuracy=Bad),.., Pr(Accuracy=excellent), this probability decreases if any of the factors is increased.

10. AGEING FACTORS

10.1 Introduction

The quality of collected WIM-data from a given site is not stable in time, due to evolution of some critical parameters. The lay-out of the site will generally not change during lifetime of a WIM-system. The road manager should take care that, if modifications are applied, it is reported to the WIM-site operator. Modification in the site lay out, like lane width, obstacles and visual obstacles, but also speed limits etc. could (should) change the behaviour of drivers and can effect in measuring results. For the WIM-site manager information in relevant to attribute slight changes in measuring results to these modifications.

The pavement parameters such as evenness, rutting and, sometimes deflection, will evaluate in time, depending on traffic, climate (temp). As explained in chapter 7 the direct effect of the different parameters on the accuracy and quality of WIIM-measurements is not yet very known. To introduce ageing factors of these parameters is one step further. In this chapter a short introduction to this issue is presented; qualification of these effects is not possible in this stage.

10.2 Sensors

Some type of sensors are more sensitive to ageing than others. The sensibility of capacitive weighing mats will decrease in time due to hardening of the isolators between the metal plates. For piëzo-cables a similar phenomena is known. In general a solution for this effect is tuning the amplifiers or modifying calibration factors. These kind of effect are hardly to be taken into account in a QA-system as described in this report.

10.3 Pavement

For pavement parameters the expected deterioration can be taken into account. From the parameters mentioned in chapter 7 such as the type of pavement, the location, the climate and the traffic a raw indication could be estimated for example of the rutting after several years. Such a raw indication can is only used to decrease the expected quality of data when no actual information is available

11. IMPLEMENTATION AND DISSEMINATION PLAN

During the process of the WAVE project in became clear that quality assurance of WIM systems is a subject that in some countries is in the initiating phase. The goals set in the Work Package description had to be adjusted due to the stage of development of quality assurance found during the inventory. The contractors contributing to WP2 had to go back to de basic principles of WIM in order to define critical factors and environmental impacts. This process, however very useful, led to an initial quality system that should be updated regularly when more and more information becomes available in the European database. In accordance with the above mentioned the implementation and dissemination plan of results from WP2 concentrates on two subjects:

- to present the values and benefits of a centralised WIM-database for Europe by means of statistics about traffic and goods transport, infrastructure loading.
- to inform (potential) users of WIM-information about the necessity of quality assurance and standardisation of statistics for European coverage of information.

The database developed under the COST-323 action and the QA-procedures as described in this report will be used as demonstration facility. Organisms like Eurostat, providing a.o. statistics on transport in Europe, and FEHRL (Federation of European Highway Research Laboratories) are potentially interested, however, did not show direct involvement in financial funding at this stage. In this process the ongoing implementation of WIM-systems in a lot of European countries (Germany, England, Netherlands, Hungary, Switzerland, Austria) the benefits of QA-procedures become more and more obvious. In order to realise a European WIM-database a lot of technical and financial problems remain to be solved. In order to design a cost-effective European data-acquisition system the infrastructure on national level have to be ready to be connected to such a system.

The internet technology now available will be used more and more to connect databases an to exchange data(information). A marketing action is required in order to investigate the accessibility of existing WIM-databases in Europe by means of this technology

12. LIST OF DELIVERABLES.

No.	DELIVERABLES	Access
1	Reports on data quality assurance (WP2.1) - *in progress reports of WAVE (, proceedings of the ICWIM2 (Lisbon, 1998) conference, of the mid-term and Final Symposium of Wave proceedings (Paris, 1999)*	Public
2	Report on database (WP2.2.) - *in the Final Symposium o WAVE proceedings (Paris, 1999) and the final report of the WP2*	Public
3	Quantifying WIM Measurement Accuracy - report in co-operation with third party: CQM (project report no: E1650-2)	Public

13. CONCLUSIONS AND RECOMMENDATIONS.

The work planned in WP 2 of the WAVE project, the development of a Data Quality Assurance system for a European WIM-database was not completely realised within the scope of the project.

After inventory of existing WIM-data quality systems the conclusion was that, besides general checks on statistical data and coherence tests, no technology or procedures are operational for quality assurance of WIM-data. Also WIM-accuracy influence factors are generally not recorded.

With this background, the main influence factors were inventoried and discussed, in order to design a quality assurance system for a pan-European WIM-database, that is capable of labelling data files with a quality-mark, independent to the supplier.

Recording influence factors by the local authorities maintaining the WIM-system(s) is the minimum support required to enable a centralised quality assurance system.

It is therefore strongly recommended to record this information.

The performance of a WIM-system in terms of accuracy can be divided in two items, the bias an the standard deviation. For these items respectively the calibration method and the external influence factors the dominant subjects.

For the qualification of influence factors can be concluded that relation between evenness an dynamic impact force is a relative well known phenomena with a direct impact on the measurement accuracy (i.e. the standard deviation). For other factors (f.e. climate) only some general ideas are available. These factors should be recorded as recommended before. Due to the complex relations between the different factors and types of WIM-systems designing a scientific based QA-system is not possible within the state of the art of WIM in Europe.

An alternative method was introduced, using experts opinions by means of an experimental method. It can be concluded that such a system, even with relatively little response of experts, is useful. The design of the used questionnaire is critical.

The calibration procedure is the main factor concerning the (possible) bias in a WIM-system. The qualification procedure for calibration procedures is prepared, also taking into account the results of WP3.2 (Calibration of WIM-systems).

The proposed procedures for qualifying WIM-accuracy can be used as a basis for the European WIM-database. Recording of the main influence factors is required to improve the system and therewith its performance.

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15. LIST OF FIGURES AND TABLES

Figures

Tables