COST 323
”Weigh-in-Motion of Road Vehicles”

Final Report

APPENDIX 1
European WIM Specification

Version 3.0, August 1999

1. FOREWORD

The COST 323 Management Committee and the contributors to this document have carefully collected the information and data published herein, in accordance with the latest scientific and technical principles. Nevertheless the editorial staff disclaim all liability on their part for any injury which may result from use of the data and information published herein.

This document does not constitute an official standard but provides a reference upon which standardisation committees can draw if they choose, and technical specifications for WIM users and manufacturers. They may both refer to these specifications. The document specifies WIM systems in general, but does not specify products. In its final stage, this specification will constitute a pre-standard to be submitted to the CEN to assist in the preparation of an European Standard on WIM.

This document combines requirements or general clauses (numbered in bold), with some more informative explanations and examples, particularly in the field of statistics, to clarify or help with the implementation of the specifications. In order to distinguish them, the informative paragraphs are marked with a bar in the margin. They may be considered as parts of a "Handbook on WIM".

The contributions and remarks of the European WIM manufacturers were taken into account, and this specification was used for the evaluation of WIM systems by testing carried out by the COST 323 action.

These recommendations were developed such as to be widely independent on the technology and products (e.g. the type of sensor or electronics of the WIM system considered). They are expected to evolve with time, and future revisions may be done if needed.

The appendix I provides the simplified requirements of practical use for common users. Only the main clauses are presented; references are made to the detailed specification. It may be read before the detailed specification. That is recommended for the practitioners.

The scientific background used in this specification is presented in (B. Jacob, 1997).

Keywords

Traffic loads, Pavement conditions, Vehicle loads, Gross weight, Axle loads, Weigh-In-Motion, WIM Sensors, WIM Systems, Calibration, WIM data/system acceptance, Traffic data, WIM Specification, WIM Standard.

2. CONTEXT, SCOPE AND OBJECTIVES

This document has been produced by the COST 323 Management Committee, as part of the COST Transport Action "WIM-LOAD". It gives general and detailed recommendations for site selection, installation, operation, calibration and assessment by testing of WIM systems. It is based on COST 323 member countries and US experience ((NIST Handbook 44, 1995), (R. Gillmann, 1992), (TRL, 1994)), and existing national specifications (METT-LCPC, 1993) and (NWML, 1995)). However there are currently only a few specification documents and no official standard on WIM in Europe. Moreover, the existing US standard on WIM (ASTM, 1994) is mainly designed for model approval, or to indicate the potential upper limit of performance which can be achieved by the particular type of system as the road surface conditions shall be the best available for conducting the acceptance test. The main objective of this document is to cover the need for a complete specification, covering both aspects: (1) model approval and (2) on site acceptance test and accuracy assessment, pending the publication of an official European Standard produced by the CEN. It also provides a technical basis for such a standard. Therefore this is a "pre-standardisation document".

2.1. This specification meets the user's requirements, and should facilitate the relationships between manufacturers or suppliers and customers. The requirements of accuracy for the different applications are based on the ***Requirements and Needs of Road Vehicles WIM in Europe*** published by the COST 323 Management Committee.

Even if in some situations, particularly for legal purposes, lorry weighing is currently limited to the use of static scales, in many European countries and for multiple applications, Weigh-In-Motion (WIM) systems are routinely or experimentally used. Therefore common specifications are useful to check the real performance of WIM systems and to organise such trials. Moreover, the use of WIM systems for legal enforcement purposes is expected to become a main challenge in a near future, and will require a strong legal and standardised basis.

2.2. This specification may be referenced or used to draft any general or particular specifications, for any call for tender, and to analyse performance or acceptance test data of WIM systems. They apply to fixed WIM stations as well as to portable WIM stations.

2.3. This specification mainly concerns "HS-WIM" (High Speed WIM) systems, i.e. systems installed on one or more traffic lane(s) of a road, and operated automatically under normal traffic conditions. However, it may also be applied to "LS-WIM" (Low Speed WIM) systems, i.e. systems installed in a specific weighing area, outside of the traffic lane(s), on which the vehicles to be weighed are diverted by a competent authority (such as police); these systems are also automatically operated, but the speed is limited (max. 5 to 20 km/h in general) and the travelling conditions of the vehicles are controlled.

2.4. This specification deals with on-site full WIM system performance assessment and model (type) approval, but excludes laboratory (product) tests or parts of system performances (e.g. sensors only). That would be the objective of product standards.

2.5. The scope of this specification covers all the WIM needs presented in (COST 323, 1997a), except trade purpose for which the OIML (International Organisation for Legal Metrology) recommendation should be used. For load enforcement of road vehicles, one or the other may be applied, depending on the national requirements and legislation.

3. TERMINOLOGY

The main terms used in this document are listed here. Some additional terms used in this document are defined in the ***Glossary of terms***, containing a common multilingual terminology, and published by the COST 323 Management Committee (COST 323, 1998b). Some additional detailed definitions on the accuracy of WIM systems as well as mathematical and statistical principles used, are presented in (B. Jacob, 1997).

- **Accuracy class:** class of measuring instruments (in its environment) that meet certain metrological requirements that are intended to keep errors within specified limits.
- **Accuracy of a measurement:** closeness of agreement between a measured value and a (true) value accepted as a reference value.
- **Axle:** an axle comprises two or more wheel assemblies with centres lying approximately on a common axis oriented transversely to the nominal direction of motion of the vehicle.
- **Axle group load:** the total load of all wheels included in a group of axles
- **Axle of a group:** one axle of a vehicle that belongs to a group of axles.
- **Axle load:** sum of all the wheel loads of an axle of a vehicle.
- **Axle load scale (Axle load weigher):** a device which measures the combined wheel loads on an axle, tandem axle or tridem axle, at once.
- **Bending plate:** plate instrumented with strain gauges and placed under wheels or axles to measure their static or dynamic tyre forces.
- **Bridge WIM:** WIM using an instrumented bridge as a large sensor; the strains measured in some of the bridge elements are used to determine through software the gross weights and axle loads of vehicles crossing the bridge.
- **Calibration:** adjustment to a reference level of values from any measuring device.
- **Capacitive mat or strip:** a mat or strip sensor which measures an applied force by the variation in capacitance (dielectric coefficient) of isolated plates.
- **Calibration factor:** numerical factor by which the raw result of a measurement is multiplied to compensate for systematic error.
- **Coefficient of variation:** ratio of the standard deviation to the mean.
- **Confidence interval:** interval which contains the true value of a parameter represented by a random variable, with a given probability.
- **Confidence level:** probability that an interval contains the true value of a parameter represented by a random variable.

- **Dynamic vehicle tyre force:** the component of the time-varying force applied perpendicularly to the road surface by the tyre(s) on a wheel of a moving vehicle.

In addition to the force of gravity, this force can include the dynamic effects of influences such as road surface roughness, vehicle acceleration, out-of-round tyres, dynamically unbalanced wheels or tyres, tyre inflation pressure, vehicle suspension and aerodynamic features and wind. For purposes of this specification, the WIM system shall be adjusted or calibrated to indicate the magnitude of the vertically downward, measured dynamic vehicle tyre force in units of mass (kilograms, kg or megagrams, Mg). The indicated mass can be converted to units of force by multiplying it by the local value of acceleration of free fall, if it is known.

- **Error:** difference between a measured value and the true value or the accepted reference value (relative and absolute errors).

- **Fibre optic sensor:** strip sensor incorporating an optic fibre; the fibre bending resulting from an applied force (by the tyres on a wheel or an axle) modifies the light propagation conditions; the applied force may be derived from this modification.

- **Gross weight (GW):** a force due only to the external force of gravity acting vertically downward on the total mass of a vehicle, including all connected components; its magnitude is the total vehicle mass multiplied by the local value of the acceleration of free fall.

The force of gravity – thus, the acceleration of free fall – is different at various locations on or near the surface of Earth; therefore, weighing devices in commercial use or in official use by government agencies for enforcement of traffic and highway laws or collecting statistical information are usually used in one locality and are adjusted or calibrated to indicate mass at that locality. The indicated mass can be converted to weight (in units of force) by multiplying by the local value of acceleration of free fall, if it is known. For purposes of this specification, - and in accordance with common weighing practice – the WIM system shall be adjusted or calibrated to indicate the magnitude of estimated weight and load in units of mass (kilograms, kg or megagrams, Mg), and the direction of the associated force vector will always be downwards toward the approximate centre of Earth.

- **Group of axles:** set a set of axles on the same vehicle, defined by the total number of axles included in the group (linked by a common suspension) and their respective interspaces. In Europe, without standardised definition of an axle group based on axle spacing, the geometrical criterion to identify a group of axles by road sensor(s) is that the centres of axles (wheelbase) are spaced less than 2.2 m each from the next one.

- **High Speed WIM (HS-WIM):** weighing vehicles in motion in the traffic flow, at speeds up to 130 km/h.

- **Impact force:** a measured force applied to the pavement by a moving vehicle's tyre(s) (the different tyre forces of a vehicle may be measured at the same time or at the same place). For purposes of this specification, the WIM system shall be adjusted or calibrated to indicate the magnitude of the vertically downward, measured dynamic vehicle tyre force in units of mass (kilograms, kg or megagrams, Mg). The indicated mass can be converted to units of force by multiplying it by the local value of acceleration of free fall, if it is known.

- **Impact factor:** the ratio of the impact force to the corresponding wheel/axle load(s) or gross weight of the stationary vehicle.
- **Load cell:** a device that produces a signal proportional to the load applied to it.
- **Low Speed WIM (LS-WIM):** weighing a slowly moving vehicle, usually on a specific area outside the traffic flow, on a horizontal, straight and even pavement surface under controlled conditions, such as constant and low speed (e.g. 5 to 15 km/h) in order to minimise dynamic effects.
- **Magnetic (or inductive) loop:** insulated copperwire cable buried in the pavement or bonded on the pavement surface, used for vehicle presence detection.
- **Mean (arithmetic); average:** first moment of a (sample) distribution; sum of the values of a sample divided by the number of values.
- **Outlier(s):** value(s) in a series of homogeneous data which has(ve) a much lower probability of occurence than expected according to the sample size and distribution; an outlier is suspected of being an erroneous measurement, and may be eliminated under certain conditions.
- **Performance test:** a test to determine whether an equipment is capable of performing its specified functions; if it is made just after the initial installation or after an important repair, it is called an on-site **acceptance test**.
- **Piezo-electric cable:** a coaxial cable containing a piezo-electric substance, which converts an applied strain or pressure into an electrical signal which is related to the magnitude and direction of the applied strain or pressure. A **piezo-electric sensor** is a strip sensor containing a piezo-electric cable; it may be of two types: **piezo-ceramic sensors** and **piezo-polymer sensors**. A **piezo-quartz sensor** is a strip sensor which uses piezo-electric crystal quartz.
- **Piezo-resistive sensor:** a sensor which indicates the magnitude of an applied force through a variation in its electrical resistance.
- **Range:** the whole interval extent on which a parameter measurement is valid with a given system.
- **Repeatability:** closeness of the agreement between the results of successive measurements of the same variable carried out under the same conditions (called repeatability conditions) - same procedure, same observer, same instrument in same conditions, same location, repetition over a short period of time, homogeneous with respect to the environmental conditions.
- **Reproducibility:** closeness of the agreement between the results of measurements of the same variable carried out by similar instruments under different conditions (called reproducibility conditions) – e.g., several observers, instruments, locations, times.
- **Resolution:** the smallest value of a measured parameter that a measuring device is able to discriminate within the measuring range.

- **Sensor:** part of a measuring instrument or chain that is directly affected by the parameter to be measured and produces a related signal.
- **Single axle:** axle spaced by 2.2 meters or more from the nearest neighbour axle of a vehicle.
- **Standard deviation:** positive square root of the variance (characterises the scattering of a sample of data).
- **Strip sensor:** sensor installed across the road, with an extent equal either to the lane width or half a lane width, and a longitudinal extent (in the traffic direction) of a few centimetres, but smaller than a tyre imprint length. Therefore if used as a weighing sensor, the signal must be integrated during the time where the tyre applies a pressure on it.
- **Tandem axle:** group of two axles, with a wheelbase less than 2.2 m.
- **Tolerance:** width of a confidence interval (δ) in which an error remains with a specified or required confidence level.
- **Tridem axle:** group of three axles, with wheelbases less than 2.2 m.
- **Variance:** centred second moment of a (sample) distribution, which characterises the scattering of this distribution.
- **Weigh-bridge:** a weighing device which measures the complete stationary vehicle weight at once (generally approved for legal weighing and thus suitable for generating gross weight reference values).
- **Weigh-In-Motion (WIM):** process of estimating the weight of a moving vehicle, and the portion of that weight that is carried by each of its wheels or axles, by measurement and analysis of dynamic vehicle tyre forces.
- **Weigh-In-Motion system (station):** set of mounted sensor(s) and electronics with software which measures dynamic vehicle tyre forces and vehicle presence of a moving vehicle with respect to time and provides data for calculating wheel and/or axle loads and gross weights, as well as other parameters such as speed, axle spacing, silhouettes, etc.
- **Wheel load:** the portion of the gross weight imposed upon the weighing device by the tyre(s) of a stationary wheel at the time of weighing, expressed in units of mass (kilograms, kg or megagrams, Mg), due only to the vertically downward force of gravity acting on the mass of the static vehicle.

Units

The SI recommends to express forces in N and kN (for large values), and masses in kg and Mg (for large values). 1 Mg=1000 kg (also a metric ton). The use of ton is depreciated in scientific use, while still mostly used by engineers, police, lawyers, road authorities and in most of the laws.

Because this specification is mainly for practical use, only the mass units will be used, either kg pr ton (1t=1Mg). When forces are considered, the ratio to the corresponding mass is 9.81 N/kg.

4. USER AND PERFORMANCE REQUIREMENTS

4.1. The clauses of this document should be applied to specify and check the performance and accuracy of any WIM system in its environment. It contains definitions and criteria of acceptance.

4.2. The WIM systems are classified in six accuracy classes, each of them corresponding to a range of applications or requirements. Additional classes are given for systems which do not meet the main classes.

4.3. The accuracy is mostly referred to the weights and static loads, i.e; for weighing purposes, and rarely to the real tyre impact forces applied by the wheels/axles on the pavement and on the WIM sensors, such as for technical studies on pavement and vehicles. The distinction must be clearly specified in writing, case by case. In the first alternative, it is recommended to specify how the static loads and weights are obtained, and especially the issue of the static axle loads. In the second alternative, the means to obtain the reference values of the impact forces must be specified.

For practical reasons but also according to the most frequent requirement, reference to the static loads/weights may be assumed unless another reference value is specified.

Both of these references raise some difficult questions and issues, as mentioned in (B. Jacob, 1997).

The accuracy of a WIM system in its conditions of use, i.e., under moving traffic tyre loads, may only be defined in a statistical way (B. Jacob, 1997), by a confidence interval of the relative error of a unit (an axle, an axle group or a gross weight), defined by: $(Wd\text{-}Ws)/Ws$, where Wd is the impact force or dynamic load measured by the WIM system and Ws the corresponding static load/weight (or any other specified reference value) of the same unit. Such a confidence interval centred on the static load/weight, is noted: $[-\delta;+\delta]$, where δ is the tolerance for a confidence level π (for example 90 or 95%).

Even for systems supporting the traditional definition of accuracy (OIML, 1996), weighing statically is not representative of real conditions of WIM system use.

4.4. According to (COST 323, 1997a), the main requirements and applications of WIM may be classified with respect to the statistical accuracy as summarised below with increasing levels of accuracy:

1. Statistics: Economical and technical studies of freight transport, general traffic evaluation on roads and bridges, collecting statistical data, etc..
δ up to of 20 to 30% (class D+(20), or D (25))

2. Infrastructure and preselection: Detailed analysis of traffic, design and maintenance of roads and bridges, accurate classification of vehicles, preselection for enforcement, etc..
δ up to of 10 to 15 - 20% (class B (10), or C (15))

3. Legal purposes: Enforcement and industrial applications, but only if the legislation allows the use of WIM for that purpose. Currently static weighing or LS-WIM are required for these applications; but some development is going on to increase the possibilities of HS-WIM for legal purposes.
δ up to of 5 to 10% (class A (5), or B+ (7))

These figures are only given here as an indication; each user can define his own requirements for his particular application. Moreover the requirements depend on the environmental and road conditions. The chapter 8 specifies which figure apply to each entity (gross, axle, etc.).

Any level of accuracy not only refers to the performance of the WIM system used (i.e., the sensor(s) and electronic station with its software), but also to the calibration procedure and frequency, , to pavement/road quality and evenness and vehicle behaviour.

The confidence π in the accuracy level δ (the confidence interval width) of a WIM system depends greatly on the conditions of measurement, that means principally the repeatability or reproducibility conditions of the sample measured, the environmental repeatability or reproducibility conditions and on the sample size and content (types of vehicles).

4.5. Choice of an accuracy class with respect to the application

Different needs may lead to different accuracy requirements with respect to the weights. The following requirements are given unless otherwise stated by the customer:

Class A (5): legal purposes such as enforcement of legal weight limits and other particular needs; to provide reference weight values for in-service checks, if the classes B(10), C(15), D+(20) or D(25) are required for all the traffic flow vehicles (assuming that it is not possible weigh in static such a large population);

Class B+ (7): enforcement of legal weight limits in particular cases, if the class A requirements may not be satisfied, and with a special agreement of the legal authorities; efficient preselection of overloaded axles or vehicles; to provide reference values for in-service checks, if the classes C(15), D+(20) or D(25) are required for all the traffic flow vehicles (assuming that it is not possible weigh in static such a large population);

Class B (10): Accurate knowledge of weights by axles or axle groups, and gross weights, for:

- infrastructure (pavement and bridge) design, maintenance or evaluation, such as aggressiveness evaluation, fatigue damage and lifetime calculations,
- preselection of overloaded axles or vehicles,
- vehicle identification based on the loads.

Classes C (15) or D+(20): Detailed statistical studies, determination of load histograms with class width of one or two tonnes, and accurate classification of vehicles based on the loads; infrastructure studies and fatigue assessments.

Class D (25): Weight indications required for statistical purposes, economical and technical studies, standard classification of vehicles according to wide weight classes (e.g. by 5 t).

Additional **classes E(30)**, **E(35), etc.**, are defined for WIM systems which do not meet the class D(25) requirements. These classes are specified in the chapter 8, to assess the accuracy of rough systems or of systems installed on poor WIM sites. However, they may be useful to give indications about the traffic composition and the load distribution and frequency.

5. CRITERIA FOR THE CHOICE OF WIM-SITES

The WIM site characteristics have some influence on the in-motion vehicle behaviour and may lead to large discrepancies between the axle impact forces and the corresponding static loads. Therefore the specified criteria about the road geometry and the pavement characteristics are given in order to reduce these discrepancies and to keep them within some limits in accordance with the required accuracy levels.

The accuracy of a bridge WIM system also depends highly on the selection of the weighing site, particularly on the type of the superstructure and the evenness of the approach.

However these criteria, and above all those relating to the pavement profile, are mainly given as indicative, because only the specified WIM system performance (e.g. accuracy and durability) is mandatory. If some systems, as a result of their principal or intrinsic nature, may tolerate weaker criteria and meet the accuracy and durability requirements - that should be proven by testing -, then they may be installed on other sites than those hereafter specified.

5.1 Road Geometry

5.1.1. It is strongly recommended that road section between 50 m upstream and 25 m downstream of the system meets the following geometrical characteristics:

- longitudinal slope < 1% (class I site) or < 2% (other site classes), depending on the site class (see 5.2.2) and as far as possible constant;
- transverse slope < 3%;
- radius of curvature > 1000 m (but a straight road would be preferred).

5.1.2. The WIM systems should be installed away from any area of acceleration or deceleration, (i.e. close to a traffic light, toll station, etc.), in order to weigh vehicles travelling at uniform speed. It is also desirable to avoid the area where drivers make gear changes, such as slip-roads, etc.

5.1.3. It is also desirable to avoid areas where the number of lanes changes as this can lead to vehicles changing lane at the site.

5.2 Pavement Characteristics

The pavement characteristics directly influence the signal recorded by any WIM sensor, because of:

- the pavement/vehicle interaction leading to dynamic impact forces,
- in most cases, the road is the support for the sensor and therefore forms part of the measurement device.

Thus not only the longitudinal evenness but also deterioration (such as rutting, deformation, etc.) limit the accuracy of the measurements, while cracking may reduce the WIM sensor durability or affect its response. The deflection and the transverse evenness may also affect the reliability and durability of the sensors.

5.2.1. Three WIM site classes are proposed, more or less with respect to the three application categories mentioned in chapter 4. The criteria for rutting, deflection and evenness are given in Table 1. For more details about the different types of pavements, see (COST 324, 1995).

Table 1: Classification and criteria of WIM sites

			WIM site classes		
			I Excellent	**II Good**	**III Acceptable**
Rutting (3 m - beam)		Rut depth max. (mm)	≤ 4	≤ 7	≤ 10
Deflection (quasi-static) (13 t - axle)	Semi-rigid Pavements	Mean deflection (10^{-2} mm) Left/Right difference (10^{-2} mm)	≤ 15 ± 3	≤ 20 ± 5	≤ 30 ± 10
	All bitumen Pavements	Mean deflection (10^{-2} mm) Left/Right difference (10^{-2} mm)	≤ 20 ± 4	≤ 35 ± 8	≤ 50 ± 12
	Flexible Pavements	Mean deflection (10^{-2} mm) Left/Right difference (10^{-2} mm)	≤ 30 ± 7	≤ 50 ± 10	≤ 75 ± 15
Deflection (dynamic) (5 t - load)	Semi-rigid Pavements	Deflection (10^{-2} mm) Left/Right difference (10^{-2} mm)	≤ 10 ± 2	≤ 15 ± 4	≤ 20 ± 7
	All bitumen Pavements	Mean deflection (10^{-2} mm) Left/Right difference (10^{-2} mm)	≤ 15 ± 3	≤ 25 ± 6	≤ 35 ± 9
	Flexible Pavements	Mean Deflection (10^{-2} mm) Left/Right difference (10^{-2} mm)	≤ 20 ± 5	≤ 35 ± 7	≤ 55 ± 10
Evenness	IRI index	Index (m/km)	0 - 1.3	1.3 - 2.6	2.6 - 4
	APL(1)	Rating* (SW, MW, LW)	9 - 10	7 - 8	5 - 6

The rutting and deflection values are given for a temperature below or equal to 20°C and suitable drainage conditions.

(1) *The APL is a device developed in France and in use in various countries, which measures the longitudinal profile; it consists of two single wheel trailers operating at 72 km/h, towed by a car.*

* *the rating quantifies the logarithm of the energy dissipated in one of the wavelength ranges:* SW = *Small Wave-lengths (0.7-2.8 m)*, MW = *Medium Wavelengths (2.8-11.3 m)*, LW = *Large Wavelengths (11.3-45.2 m). The scale is from 10 (lowest energy, excellent evenness) to 1 (highest energy, poorest pavement surface).*

<u>Comments about the deflection</u>:

(i) The deflection criteria are not applicable to concrete pavements (for such pavements, the values should be much smaller than the limits proposed...). Nevertheless for concrete slab pavement, the slab banging motion should be limited to 0.05 mm for sites in class I and to 0.10 mm for sites in classes II and III.

(ii) For granular pavements (pavements in which the granular layer provides the structural strength of the pavement) the deflection values will be much higher. For this type of pavements special care should be taken by the choice of the mounting method and materials.

(iii) The quasi-static deflection is measured using a Deflectograph (long chassis) with a 13 t axle load at 2 to 3.5 km/h; a linear correction may be done for other axle loads. The measuring procedure is as follows: the left and right wheel paths are measured every 4.2 m; the largest of the two values is taken; then the mean is calculated along a section of 200 m (the WIM sensor being in the middle). The difference between the left and right values should not exceed the figures given in the Table 1 at any distance less than 4.2 m from the WIM sensor(s).

(iv) The dynamic deflection limits are based on FWD measurements, using a Dynatest 8000, with a test load of 5 t, and a reference temperature of 20°C. A linear correction may be made for other loads. It is recommended to make at least three measurements in each wheel path for the section considered, and to apply the same procedure as in (iii) to calculate a mean deflection.

Finally, it should be recalled that the deflection affects the durability of the sensors, while the left/right difference may limit the accuracy of the measurements.

<u>Comment about the evenness:</u>

The measured evenness in terms of ratings at 200 m intervals is sufficient for screening sites; it is however necessary to consider more carefully the exact area of installation within the 200 m so as to avoid a single point having poor evenness:

- for class I and II sites, by accurate-scale operation,
- for a class III site, using the 3 m beam.

5.2.2. The pavements should also meet the following criteria:

- no hard spots in the underlying courses or under the wearing course (toll slabs, service tunnels, etc.);
- thickness of bonded layers greater than 10 cm;

- good mechanical bonding between courses, in particular of bituminous concrete on granular materials stabilised by hydraulic binders. The sensors must be installed in homogeneous layers, not in a joint;
- surfacing should be deterioration-free in the area of sensor installation;
- pavement homogeneous across each traffic lane, ruling out the presence of joints of coated materials in the length of a sensor.

5.2.3. The recommended site class/WIM system accuracy pairings are given in Table 2.

Table 2: Choice of a WIM site according to the accuracy required

Accuracy	site I (Excellent)	site II (Good)	site III (Acceptable)
Class A (5)	+	-	-
Class B+ (7)	+	-	-
Class B (10)	+	+	-
Class C (15)	(+)	+	+
Class D+ (20)	(+)	(+)	+
Class D (25)	(+)	(+)	+

legend: '-' *means insufficient,* '+' *means sufficient,* '(+)' *means sufficient but not necessary*

Comment: This table does not give a strict relationship between the accuracy classes and the test site: some types of WIM systems - depending on the type of sensor and the measurement principle - may require higher or lower site classes to meet the same accuracy level. For example, large scales or large-based sensors (i.e. longer than the tyre imprint in the direction of the traffic flow) are less sensitive to the pavement evenness than are narrow-based sensors. Moreover multiple-sensor WIM systems may be installed in pavements with poorer evenness, if a suitable algorithm performs calculations to reduce the dynamic effects.

5.3 Particular Requirements for Bridges

5.3.1. The basic bridge selection criteria recommended are summarised in Table 3.

Accuracy of the bridge WIM results is strongly related to the number of trucks (axles) which drive over those parts of the bridge which influence the structure at the same time (one truck at a time gives best results). Therefore the length of the structure and the traffic density have to be judged together (the more dense the traffic, the shorter is the optimal length of the structure).

If the influence line is used in the weight assessment algorithm, an influence line based on actual strain readings can improve the accuracy of calculation. This is particularly important when a continuous bridge is instrumented. With this type of structure it is also essential that all the spans which considerably influence the behaviour of the instrumented span (where the strains of the superstructure are measured) are taken into account.

Table 3: Bridge selection criteria

Criteria	Optimal	Acceptable
bridge type	steel girders, prestressed concrete girders, reinforced concrete girders, culvert, steel orthotropic decks (1)	concrete slab
span length (2) (3)(m)	5 - 15	8 - 35
traffic density	free traffic - no congestion (traffic jam)	
evenness of the pavement before and on the bridge	class I or II (Table 1)	class III (Table 1)
skew (°)	≤ 10	≤ 25 ≤ 45 (*)

(1) expected to be optimal, research work in progress in 'WAVE'

(2) this criterion applies for the length of the bridge part which influences the instrumentation

(3) except culverts

(*) after inspection of calibration data

5.3.2. To provide accurate velocity information for the vehicles, which is an important parameter in the weight evaluation algorithm, the position of the axle detectors must be measured very carefully.

5.3.3. Braking or accelerating of vehicles on the structure due to junctions close to the site or any other reason must be avoided since non-constant speed over the structure significantly decreases the accuracy of the calculated weights.

5.3.4. Axle detectors have to provide reliable information in any weather condition. If removable axle detectors are used, special attention is to be paid to their mounting on the surface of the pavement.

5.3.5. Culverts (J.I. Brown and R.J. Peters, 1988) should be single span, precast and uncracked. A concrete box with a simply supported lid is optimal but an integral box or a steel or concrete pipe is acceptable. The ideal span is 1.2 to 2.7 m but spans of 2.7 to 4.8 m are acceptable. The ideal thickness of pavement over culvert is 0.5 to 1.0 m but a thickness in the range 0.2 to 2.0 m is acceptable.

6. ENVIRONMENTAL REQUIREMENTS

Most of the suppliers of WIM devices specify some environmental requirements for the use of their equipment. These requirements usually meet some existing standardised criteria, either for civil or military electronic devices. The following criteria are given to provide a common framework or to detail some requirements more specific to WIM sensors. They may be adapted by each customer with respect to the particular conditions of the WIM site chosen.

These requirements mainly concern the climatic conditions, but also deal with the traffic conditions and the facilities needed to install and operate the WIM systems.

6.1 Sensors

6.1.1 Climatic Conditions

6.1.1.1. The sensor must operate properly in an ambient temperature in the range of: -20°C - +60°C.

For sensors which are supported by the pavement (such as strip sensors), the pavement modulus may have a strong influence on the sensor response; this is especially the case for bituminous pavements. Bituminous pavement modulus varies by orders of magnitude with the temperature. Some indicative figures are given in Table 4.

Table 4: Variation of the pavement modulus (bituminous material) with temperature

Temperature	- 15 °C	0 °C	15 °C	30 °C
Scale factor of the pavement modulus	10	8	5	1

This phenomenon may affect both the accuracy of the WIM system and the durability of the sensors. The system should take it into account.

6.1.1.2. Salt and water ingress: the sensors must be insensitive to water and salt exposure (in areas where snowfalls and/or ice may occur). If the pavement is not well drained, the deflection may increase after rainfall.

6.1.2 Traffic Conditions and Mechanical Resistance

6.1.2.1. The sensors must survive if they are crossed by tanks (up to 60 t) and other tracked vehicles, or by a deflated tyre. In cold climate areas, the sensors must also survive under studded tyres and snow-clearing devices. This requirement may be more flexible for portable systems used temporarily over short time periods.

6.1.2.2. More generally, the sensors must always remain fixed in the pavement or in the road under heavy traffic flow, until their removal or the pavement replacement, for safety reasons. This particularly concerns portable WIM sensors and sensors glued or attached to the pavement surface.

6.2 Electronics

6.2.1. The electronic devices and components must operate in the temperature range: - 20°C - + 60°C. It should be noticed that the upper value may be reached with an ambient temperature of 30 to 35 °C, in the absence of a cooling device.

6.2.2. Relative humidity in the range of 0 to 90% (not condensing) must be supported.

6.2.3. The electronics must be protected against lightning as well as against any external electrical or magnetic field. This may also apply for some types of sensor.

6.2.4. It is recommended that systems should not be installed under high voltage power line, or close to radio transmitting and railways tracks.

6.3 Facilities and Other

6.3.1. The availability of some additional facilities on the WIM site is generally recommended. We may mention:

- electricity supply for sensor installation and WIM system operation (an alternative solution commonly used in sunny climates is the use of solar cells),
- communication link (such as telephone line or other) to connect the WIM station if it is to be remotely monitored and for data collection,
- road side cabinet to protect the WIM station against rainfall, snowfall, sunshine, vandalism, etc..

6.3.2. For calibration and testing purposes, it is recommended to have a static weighing area or a static scale close to the WIM site. A preferable site should allow for a reasonable run time for a calibration or test vehicle to perform a complete loop of the WIM site.

6.3.3. For maintenance and checking it is recommended to have a parking lot close to the system.

6.3.4. It is important to avoid any overpass (aerodynamic effects) or bridge approach (poor evenness).

6.3.5. It is not recommended to install road sensors on a bridge or on any structure subject to dynamic effects.

7. ON-SITE SYSTEM CHECKS AND CALIBRATION

7.1 General Recommendations

7.1.1. After installation and general checking, an initial calibration must be performed before an operational use of any WIM system. The accuracy of WIM data depends greatly on the calibration procedure of the WIM system.

A general statistical procedure for calibration and further checking of WIM systems, with respect to the statistical accuracy and classes is described in (B. Jacob, 1997).

7.1.2. Before the on-site calibration, it is recommended to check by sampling, the expected performance of sensors and electronics. Checking methods have been developed in some countries or are proposed by the vendors, depending on the sensor technology. Some indications are given in the Appendix II.

7.1.3. The purpose of the WIM system and its application should guide the selection of a calibration method. The reference values used for calibration must be chosen accordingly.

It is important to note that a WIM system measures instantaneous impact forces, and only estimates weights. WIM data deviations from weights could be considered both as measurement errors and as those resulting from dynamic effects.

7.1.3.1. If the WIM data are used to estimate weights and static loads (the most common case), it is required to minimise the differences (bias) between WIM and weight data. Therefore, the reference values should be either total vehicle weights or static axle loads (or both). The accuracy of these reference values should be in agreement with the expected accuracy of the WIM system to be calibrated, according to the general metrological requirements (see also 8.3).

7.1.3.2. If the WIM data are used to provide instantaneous impact forces, the reference values should be the “true” impact forces applied by the wheels or axles when they hit the WIM sensors.

These “true impact forces” are generally not easy to measure accurately with a perfect synchronisation with the WIM; however, some techniques were developed, using either shock or pressure devices (see 7.2.2), or instrumented vehicles (see 7.2.4).

7.1.4. The temperature (ambient or of the pavement) should be recorded throughout all the calibration procedure. The sensitivity of the WIM system to temperature variations should be checked.

The calibration is assumed to be over during a short time period, such as one or two consecutive days, except for automatic self-calibration (see 7.2.5).

7.1.5. It is recommended to check regularly the accuracy of an operational WIM system, e.g., once or twice a year (in-service calibration or calibration check). For a newly installed WIM system, it is recommended to carry out some check(s) during the first two or three month period of use. Calibration checks may be carried out using the same methods than for an initial calibration (see 7.2 and Appendix III), but with less reference values or test vehicles and runs.

7.2 Calibration Methods

Different calibration methods are commonly used, which depend on the sensor type, the application and requirements of the user and the time and means available.

7.2.1 Static Calibration

7.2.1.1. Such a calibration may only be used for those WIM systems which also allow static measurements. It should be noticed that a static calibration will only remove the intrinsec bias of the WIM system, but will not take into account the surrounding pavement conditions and pavement/vehicle interaction, and thus will generally not comply with the objectives of 7.1.3.1 and 7.1.3.2.

The sensors which may be calibrated in static are: strain gauge and load cell scales, piezo-quartz crystal bars, capacitive strips or fibre optic sensors, but not piezo-ceramic or piezo-polymer cables. Even for the strip sensors (piezo-quartz, capacitive strips and fibre optic), the static calibration is not easy to perform because of the small area of the sensor (and thus the difficulty to apply a mass of several tons), and the loading condition differs from that under traffic flow, because the integration of the signal may not be performed during a static test.

This calibration method is especially convenient if the weight is to be estimated with low speed WIM systems on excellent pavement sites.

7.2.1.2. The method consists, as for a static weighing scales, of placing calibration masses of various intensities on the scale (sensor) and relating the system measurements to the masses. At least three masses uniformly distributed within the scale range of the loads to be weighed must be used; three repetitions shall be done for each mass. For strip sensors, a special plate must be used to apply the whole calibration mass only to the sensor; this may not be easy because of the minimum calibration mass sizes, which greatly exceed the dimensions of the sensor.

7.2.1.3. For large scales, it is possible to use an accurately pre-weighed lorry and to place its axles successively on the scale, but because of the weak and poor definition of a static axle load (OIML, 1996), this is not recommended. An alternative method may consists of placing a reference portable static scale between the tyre and the WIM scale. In such a case, at least three axles must be used with static loads uniformly distributed within the scale range of the loads to be weighed, and three repetitions for each axle weighing shall be done.

7.2.1.4. For bridges (Bridge-WIM), it is recommended to use at least one two axle or three axle (single + tandem) rigid lorry, accurately pre-weighed, empty and full. Accuracy can be improved by using two or more calibration lorries with different distributions of weights between axles.

7.2.2 Use of Shock or Pressure Variation Devices

The principle of such calibration methods is to apply to the sensor some repeatable calibrated shocks or pressure variations. It may be done using a DYNAPLAQUE, a FWD (Falling Weight Deflectometer), a Piezodyn (M. Huhtala and B. Jacob, 1995), or any other similar devices.

The advantage of such a method is that it is almost independent of the pavement profile and of the calibration vehicle characteristics and speed or load (see 7.2.3). However the tests performed have shown that most of the devices used give results scattered along a WIM sensor, not only because of an eventual heterogeneity of the sensor itself, but also because of the impact conditions around the sensor. Moreover, the impact conditions are very different from a tyre imprint and the force applied by an instantaneous vertical force. This method also requires the closure of the traffic lane during the calibration, which may be difficult for busy highways or motorways.

This method is mainly devoted to calibration with respect to impact forces, but not to the weights. It could be of interest if the WIM system is used for impact force measurements (7.1.3.2) , as in (M. Huhtala and B. Jacob, 1995), but until now this method has not yet been proven to be effective.

7.2.3 Use of Pre-Weighed Calibration Lorries

7.2.3.1. This method is recommended when the WIM system is intended to estimate the weights (7.1.3.1).

It is the most commonly used method because of its relative simplicity and directness, and because it is suitable for all kinds of WIM systems. This method partially eliminates the repeatable pavement dynamic effects (bias), but is sensitive to the calibration (test) vehicle characteristics, such as suspension type and parameters, dry friction, etc..

7.2.3.2. The main principle consists of passing some test (calibration) pre-weighed vehicles over the WIM system, repeatedly. The calibration is generally assumed to be carried out over one or two consecutive days, with homogeneous temperature and climatic conditions (environmental repeatability condition (I) see 11.1.4)). According to the test plan we may define:

(r1) full repeatability conditions: if only one vehicle passes several times at the same speed, the same load and the same lateral position;

(r2) extended repeatability conditions: if only one vehicle passes several times at different speeds (according to the traffic lane conditions), different loads (e.g. fully loaded, half-loaded and empty), and with small lateral position variations (according to the real traffic paths);

(R1) limited reproducibility conditions: if a small set of vehicles (typically 2 to 10), representative of the whole traffic composition expected on the site (silhouettes and gross weights), is used, each of them passing several times, at different speeds, different loads, and with small lateral position variations;

(R2) full reproducibility conditions: if a large sample of vehicles (i.e. some tens to a few hundred) taken from the traffic flow and representative of it, pass on the WIM system and are statically weighed before or after it.

7.2.3.3. A proper initial calibration (after installation or modification of a WIM system), requires to be done in condition (R1), with at least three or four test vehicles, according to the traffic to be weighed:

- a 2-axle rigid van, fully loaded (around 3.5 t, ± 1 t);
- a 2-axle, a 3-axle or a 4-axle rigid lorry loaded between 10 and 25 t, close to its maximum permitted load;
- a tractor with a semi-trailer supported by a tandem or a tridem axle (the tridem is preferred), loaded at more than 30 t.
- a lorry with a trailer (2+2, 3+2, 2+3, 3+3 axles), fully loaded.

If possible, the last two vehicles will be used fully loaded and half loaded. The tandem or tridem axles should be better equipped with air suspension. However, if mechanical suspensions are used to be representative of the common vehicles on the site, some care should be taken to measure the static reference axle loads (see 8.3).

It is also recommended to use one of the standard test plans described in the Appendix I, as they were designed to optimise the number of runs and vehicles versus the confidence level. Moreover, that would allow to use the graphs given in this Appendix I to facilitate the initial verification, after calibration.

The conditions must be specified before the calibration, and the results (in terms of accuracy class) must be analysed according to them (see 11.), for the level of confidence being used.

The higher the conditions (from (r1) to (R2)) the more representative the calibration sample of the real traffic conditions, but the procedure becomes longer and more costly! Nevertheless this calibration procedure may be performed without traffic stopping ((r1) to (R1)).

7.2.3.4. A calibration may be performed in condition (r2), in the case of an agreement between the customer (or user) and the supplier. Except for bridge WIM, the calibration vehicle chosen must be of the most common vehicle type to be weighed, and with three loading cases: empty, half loaded and fully loaded.

7.2.3.5. A sample of at least 10 significant runs - i.e. 10 runs with successful measurements - per lorry (or lorry loads) is recommended to guarantee the validity of the method, but the larger this sample the smaller the statistical uncertainty. The sample size will be determined according to the customer's requirements.

7.2.3.6. The runs mentioned in 7.2.3.5 must be split, for each vehicle (load case) into 2 or 3 speed levels, being representative of the velocity range on the WIM site; e.g. for a free motorway, 70 and 95 km/h may be used, while on other sites, 50, 70 and 90 km/h would be better (however, the used speeds should mostly remain within the legal limits). A recommended simple rule is to take as speed levels the mean velocity V_m, $0.8V_m$ and $1.2V_m$ and then to allocate the run numbers according to the following proportions: 60%, 20% and 20%.

7.2.3.7. The initial calibration with only one vehicle and one load case <u>is not recommended</u> and may only be used if it is not possible to do otherwise or if only one type of lorry is to be weighed, under a full agreement with the customer (or user). In such a case, 10 significant runs should be made at three speed levels, and then the data are analysed in only one sample (with the rules of condition (r1)). But calibration checks may be done in conditions (r1) or (r2).

7.2.3.8. The static weighing operation must be made carefully, such as 8.3:

7.2.3.9. After the data collection, the calibration may be done following various methods. The calibration methods most commonly used are briefly described in the Appendix III. The choice of the most appropriate method should be made according to the WIM station software performance and to the user's requirements. In any case, the method used must be clearly explained or referred to in the calibration report.

7.2.4 Use of Instrumented Calibration Lorries

7.2.4.1. This method is of special interest if the WIM system is intended to measure instantaneous axle impact forces (7.1.3.2), instead of static loads, or to calibrate multiple sensor arrays.

In such a case, the methods described in 7.2.3 (and in Appendix III) introduce some bias by partially eliminating the dynamic effects being sought. This is the case for some research purposes such as spatial repeatability investigations or pavement/vehicle interaction and pavement damage studies. For multiple-sensor WIM systems, the spatial repeatability is used to improve the accuracy of the static load estimator.

The advantage of this method is to make a "true" calibration on the parameter actually measured by a WIM system, i.e. the wheel or axle impact force. Its disadvantage comes from the cost and difficulties of getting and operating such instrumented lorries, which also require specialised technicians. Also there are only very few such instrumented vehicles available actually, and the information and documentation about them are very poor.

The quality of the calibration greatly depends on the accuracy of the lorry instrumentation, which measures continuously each wheel impact force on the pavement as the vehicle travels. But these measurements are indirect, by the mean of accelerations and strain records, and generally require a lot of computation afterwards.

7.2.4.2. It is necessary to very accurately synchronise the on-board measurements with the WIM sensor measurements, when a wheel or axle passes on it.

7.2.4.3. The instrumented vehicle must have been itself carefully calibrated under dynamic loading and its intrinsic accuracy must be in agreement with the common metrological rules, depending on the WIM system expected accuracy (e.g. the tolerances of the on-board measurements should be between 1/5 and 1/3 of those of the WIM system).

7.2.4.4. The calibration procedure consists of fitting the WIM records to the on-board measured impact forces for the same wheel or axle. As explained in the Appendix III, only one average calibration coefficient may be calculated, or different coefficients depending on the axle rank (or on the lorry type if several instrumented lorries of different types are available!). The formulas given in Appendix III should be used, replacing the static loads by the reference impact forces provided by the instrumented vehicle(s). In this method the axle loads and forces must be used instead of the gross weights.

7.2.4.5. The calibration procedure (test plan) should be made with at least three load cases (full, half load and empty) and two or three speed levels per load case; three significant runs for each load and speed should be made.

7.2.5 Automatic Self-Calibration Procedures and Software

This kind of method, introduced in France in the early 1980's, has the great advantage of providing a permanent automatic recalibration of a WIM system installed on a trafficked road, and therefore to correct any trend or bias due to sensor, electronics or pavement changes or due to external effects, such as temperature variations. However, it was shown that this procedure requires a prior knowledge of the traffic pattern and may be worst than nothing in some particular circumstances.

7.2.5.1. The principle consists in fitting some statistics recorded and computed by the WIM system to some target values depending on the site-specific traffic.

In most countries and road networks, there are some "characteristic vehicles" which have some axle(s) and/or gross weight with a low coefficient of variation and a quite constant mean (the target value). In such a case, the moving average of a certain number of these axle loads or gross weights becomes almost constant for a large enough sample size, and may be fitted to the target value. This provides a new coefficient of calibration after the passage of the required number of characteristic vehicles.

Nevertheless it must be noted that such a procedure introduces a statistical error due to the sample size of the considered "characteristic vehicles". Therefore the time interval between two recalibrations (calculation of a new calibration coefficient) must be a compromise between the reduction in statistical variance (by increasing the sample size) and the delay in recalibration. If the temperature influence is to be eliminated, it is recommended to have such an interval in the range of 1 hour to a few hours. If only some long-term trends are to be eliminated, this time interval may be longer (e.g., 1 day to a few weeks).

7.2.5.2. An automatic self-calibration procedure requires a good prior knowledge of the site-specific traffic composition and statistics of the axle and vehicle loads. Its efficiency depends greatly on this knowledge but also on the traffic intensity; the higher the traffic flow the more efficient the self-calibration. Therefore this procedure should be used with caution on secondary roads with low traffic volumes.

7.2.5.3. Also is noted that the automatic calibration system is active per lane. So in case of more than one instrumented lane, the traffic on each lane should be taken into account separately.

7.2.5.4. The frequency of recalibration (or new calibration coefficient calculation) must be adapted to the eigenfrequency(ies) of the perturbations to be eliminated, and to the traffic flow (of characteristic vehicles).

7.2.5.5. A WIM system needs some time to be automatically self-calibrated (e.g., 1 to 5 days depending on the traffic flow and composition), and to give stabilised results. The user should check that, or the supplier gives some warranty, before the system may be used for an operational purpose.

7.2.5.6. It is recommended to consistently check the self-calibration by screening the calibration coefficients to avoid gross errors which may occur for various reasons, such as a temporary lack of characteristic vehicles, some unexpected change in the target values, etc.. Thus, the calibration coefficients should be recorded in permanent files by the WIM systems using this procedure, and easily readable with their date and time (in case of detailed data records; otherwise, some statistics on these coefficients should be provided). It is also necessary to perform periodical calibration checks (e.g., once or twice a year) using pre- or post-weighed lorries, or by some coherence tests on the statistics delivered by the system.

7.2.5.7. It is recommended to record the temperature in order to check the correlation between it and the calibration factor, and to evaluate the statistical error.

Finally it should be noted that even if this type of calibration is very easy and inexpensive to implement after performing the appropriate preliminary studies and after the development of the proper software, it may also introduce some uncontrolled bias or variance.

8. ACCURACY CLASS TOLERANCES WITH RESPECT TO THE WEIGHT

8.1 General

8.1.1. A WIM system must be checked following a well defined procedure or test programme and can then be classified into one of several accuracy classes according to the test results. These accuracy classes are defined with respect to the weight estimation; but in some particular cases another reference may be adopted, such as independently measured impact forces.

8.1.2. The principle adopted for this classification consists of fixing the tolerance δ, i.e. the width of the confidence interval for an individual WIM measurement, and for a given level of confidence π. The requirement for this level depends on the calibration or test conditions, if this is performed using pre-weighed vehicles in motion (as described in section 7.2.3). For static calibration with calibrated masses or pre-weighed vehicles, this level of confidence must be 100 %.

8.1.3. In the statistical approach, adapted to most of the existing WIM systems, any individual measurement (of an axle, axle group or gross weight) must have a probability π higher than a required value π_0 of being within the interval $[Ws(1-\delta);Ws(1+\delta)]$ centred on the static load, where Ws is the corresponding static load. It also means that statistically a proportion π of a large sample of WIM data should be within the previous interval. Or the customer risk on an individual measurement is lower than $(1-\pi_0)$ under some specified conditions. The mathematical and statistical background is developed in (B. Jacob, 1997).

The principle used is that the tolerance δ only depends on the accuracy class and on the entity considered, which may be the:

- axle load (single axle),
- axle load (axle belonging to a group),
- axle group load,
- gross weight,

and additionally:

- vehicle speed
- inter-axle distance
- vehicle classification (proportion of vehicle of a given type, by silhouette or load)

One criterion is considered for each of these entities.

The level of confidence π of any sample of data only depends on the test conditions ((r1) to (R2)), on the environmental test conditions ((I) to (III) (see 11.1.4)) and on the sample size (number of runs and of test vehicles), and must be higher than a specified value π_0 which also depends on the test conditions and sample size.

The test plan may depend on the WIM system type, accuracy class required and application.

This specification only considers individual measurements, while it is almost impossible to assess the accuracy of a WIM system using only aggregated data. If some WIM systems deliver only statistics during operational period of use, detailed data should be provided for calibration and accuracy tests.

8.2 Accuracy Class Tolerances

8.2.1 The tolerances for a load from a single axle, a group of axles, an axle belonging to a group and a gross weight are distinguished, because the dynamic effects resulting from the pavement/ vehicle interaction affect the WIM measurements. They are given in Table 5. The Table 6 provides tolerances for further classes E(xx) if needed in some cases. Additional classes may be obtained, either by interpolation or extrapolation using the curves given in Figure 1.

8.2.2. The accuracy requirements for axles in a group do not apply to bridge WIM systems most of which do not provide such information. The accuracy requirements for single axles may also be exempt for these systems, some of which do not provide such reliable information, but only if it is clearly specified by the system provider or supplier.

Table 5: Tolerances of the accuracy classes (δ in %)

Criteria (type of measurement)	**Domain of use**	**Accuracy Classes: Confidence interval width δ (%)**						
		A (5)	**B+ (7)**	**B (10)**	**C (15)**	**D+(20)**	**D (25)**	**E**
1. Gross weight	Gross weight > 3.5 t	5	7	10	15	20	25	> 25
Axle load:	Axle load > 1 t							
2. group of axles		7	10	13	18	23	28	> 28
3. single axle		8	11	15	20	25	30	> 30
4. axle of a group		10	14	20	25	30	35	> 35
Speed	V > 30 km/h (1)	2	3	4	6	8	10	> 10
Inter-axle distance		2	3	4	6	8	10	> 10
Total flow		1	1	1	3	4	5	> 5

(1) *This condition applies only for the sensors/systems which do not work statically or at very low speed.*

The class designation by numbers δ_c = 5, 7, 10, 15, 20, 25, and so on (tolerances for the gross weights) is in agreement with the OIML recommendation, and allows for use of any classes before A(5) or interpolated classes between the specified classes (e.g., class(13)).

Table 6: Tolerances of the accuracy classes E

Criteria (type of measurement)	Accuracy Classes E Confidence interval width δ (%)					
	E(30)	**E(35)**	**E(40)**	**E(45)**	**E(50)**	**etc.**
1. Gross weight	30	35	40	45	50	...
2. Group of axles	33	39	44	49	55	...
3. Single axle	36	42	48	54	60	...
4. Axle of a group	41	47	53	59	65	...

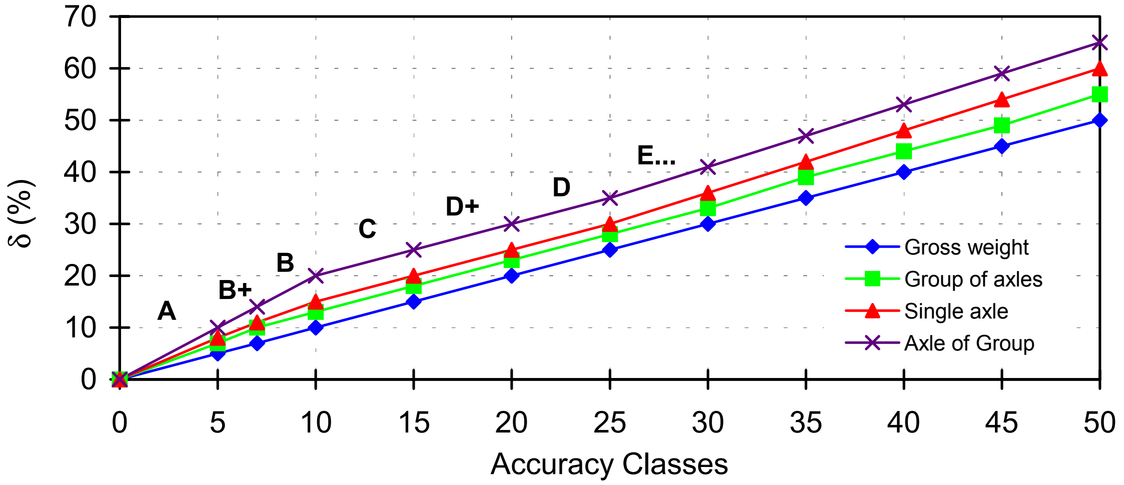


Figure 1: Graphical representation of the accuracy class tolerances

8.2.3. Tolerance extrapolation and interpolation

8.2.3.1. If more classes are needed, behind E(50), the tolerances for each criterion may be extrapolated by:

Group of Axes (GA)	δ=1.0467 δ_c + 2.1556	For $\delta_c \geq 50$
Single Axles (SA)	δ=1.1333 δ_c + 2.6667	For $\delta_c \geq 50$
Axles of a Group (AoG)	δ=1.1333 δ_c + 7.6667	For $\delta_c \geq 50$

Where δ_c is the tolerance for the gross weight, and the accuracy class name is E(δ_c). These values must be incremented by steps of 5%. The δ values obtained with the above formula must be rounded up/down to the closest integer.

8.2.3.2. if interpolated classes from 0 to 50 (between the figures given on the line for gross weight in Table 5 and Table 6) are used, the tolerances for each criterion may be interpolated by:

Group of Axles (GA):	$\delta = \delta_c / 0.7$	For $\delta_c < 7$
	$\delta = \delta_c + 3$	For $7 \leq \delta_c < 30$
	$\delta = 1.2\ \delta_c - 3$	For $30 \leq \delta_c < 35$
	$\delta = \delta_c + 4$	For $35 \leq \delta_c < 50$
Single Axles (SA):	$\delta = \delta_c (85 - \delta_c) / 50$	For $\delta_c < 10$
	$\delta = \delta_c + 5$	For $10 \leq \delta_c < 25$
	$\delta = 1.2\ \delta_c$	For $25 \leq \delta_c < 50$
Axles of a Group (AoG):	$\delta = 2\ \delta_c$	For $\delta_c < 10$
	$\delta = \delta_c + 10$	For $10 \leq \delta_c < 25$
	$\delta = 1.2\ \delta_c + 5$	For $25 \leq \delta_c < 50$

8.2.4. The criteria on speed, axle spacing and counting are not mandatory in this specification, as they are other standards for that, which concern much more devices than WIM systems. The tolerances given for these criteria are reasonable accepted values for WIM systems. However, it should be noticed that many strip sensor WIM systems use the speed for the load calculation, and thus any imprecision on speed would have some effect on the weighing accuracy.

8.2.5. For any other WIM system, all the criteria mentioned in the Table 5 must be checked, as far as the corresponding data are provided by the system. Only if the manufacturer or vendor clearly claims prior to the test that some of the data provided are not reliable (and this should be stated in writing), and with the agreement of the user (customer), some criteria may be excluded. If the static reference (see 8.3) are not fully reliable for the axle of a group equipped with steel suspension, that may be often the case, these axles will not be considered individually for the analysis, while the group will be taken into account.

8.2.6. The accuracy class accepted for any WIM system is the best class for which all the criteria are satisfied, or the relevant criteria if some are excluded according to 8.2.2 or 8.2.3. Nevertheless it is recommended to give an account, after each test, of the results for each criterion separately, in order to inform the user about the reliability of each type of data.

8.2.7. For specific user's requirement, it is also possible to classify a WIM system in different classes for each criterion, but in such a case the mention of the accuracy class must always be made with the name of the criterion checked. Without this mention, only the class defined in 8.2.4 may be mentioned.

8.3 Reference Gross Weights and Axle Loads measured in Static

If the reference values used for calibration or accuracy assessment are weights and static loads, the following rules and clauses should be applied.

8.3.1. The static weighing operations must be done either axle by axle, or by group of axles, or on a weigh-bridge in order to weigh a whole vehicle at once. If possible, it is strongly recommended to weigh the gross weights on an approved weigh-bridge to get a reliable weight W_s.

Static axle loads should be measured by axle or wheel scales, which are approved for enforcement and commercial applications, either mounted in grooves and carefully levelled to the road surface, or laid on the road surface. The road surface on the weighing area should be flat and horizontal. In the latter case, it is recommended to:

- use as many scales as the number of wheels/axles to be weighed for one vehicles, or
- use a ramp or any device to level all the wheels/axles.

The level difference between axles of a same group should not exceed 2 mm. The level difference between single axles or groups of axles should not lead to more than 0.5% slope (i.e. 1.5 cm for 3m spacing).

8.3.2. During wheel or axle static weighing operation, the vehicle brakes must be fully released.

8.3.3. Because the static wheel or axle weighing operation using wheel/axle weighers is not fully repeatable (due to the braking conditions and the internal dry friction forces of the vehicle suspensions), it is recommended, above all for calibration and also if mechanical suspensions are used, to repeat n times the static weighing axle by axle and then to derive the static reference axle loads Ws_i by:

$$Ws_i = \frac{Ws}{\sum_{i=1}^{q} \sum_{j=1}^{n} Ws_{i,j}} \sum_{j=1}^{n} Ws_{i,j} \tag{1}$$

where i is the axle rank, q is the number of axles of the vehicle, Ws is the reference gross weight measured on a weigh-bridge, and $Ws_{i,j}$ is the measured load of axle i during the j^{th} weighing.

It s recommended to take $n=10$, but any value may be accepted. Even for $n=1$, it is recommended to use this equation to get the axle reference static loads, if the gross weight was measured on a weigh-bridge.

If n is large enough (i.e. $n \geq 8$ *to* 10), it is recommended to eliminate the weighings which could have provided statistical outliers, identified by any statistical test.

8.3.4. The results of lorry weighing during an enforcement operation by the police may introduce a bias. Therefore, it is recommended that lorries (rented for example) specially allocated to the test for one or two consecutive days are used.

9. TYPE (MODEL) APPROVAL OF A WIM SYSTEM

A type (or model) approval is a complete standardised procedure to be applied once to any newly manufactured measuring system, before to market it, in order to deliver a quality label and some target performance under known conditions of use. This chapter only deals with the on-site accuracy assessment of a WIM system by testing, as part of a type approval procedure to be developed in the future. The same approach and tools as for initial or in service verifications and acceptance tests (see chapter 10 and 11) are used. However, the site characteristics and the test plan are fully described in this chapter, while they are left to the user's decision in chapter 11.

Before to be marketed with a quality label and a specified accuracy performance, any WIM system should pass the test procedure described in this chapter. The test must be organised under the responsibility of an official agreed organisation, to ensure the neutrality and the reliability of the conclusions. An official report should be written and published giving an account of the test results. The Appendix IV gives some indication about the result format and presentation.

9.1 Scope

The type approval test intends to assess the accuracy performances of a WIM system under fully specified conditions, and over a short time period. Therefore, it does not give any information about the durability or trend of the system and its parts, which are highly dependent on the environmental and traffic conditions.

The site conditions are chosen as representative of the best quality site for WIM, in order not to introduce too much site effect. Therefore, the real performance on common sites may significantly differ (being below) from those assessed through the type approval.

9.2 Choice of the Test Site

9.2.1. The type approval test may be organised either on a fully protected site (outside the traffic flow) or on an existing road under traffic. If the WIM system is currently equipped with an automatic self-calibration procedure, only the second case is applicable.

9.2.2. The site must definitively be in class I (excellent), according to the chapter 5. Moreover, the radius of curvature should be longer than 2500m, and a straight road is highly recommended. All the site characteristics listed in chapter 5 must be reported in the test report.

9.3 Installation and pre-Calibration of the System

9.3.1. The system should be installed by the manufacturer or the vendor, prior to the test, according to the recommended common procedures.

9.3.2. A pre-calibration of the system should be done, preferably the day before the test, or if not possible, the same day. For this operation, two test lorries will be used, chosen in agreement with the manufacturer or the vendor among those listed in 7.2.3.3. One load per lorry will be used, chosen in agreement with the manufacturer or the vendor. Each lorry will make 8 runs over the WIM system:

- 4 runs at V_m,
- 2 runs at $1.2V_m$
- 2 runs at $0.8V_m$.

For a high-speed WIM system, V_m will be taken equal to 75km/h. For a low-speed WIM system, V_m will be the recommended operation speed.

9.3.3. After the measurements described in 9.4.2, the static reference axle loads and gross weights will be given to the manufacturer or vendor, who will be allowed to adjust its system, software, etc..

9.3.4. For a system equipped with an automatic self-calibration procedure being tested under real traffic flow, the system will be installed some time before the test, according to the clause 7.2.5.5. After this period, a calibration check will be carried out according to 9.4.2 and 9.4.3, and the manufacturer or vendor will be allowed to adjust the target values of the self-calibration algorithm. If needed, another period of time will be allocated to allow the system to stabilise its calibration under the traffic flow.

9.4 Test Plan

9.4.1. The test will be carried out using the standard test plan N°3 (see Appendix I), with four test lorries and a total of 110 runs. The test may be carried out within one or two consecutive days. The climatic conditions should be carefully reported in the test report (temperature variation range, weather, eventual precipitation, etc.). Any other special event which could affect the results should also be reported.

9.4.2. In addition to the 110 runs specified in 9.4.1, two of the test vehicles will make 6 additional abnormal runs in order to check the ability of the system to detect such situation, and eventually to mark the wrong measurements with a violation code. These runs will be done as:

- 2-axle rigid lorry: 3 more runs, one with half of the vehicle (left or right half) outside the sensor(s), one run with the first axle passing on the sensor(s) and the second axle passing outside or partially outside the sensor(s), and one run with the lorry braking while passing on the sensor(s) (speed variation from 90 km/h to 60 km/h, or 12 to 5 km/h for a low-speed WIM system).

- Semi-trailer with a tridem: 3 more runs, one with half of the vehicle (left or right half) outside the sensor(s), one run with the tractor passing on the sensor(s) and the semi-trailer (tridem) passing half outside the sensor(s), and one run with the lorry braking while passing on the sensor(s) (speed variation from 90 km/h to 60 km/h, or 12 to 5 km/h for a low-speed WIM system).

9.4.3. During the test, the manufacturer or vendor will not be allowed to access to the system. After the test measurement completion, the raw data file(s) with the detailed vehicle by vehicle recorded data will be given both to the test organiser and to the manufacturer or to the vendor for its own check.

9.5 Reference Static Loads and Weights

For both pre-calibration (see 9.3) and the test (see 9.4), the test vehicles will be weighed on an approved weigh-bridge and on wheel/axle scales. The rules of section 8.3 will be applied, with $n \geq 6$ (see 8.3.3). It will be checked that the standard deviations of the static axle loads are less than 1/3 of those measured in motion.

9.6 Test Analysis and Report

9.6.1. All the recorded data, except those marked with a violation code by the system, will be considered. A careful analysis and report on the abnormal runs will be done in the report.

9.6.2. The data analysis will be done as for and in-service verification (see 10.2) according to the clauses 11.4.1, 11.4.2, 11.4.3.1, 11.4.4, 11.4.5, 11.4.6 and 11.4.7. The test conditions will be (I) (environmental repeatability, see 11.1.4) and (R1) (limited reproducibility, see 7.2.3.2). The results will be reported according to the Appendix IV format.

9.6.3. A second analysis will be carried out as for an initial verification (see 10.1), by removing the mean bias on the gross weight for all runs, applying by software a constant multiplicative factor on all the recorded axle loads. The *k* factor mentioned in 10.1.3 will be used to assess the accuracy classes for each criterion.

9.6.4. The test report will present both analysis (9.6.2 and 9.6.3). In case of significant discrepancies between both, some explanations should be given, as far as possible, about the effect of the mean bias.

10. INITIAL AND IN-SERVICE VERIFICATIONS

A verification of a WIM system may be done either:

- as an initial verification (section 10.1),

  or

- in-service (section 10.2).

10.1 Initial Verification

10.1.1. After installation, or some modifications (of sensors, hardware or software), repair or part replacement, a WIM system must be (re)calibrated, according to one of the procedures proposed in chapter 7 and Appendix III and to the manufacturer's specification.

In most cases (unless if an automatic self-calibration procedure is used) the calibration procedure provides data which may be used for an accuracy evaluation. In such a case, **the same sample is used** for calibration and for accuracy assessment. This is an initial verification.

10.1.2. If the WIM system is calibrated using static calibration masses (see 7.2.1) or with a fully repeatable calibrated shock device (see 7.2.2), then all the results (relative errors) must be within the interval $[-\delta/2; \delta/2]$ of the relevant accuracy class and of the criterion considered (single axle, axle group or gross weight).

This section only applies to bending plates, with strain gauge or load cell scales, and for weigh-bridges, which are able to measure static loads. In particular cases it may also be applicable to some strip sensors, and may be extended with caution to sensors calibrated with shock devices.

10.1.3. If the WIM system is calibrated using repeated runs of pre-weighed vehicles or instrumented vehicles, the confidence intervals given in Table 5 (and Table 6, if needed) are considered, but the tolerance δ are reduced by a multiplicative k factor, where $k=0.8$.

The required level of confidence of this interval $[-k.\delta; k.\delta]$ is given in chapter 11.

10.2 In-Service Verification

10.2.1. An in-service verification may be done at any time of the lifetime of a WIM system. It should be done periodically, and if the conditions changes (traffic conditions, environmental conditions, etc.), or in case of any doubt about the data accuracy.

In such a verification, the data used for the accuracy assessment must not have been used for any calibration or recalibration of the system.

10.2.2. If the WIM system is checked using static calibration masses or using a fully repeatable calibrated shock device, all the results (relative errors) must be within the tolerance interval [$-\delta; \delta$] of the relevant accuracy class and of the criterion considered (single axle, axle group or gross weight), according to the measuring scale or sensor extend.

10.2.3. If the WIM system is checked using repeated runs of pre-weighed vehicles or instrumented vehicles, the confidence intervals, given in Table 5 (and Table 6 if needed), are used.

The required level of confidence of this interval [$-\delta; \delta$] is given in chapter 10.

Such a test made under moving vehicles, such as in normal traffic conditions is often more realistic than the check mentioned in 10.2.2.

11. PROCEDURE TO CHECK THE ACCURACY

11.1 General Rules

11.1.1. The assessment of the accuracy of a WIM system requires a test. This chapter deals with tests carried out using either repeated runs of pre-weighed vehicles (test vehicles), and/or the use of single runs of pre- or post-weighed vehicles from the traffic flow.

11.1.2. The more extensive the test plan means the longer the test period, a higher number of vehicle types and runs and ultimately a higher confidence in the conclusion. This means that the customer risk (i.e., the risk of accepting a system in a higher class than it is) decreases as the test becomes more extensive. In this analysis, the supplier risk, linked to the statistical estimation of the mean bias, is fixed at 5%.

11.1.3. In this procedure, the customer risk is governed by the probability of an individual error (with respect to the static load or weight) lying outside of the specified confidence interval (tolerance). An upper bound of this risk is fixed by specified values $(1-\pi_0)$, where π_0 is the minimum required confidence level. This risk $(1-\pi_0)$, or the confidence level π_0, may be chosen by the customer (see section 11.3).

Lower this risk, longer and more extensive (and expensive) the test. Then the customer should adapt it to its requirements, taking into account the manufacturer specification and the output of other extensive and detailed tests.

It should be emphasised that this risk is only assessed under the conditions of the acceptance test; it means that the farther the test conditions from the real traffic conditions, the lower the confidence and higher the customer risk.

11.1.4. Depending on the objectives, the means and the requirements of the customer, the test may be carried out during various time periods; this defines another type of repeatability or reproducibility, called "environmental repeatability or reproducibility":

- ***(I) environmental repeatability***: the test time period is limited to a couple of hours within a day or spread over a few consecutive days, such that the temperature, climatic and environmental conditions do not vary significantly during the measurements;
- ***(II) limited environmental reproducibility***: the test time period extends at least over a full week or several days spread over a month, such that the temperature, climatic and environmental conditions vary during the measurements, but no seasonal effect has to be considered;
- ***(III) full environmental reproducibility***: the test time period extends over a whole year or more, or at least over several days spread all over a year, such that the tempera-

ture, climatic and environmental conditions vary during the measurements and all the site seasonal conditions are encountered.

11.1.5. No recalibration or any manipulation, software adaptation or part exchange can be conducted on the WIM system during the test period. Only in the case of a long term test (III), or exceptionally in case (II), if some part of the system (sensor or electronics) fails, the supplier of the system may be authorised to repair it or to replace the broken part, under the control of the test organiser. A detailed report about the failure, its causes and the repair done must be provided.

11.1.6. According to the number of test vehicles (11.1.7), load and speed cases, and eventually to the use of pre- or post-weighed vehicles from the traffic flow passing the system only once, the test may be carried in (see section 7.2.3.2):

- (r1) full repeatability
- (r2) extended repeatability
- (R1) limited reproducibility
- (R2) full reproducibility

11.1.7. Test vehicles are vehicles which are pre-weighed on an approved static scale or weighbridge, and perform repeated runs over the system (see 8.3).

11.2 Test Plans

11.2.1. The definition of a test plan consists in the choice of a sample of vehicles and their number and conditions of runs. These vehicles may be either:

- test vehicles (11.1.7) provided by the organiser (pre-weighed or instrumented vehicles),
- and/or vehicles taken from the traffic flow and pre- or post-weighed; in this latter case only one run per vehicle is considered.

If both types of vehicles are used, the data of each population should not be merged in the analysis.

11.2.2. If the weights are taken as the reference values, the guidelines given in 7.2.3 should apply. If the impact forces are taken as the reference values, the guidelines given in 7.2.4 may be used.

11.2.3. It is recommended to perform the check of the test in conditions (R1) or (R2). It may be done in conditions (r2) but with at least 3 loading cases uniformly distributed within the range of axle/gross weights to be weighed, and 10 runs per loading case. It is not recommended to perform the test in conditions (r1), unless by special agreement of the user (customer). The requirements of 7.2.3.5 to 7.2.3.7 still apply.

11.2.4. In cases (II) and (III), the sample of vehicles used over each day or series of days should be similar (composition and loads), and as far as possible representative of the traffic flow.

11.2.5. The environmental conditions (especially the temperature) should be recorded during all the measurement periods.

Depending on the sensor type, temperature variations can cause bias because of sensor sensitivity or indirectly because of pavement modulus or behaviour changes.

11.2.6. The objective of this specification is to leave all the flexibility to the customer or user, so that the most adapted test plan can be chosen according to its requirements and means. The data analysis procedure described in 11.3 is able to deal with any test plan, and then the level of confidence of the results is calculated. Or the customer may choose the appropriate level of confidence (or the highest accepted risk), and build the most convenient test plan which complies with it among all of them.

For common checks, some standard simplified test plans are given in the Appendix I.

11.3 Confidence Levels

11.3.1. When a test of a WIM system is performed according to the principles of 11.2, the confidence level π to get an individual error within the confidence intervals specified in Table 5 or Table 6 (within the tolerances) may be estimated from the test results and statistics. In the following, the individual errors are assumed to be random, independent of each other and normally distributed.

The mean error estimation is affected by a statistical uncertainty, which depends on the sample size *n* (the uncertainty is removed for an infinite sample size !). This uncertainty is taken into account in the specified values of the following tables and in the formulas of section 11.4, assuming that the samples have normal distributions (this may be checked by testing if required).

11.3.2. Depending on the test plan repeatability or reproducibility conditions (r1) to (R2), and on the environmental repeatability/reproducibility conditions (I) to (III), the minimum values π_0 of the required level of confidence for the confidence intervals specified in Table 5 and Table 6 are given in Table 7, Table 8 and Table 9, and in Figure 2. π_0 increases with the size *n* of the test data sample. These values are also calculated by formula in the computer (Excel sheet) tools presented in the Appendix IV. They were chosen as explained in (B. Jacob, 1997).

Table 7: Minimum levels of confidence π_0 , of the centred confidence intervals (in %) - case of a test under "environmental repeatability" (I)

Test conditions \ Sample size (*n*)	10	20	30	60	120	∞
Full repeatability (r1)	*95*	*97.2*	*97.9*	*98.4*	*98.7*	*99.2*
Extended repeatability (r2)	*90*	*94.1*	*95.3*	*96.4*	*97.1*	*98.2*
Limited reproducibility (R1)	*85*	*90.8*	*92.5*	*94.2*	*95.2*	*97.0*
Full reproducibility (R2)	*80*	*87.4*	*89.6*	*91.8*	*93.1*	*95.4*

For sample size n not mentioned in this table, the figures may be interpolated using Figure 2, or a linear interpolation, or they are calculated in the Excel sheet presented in the Appendix IV.

Table 8: Minimum levels of confidence π_0 , of the centred confidence intervals (in %) - case of a test under "limited environmental reproducibility" (II)

Test conditions \ Sample size (*n*)	10	20	30	60	120	∞
Full repeatability (r1)	*93.3*	*96.2*	*97.0*	*97.8*	*98.2*	*98.9*
Extended repeatability (r2)	*87.5*	*92.5*	*93.9*	*95.3*	*96.1*	*97.5*
Limited reproducibility (R1)	*81.9*	*88.7*	*90.7*	*92.7*	*93.9*	*96.0*
Full reproducibility (R2)	*76.6*	*84.9*	*87.4*	*90.0*	*91.5*	*94.3*

For sample size n not mentioned in this table, the figures may be interpolated using Figure 2, or a linear interpolation, or they are calculated in the Excel sheet presented in the Appendix IV.

Table 9: Minimum levels of confidence π_0 , of the centred confidence intervals (in %) - case of a test under "limited environmental reproducibility" (II)

Test conditions \ Sample size (*n*)	10	20	30	60	120	∞
Full repeatability (r1)	*91.4*	*95.0*	*96.0*	*97.0*	*97.6*	*98.5*
Extended repeatability (r2)	*84.7*	*90.7*	*92.4*	*94.1*	*95.1*	*96.8*
Limited reproducibility (R1)	*78.6*	*86.4*	*88.7*	*91.1*	*92.5*	*95.0*
Full reproducibility (R2)	*73.0*	*82.3*	*85.1*	*88.1*	*89.8*	*93.1*

For sample size n not mentioned in this table, the figures may be interpolated using Figure 2, or a linear interpolation, or they are calculated in the Excel sheet presented in the Appendix IV.

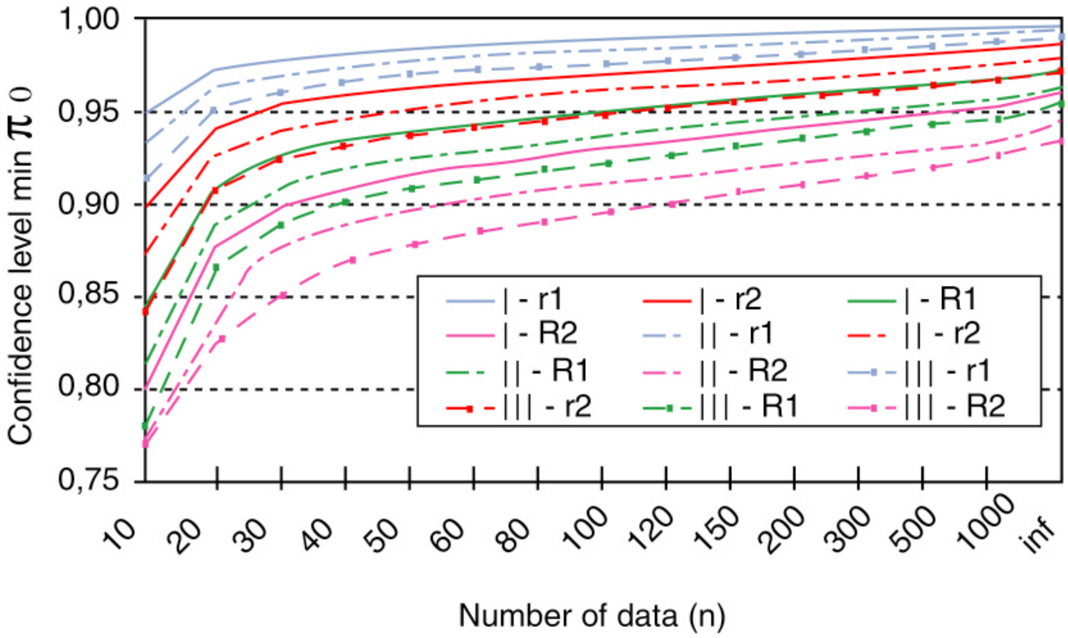


Figure 2: Graphical representation of the minimum confidence level with the number of data

11.3.3. It is recommended to require - by the choice of the test plan - a confidence level greater or equal to 90 % in reproducibility conditions (R1) and (R2), and greater or equal to 95 % in repeatability conditions (r1) and (r2), but in particular cases it may be less.

11.3.4. For some applications, especially the legal applications (e.g., enforcement), higher confidence levels may be required, such as 99% or 99.5%. Even if such values exceed the maximum value given in the Table 7, Table 8 and Table 9, they may be obtained for a large enough tolerance δ on the considered criterion (i.e. using a lower accuracy class): for a given system (accuracy), higher the tolerance, higher the confidence level. The effective confidence level is calculated (see 11.4.6).

11.4 Test Results Analysis

After the end of the data collection, the detailed analysis of the test results will be done through the following steps:

11.4.1. Report on the system failures or malfunctions, including statistics about the time of operation, the time interval between failures, etc..

11.4.2. Statistics about the number of properly recorded vehicles by the WIM system (if any reference is available on the theoretical number of vehicles passed, at least for the vehicles of the test sample). Analysis of the errors automatically detected by the system (error code provided) and the missed ones.

In this step, the percentage of missing vehicles (not including the vehicles recorded with an error code) must be lower than the values indicated in the last line of Table 5.

The percentage of vehicles recorded with an error code may be higher (without any specified upper limit), but only in so far as it concerns the traffic conditions: vehicle passing partially off-scale, braking or accelerating over the specified limits of the system, etc..

11.4.3. Outliers: the issue of the statistical outliers (not detected by the system in its recording process) must be considered carefully. Two cases may be considered, and then only one of them or both may be treated according to the test requirements.

11.4.3.1. No outlier elimination: if the objective of the test is to provide the real system performance for a customer who generally uses the data as they are recorded, without any further statistical analysis, then all the data recorded except those with an error code are included in the analysis described below.

11.4.3.2. Outlier elimination: if the objective of the test is to provide the theoretical system performance for a customer who may perform some further statistical tests on the recorded data, then some statistical tests of outliers must be applied on the homogeneous populations (take care of the Normality required for most of these tests; if it is the case, this Normality must also be checked by testing). The outliers identified by the relevant tests are accounted for and counted as missing data after elimination (return to 11.4.2). The remaining data are only used for the analysis described below. The final report of the test must clearly report on this part of the analysis.

11.4.4. In the case of a large enough data sample, it is recommended to check the Normality of the results when only independent random errors are expected to provide the population variance; this is mostly the case and non-Normality often reveals some dysfunction. Moreover this assumption is made for the level of confidence calculation.

11.4.5. The relative errors with respect to the weights and static loads (or any other accepted reference values) are calculated, for each measurement of the different sub-populations, i.e. the axles, axle groups, axles of groups and gross weights, as:

$$x_i = \frac{(Wd_i - Ws_i)}{Ws_i}$$

where Wd_i and Ws_i are the in-motion measured value and the reference (static) value respectively of the same entity.

Then the mean m and the standard deviation s of the relative errors in each sub-population sample are calculated.

Remarks:

1. While the calibration method applied does not provide individual coefficients by lorry type or axle rank (such as in the methods 1.a. to 1.d. of the Appendix III), the samples considered

must include all the gross weight or single axle, axle of group or group of axles loads results together. For example all the single axles of any rank must be considered together, but not the front axles and the rear/drive axles separately.

If different calibration coefficients are defined by vehicle type or axle rank (or type), then the samples considered may distinguish each sub-population.

2. In case of a test in conditions (r1), the data collected for all the speed levels must be merged and analysed in only one sample, even if the full repeatability is not satisfied anymore.

11.4.6. Calculation of the confidence level

The confidence level π may be either estimated by a theoretical method (11.4.6.1) using the sample statistics of the test, or, in some cases, by a sample proportion (11.4.6.2). Both methods are presented:

11.4.6.1. Calculation of the theoretical confidence level

A lower bound π, of the probability for an individual value of a relative error, taken randomly from a normally distributed sample of size n, with a sample mean m and standard deviation s, to be in the centred confidence interval $[-\delta; \delta]$, is given at the confidence level ($1-\alpha$) by (B. Jacob, 1997):

$$\pi = \Phi(u_1) - \Phi(u_2), \text{ with } u_1 = (\delta - m)/s - t_{\nu,1-\alpha/2}/n^{1/2} \quad \text{and} \quad u_2 = (-\delta - m)/s + t_{\nu,1-\alpha/2}/n^{1/2} \qquad (2)$$

where Φ is the cumulative distribution function of a Student variable, and $t_{\nu,1-\alpha/2}$ is a Student variable with $\nu = n-1$ degrees of freedom. α is taken equal to 0.05.

Remark: If n is greater than 60, the cumulative distribution function Φ may be approximated by the cumulative distribution function of a standardised Normal variable. But this approximation is not of a very high interest in practice, and should only be used if the Student distribution function is not available.

Then the estimated level of confidence π, for each sample (and criterion) is calculated.

11.4.6.2. Estimation of π with the sample proportion π'

If the sample size n is greater than $10/(1-\pi_0)$, where π_0 is the minimum required level of confidence read in Table 7, Table 8 and Table 9 (according to the test plan), π may be statistically estimated by the proportion π' of the sample test data found within the confidence interval $[-\delta;+\delta]$.

This estimation may be eventually used while $n > 5/(1-\pi_0)$, but the statistical uncertainty increases as n decreases.

The sample proportion may only be used with the user's or customer's agreement, and if there is no possibility to calculate the π value.

11.4.7. Test of acceptance

At this stage, they are two ways to assess the accuracy level of a WIM system by testing:

11.4.7.1. For each sub-population (sample) corresponding to a criterion of the Table 5, and for the proposed (required) accuracy class defined by δ, the acceptance test is:

- if π (or π' in the case of 11.4.6.2) $\geq \pi_0$, the system is accepted in the class δ;
- if π (or π' in the case of 11.4.6.2) $< \pi_0$, the system cannot be accepted in the proposed accuracy class, and the acceptance test is repeated with a lower accuracy class (a greater δ). If the theoretical value of π is used, it should be recalculated by the equation. But π' is independent of δ.

11.4.7.2. An alternative way is to calculate, with the equation, the (lowest) value δ_{min} of δ which provides: $\pi = \pi_0$, and then to check that δ_{min} is smaller than the value specified in Table 5 or Table 6 for the proposed accuracy class and criterion.

If the sample proportion π' is used (11.4.6.2), the smallest value δ_{min} of δ which ensures that the centred confidence interval contains a sample proportion $\pi' = \pi_0$, is chosen, and the same check as above is done.

This last approach may allow to classify a system in any accuracy class, defined by the lowest accepted δ-value (δ_{min}).

11.4.7.3. Another manner to express the accuracy class for one criterion, when a value of δ_{min} has been calculated, consists of calculating the associated δ_c using the formula of 8.2.3.1 or 8.2.3.2. Then the accuracy class may be expressed by this value of δ_c (rounded to the closest upper integer) or by the closest upper standard class A(5) to E(50), etc..

11.4.8. If required by the customer or the manufacturer, some additional analysis may be performed with the test data, such as: analysis of the environmental effects, of the traffic condition effects, etc..

11.4.9. The Appendix I of this specification gives a simplified procedure, based on the use of a graphical chart for the acceptance test; this simplified procedure is very easy to implement, but only complies with the standardised common test plans.

12. DATA STORAGE, PROCESSING AND TRANSMISSION

It is out of the scope of this document to specify in too much detail the content, structure and format, of the data files containing the output from WIM systems. It is mainly the responsibility of the WIM system manufacturers or service suppliers to develop and implement software and data files, adapted to the requirements of each type of customer and user. Moreover, an excessively detailed specification could limit the progress and evolution in this domain, and prevent adaptation to the most advanced WIM technology.

12.1 Data Storage

12.1.1. This concerns the content, structure and format of the data files which contain the information recorded or computed by the WIM systems. Only the detailed data vehicle by vehicle are considered in this specification. Aggregated data highly depends on the system, softwares and contents are often customised.

These general guidelines are given to ensure user-friendless and facilitate the exchange of data between users. Some of these requirements may evolve with the WIM technology.

12.1.2. In order to avoid any confusion while reading the data files or using the data, explicit headings must appear at the top of each column (or line) of data file, table or graph. The units must also be given, and, as far as possible, the S.I. (System International) system used.

12.1.3. The division scales should be, according to the accuracy classes:

- Class A: 20 kg,
- Class B+: 50 kg
- Class B: 100 kg
- Class C: 200 kg
- Class D+(20): 200 to 500 kg
- Class D: 500 kg

12.1.4. Each type of data must be given with a number of digits in accordance with:

- the accuracy of the whole recording device,
- the accuracy and number of digits of the entire processing software,
- the accuracy requirement of the user.

It is highly recommended to record and deliver the time of passage in hh:mm:ss:cc, up to hundreds of second, because at current highway speed (e.g., 20 m/s) the inaccuracy on the vehicle spacing may be too high for many applications if this time is rounded up to the second.

12.1.5. Because most users perform further analysis by software with the data collected, it is recommended that the data files are given either in a widely distributed spreadsheet format (Excel, Quattro Pro, etc.), or in tabulated ASCII format which can easily be converted. The standard sheets supplied in the Appendix IV are in Excel.

12.1.6. It is recommended that the data files may be read and processed on common personal micro-computers, and may be exported in ASCII format to other computer systems.

12.1.7. If a WIM system is equipped with software to detect any abnormal result or error, it is recommended to:

- keep the wrong result in the detailed data files, but to mark it with an error (violation) code,
- to eliminate the wrong result in the aggregated data files, but to record the statistics of these wrong results.

In both cases, the criteria for wrong result detection must be clearly indicated not only in the technical brochure of the WIM system, but also in any document presenting the data.

12.1.8. The data file itself or the accompanying document must contain some information about the site and the WIM system, such as:

- road identification (name, administrative number - European numbering system, etc.),
- accurate location of the WIM system (milestone, traffic lane measured, etc.),
- type of sensor and of electronics used,
- date of manufacture and of installation of the WIM system,
- date of the last calibration,
- period of measurement,
- owner of the WIM system and contact person in charge of the data collection.

12.1.9. Additional information may be of great interest if available, such as:

- environmental conditions (weather, traffic, etc.) during the measurement period,
- calibration coefficient periodically computed by the system in case of an automatic self-calibration (see section 7.2.5),
- report on the eventual breakdown or failure, and any maintenance operation of the WIM system during the measurement period.

12.1.10. In order to facilitate the data transfer and analysis, the consecutive vehicles recorded should be presented one per line of the file. Some lines at the top of the file may contain the general information listed in section 12.1.8.

12.1.11. The same type of information should be as far as possible in the same column (e.g., date, vehicle length, speed, gross weight or axle of the same rank loads). Therefore it is recommended to group on the left side of the file (the first columns) the data which is common to all vehicles:

- number, error code, date and time of passage, lane, direction, lateral position in the lane, speed, length, number of axles, type (by silhouette), gross weight, etc.,

and on the right side (last columns) the data which only concerns some vehicles:

- axle loads and inter-axle distances (because of the variation in the number of axles per vehicle).

In such a way, the size of the files may be reduced, avoiding having many partially empty columns for the smallest vehicles (only the carriage return symbol - end of line - will be mixed with other data in the same column). If this principle is not applied, the number of columns must be the largest to be used for the longest vehicles.

Appendix IV gives an example of a standard detailed data file, designed for the accuracy assessment of a WIM system according to this specification.

12.2 Data Transmission

12.2.1. The specification of data transmission by telephone line, data network or Herzian wave only depends on the telecommunication standards and technology, and is treated in the relevant official documents. Any customer may specify the standard to be used according to its needs and equipment.

12.2.2. If any future standardised European formats and protocols of transmission appears, they should be used, following the user's requirement and the WIM system capability. The transmission protocol must ensure that no loss of data occurs.

12.2.3. In the case of data transmission while the WIM system is in service, the transmission operation should not interrupt data collection.

13. COST 323 VEHICLE CLASSIFICATION (NOT MANDATORY)

There are many vehicle classifications in a few or large numbers of vehicle categories used in Europe. It is not the scope of this specification to require a unique classification, while depending on the application, the regional traffic patterns, etc., one or the other may be better adapted. However, in order to facilitate some comparison between general patterns from one road to another, or to analyse in details the performance of WIM systems with respect of the type of vehicle to be weighed, a simple classification was agreed.

13.1. The classification given below is mainly based on the silhouette of the vehicles, and on their mechanical dynamic behaviour while travelling at speed. Therefore, it is adapted to WIM studies. According to the limited number of categories, the breakdown of the population of vehicles into the proposed categories should be easy using most of the detailed existing classifications. If that is not possible in some particular cases, the unidentified vehicles will be shared between the two acceptable categories, with a reasonable proportion in each.

13.2. The COST 323 classification is given by:

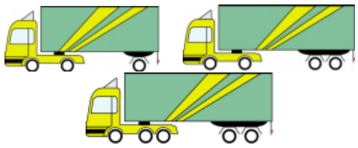
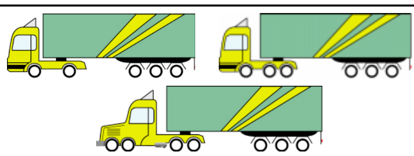
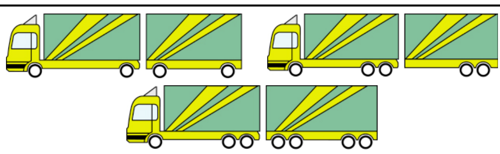
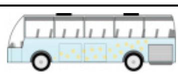
Category	Silhouette	Description
Category 1	Cars, vans (< 35 kN)	Cars, cars+light trailers or caravans
Category 2		Two axle rigid lorry
Category 3		More than 2-axle rigid lorry
Category 4		Tractor with semi-trailer supported by single or tandem axles
Category 5		Tractor with semi-trailer supported by tridem axles
Category 6		Lorry with trailer
Category 7		Busses
Category 8		Other vehicles

Figure 3: COST 323 vehicle classification

APPENDIX I. SIMPLIFIED REQUIREMENTS

I-1 Criteria for the Choice of WIM Sites

The choice of a WIM site has a great influence on the accuracy, the reliability and the durability of any WIM system. Therefore sites are classified according to the road geometry and the pavement characteristics. Table 10 indicates the recommended choice of site depending on the required accuracy level. The widths of the accuracy classes are given in I-6.

Table 10: Choice of WIM site according to the accuracy required

Accuracy	site I (Excellent)	site II (Good)	site III (Acceptable)
Class A (5)	+	-	-
Class B+ (7)	+	-	-
Class B (10)	+	+	-
Class C (15)	(+)	+	+
Class D+ (20)	(+)	(+)	+
Class D (25)	(+)	(+)	+

legend: '-' *means insufficient,* '+' *means sufficient,* '(+)' *means sufficient but not necessary*

Comment: This table does not give a strict relationship between the accuracy classes and the test site: some types of WIM systems - depending on the type of sensor and the measurement principle - may require higher or lower site classes to meet the same accuracy level. For example, large scales or large-based sensors (i.e. longer than the tyre imprint in the direction of the traffic flow) are less sensitive to the pavement evenness than are narrow-based sensors. Moreover multiple-sensor WIM systems may be installed in pavements with poorer evenness, if a suitable algorithm performs calculations to reduce the dynamic effects.

The requirements for bridge WIM systems are given in the chapter 4.3.

I-1.1 Road Geometry

I-1.1.1. It is strongly recommended that road section between 50 m upstream and 25 m downstream of the system meets the following geometrical characteristics:

- longitudinal slope < 1% (class I site) or < 2% (other site classes), depending on the site class 5.2.2) and as far as possible constant;
- transverse slope < 3%;
- radius of curvature > 1000 m (but a straight road would be preferred).

I-1.1.2. The WIM systems should be installed away from any area of acceleration or deceleration, (i.e. close to a traffic light, toll station, etc.), in order to weigh vehicles travelling at uniform speed. It is also desirable to avoid the area where drivers make gear changes, such as slip-roads, etc.

I-1.1.3. It is also desirable to avoid areas where the number of lanes changes as this can lead to vehicles changing lane at the site.

I-1.2 Pavement Characteristics

I-1.2.1. The pavements should meet the following criteria:

- no hard spots in the underlying courses or under the wearing course (toll slabs, service tunnels, etc.);
- thickness of bonded layers greater than 10 cm;
- good mechanical bonding between courses, in particular of bituminous concrete on granular materials stabilised by hydraulic binders. The sensors must be installed in homogeneous layers, not in a joint;
- surfacing should be deterioration-free in the area of sensor installation;
- pavement homogeneous across each traffic lane, ruling out the presence of joints of coated materials in the length of a sensor.

I-1.2.2. The criteria given in Table 11 should be checked over 200m upstream and 50m downstream of the WIM system.

Table 11: Classification and criteria of WIM sites

			WIM site classes		
			I Excellent	II Good	III Acceptable
Rutting (3 m - beam)		Rut depth max. (mm)	≤ 4	≤ 7	≤ 10
Deflection (quasi-static) (13 t - axle)	Semi-rigid Pavements	Mean deflection (10^{-2} mm)	≤ 15	≤ 20	≤ 30
		Left/Right difference (10^{-2} mm)	± 3	± 5	± 10
	All bitumen Pavements	Mean deflection (10^{-2} mm)	≤ 20	≤ 35	≤ 50
		Left/Right difference (10^{-2} mm)	± 4	± 8	± 12
	Flexible Pavements	Mean deflection (10^{-2} mm)	≤ 30	≤ 50	≤ 75
		Left/Right difference (10^{-2} mm)	± 7	± 10	± 15
Deflection (dynamic) (5 t - load)	Semi-rigid Pavements	Deflection (10^{-2} mm)	≤ 10	≤ 15	≤ 20
		Left/Right difference (10^{-2} mm)	± 2	± 4	± 7
	All bitumen Pavements	Mean deflection (10^{-2} mm)	≤ 15	≤ 25	≤ 35
		Left/Right difference (10^{-2} mm)	± 3	± 6	± 9
	Flexible Pavements	Mean Deflection (10^{-2} mm)	≤ 20	≤ 35	≤ 55
		Left/Right difference (10^{-2} mm)	± 5	± 7	± 10
Evenness	IRI index	Index (m/km)	0 - 1.3	1.3 - 2.6	2.6 - 4
	APL(1)	Rating* (SW, MW, LW)	9 - 10	7 - 8	5 - 6

The rutting and deflection values are given for a temperature below or equal to 20°C and suitable drainage conditions.

(1) The APL is a device developed in France and in use in various countries, which measures the longitudinal profile; it consists of two single wheel trailers operating at 72 km/h, towed by a car.

** The rating quantifies the logarithm of the energy dissipated in one of the wavelength ranges: SW = Small Wavelengths (0.7-2.8 m), MW = Medium Wavelengths (2.8-11.3 m), LW = Large Wavelengths (11.3-45.2 m). The scale is from 10 (lowest energy, excellent evenness) to 1 (highest energy, poorest pavement surface).*

Comments about deflection and evenness are given in the detailed specification, section 5.2.1.

I-2 Environmental Requirements

I-2.1. For a standard check, sufficient in a common application, it is recommended to compare the conditions of use given and guaranteed by the manufacturer, and the detailed specifications about climatic conditions, traffic conditions and mechanical resistance given in the main document, sections 6.1 and 6.2.

I-2.2. It is recommended that the site should have power supply and communication facilities; the cost of power installation can be high. The preferable site should have a static weighing area or a static scale close to the WIM site, and a reasonable time for a calibration or test vehicle to perform a complete loop across the WIM site.

I-2.3. For safety reasons it is recommended that there should be sufficient space and convenient access to install a road side cabinet. A cabinet should protect the WIM system against climatic actions and vandalism.

I-2.4. It is recommended that WIM systems should not be installed under high voltage power lines.

I-2.5. It is important to avoid any overpass (aerodynamic effects) or bridge approach (poor evenness); it is also not recommended to install road sensors on a bridge or on any structure subject to dynamic effects.

I-3 On-Site System Checks and Calibration

The following three cases should be distinguished:

I-3.1 The same Company Supplies the Sensors, Electronics and Installation

In this case, no particular checks are required; the general guarantee of the supplier is sufficient.

I-3.2 A Manufacturer Supplies Sensors and Electronics, and Another installs them

In this case, it is necessary to carry out a quick acceptance test of the sensors and electronics before installation; such a test can be done either by the client or by the installer, according to the rules specified by the contract and following the recommendations given in sections II.2 and II.3 of the appendix II of the main document.

I-3.3 Different Suppliers Provide the Sensors, the Electronics and the Installation

The client should first check the compatibility between the sensors and the electronics, or ask the electronics manufacturer or the installer to do that. Then the rules in I-3.2. should be applied.

In all cases the manufacturer's specifications or guidelines for sensor installation should be applied. Summarised specifications are given in the main document, chapter 7.

I-4 On-Site System Calibration

I-4.1. After installation, a WIM system must be calibrated (initial calibration).

I-4.2. The procedure given by the manufacturer should be applied. Its compliance with one of the detailed procedures described in the main document, chapter 8 should be checked.

If the manufacturer or supplier does not propose such a procedure, or in case of a new system or a combined system supplied by several companies (I-3.3), one of the calibration methods given in the detailed specification, sections 7.2 and Appendix II should be applied.

I-4.3. An initial verification of the installed system should be performed to assess its accuracy before acceptance. The procedure is described in chapters 10 and 11.

I-4.4. Periodical calibration and system behaviour checks should be performed, at least once per year (level 2), but preferably every month if possible (level 1).

<u>Level 1 check</u>

An easy and economical calibration and system behaviour check may be performed either:

- by a survey of the coefficients of automatic self-calibration (if this procedure is implemented),

and/or

- by comparison of the traffic patterns (e.g., the gross weight and axle load histograms or statistics), with a reference pattern or data collected by the system right after calibration.

In case of incoherence or obvious wrong results, a complete accuracy check and eventually a recalibration should be performed (see chapters 10 and 11).

<u>Level 2 check</u>

It is recommended than an in-service test be performed periodically (e.g., once per year), following the rules given in chapters 10 and 11. If a significant bias is found, a recalibration should be carried out.

I-5 Accuracy Class Tolerances with respect to the Weights

I-5.1 Accuracy Class Tolerances

Several accuracy classes for individual measurements have been defined (see Table 10). Four main criteria are considered (depending on the system, some or all of them must be considered). These classes are defined by the confidence intervals of the relative errors with respect to the static loads or weights (or in some particular cases with respect to a specified accepted reference).

Some indications about the customer requirements and the classes recommended for each type of applications are given in the detailed specification, chapter 4.

Additional classes E(30) to E(50) are defined in the detailed specification, chapter 8, for systems which do not comply with class D(25).

Table 12: Width of the accuracy classes (confidence interval, δ in %)

Criteria (type of measurement)	**Domain of use**	**Accuracy Classes: Confidence interval width δ (%)**						
		A(5)	**B+(7)**	**B(10)**	**C(15)**	**D+(20)**	**D(25)**	**E**
1. Gross weight	Gross weight > 3.5 t	5	7	10	15	20	25	> 25
Axle load:	Axle load > 1 t							
2. group of axles		7	10	13	18	23	28	> 28
3. single axle		8	11	15	20	25	30	> 30
4.axle of a group		10	14	20	25	30	35	> 35
Speed	V > 30 km/h (1)	2	3	4	6	10	10	> 10
Inter-axle distance		2	3	4	6	10	10	> 10
Total flow		1	1	1	3	5	5	> 5

(1) *For sensors which do not work statically or at very low speed.*

The criteria on speed, axle spacing and counting are <u>not mandatory</u> in this specification. The accuracy class accepted for any WIM system is the best class for which all the criteria are satisfied, or the relevant criteria if some are excluded.

The levels of confidence required within the specified intervals depends on the test conditions (test period length, repeatability and reproducibility of the test and number of measurements). These levels are specified in chapters I-7 and I-8.

I-5.2 Reference Gross Weights and Static Axle Loads

I-5.2.1. The static weighing operations must be done either axle by axle, or by group of axles, by wheel/axle weighers approved for enforcement or commercial applications, or on a weigh-bridge in order to weigh a whole vehicle at once. It is strongly recommended to weigh the gross weights on an approved weigh-bridge to get a reliable reference. In this case, the procedure described in the detailed specification (see 8.3.3) should be applied to derive the reference static axle loads.

I-5.2.2. The road surface on the weighing area should be flat and horizontal. In the latter case, it is recommended to:

- use as many scales as the number of wheels/axles to be weighed for one vehicle, or
- use a ramp or any other device to level all the wheels/axles.

The level difference between axles of a same group should not exceed 2 mm. The level difference between single axles or groups of axles should not lead to more than 0.5% slope (i.e. 1.5 cm for 3 m spacing).

I-5.2.3. During wheel or axle static weighing operation, the vehicle brakes must be fully released.

The results of lorry weighing during an enforcement operation by the police may introduce a bias. Therefore it is recommended that lorries (rented for example) specially allocated to the test for one or two consecutive days are used.

I-6 Type (model) Approval

I-6.1. A type (model) approval test should be organised once to label a newly marketed WIM system.

I-6.2. The test should be carried out on a site in class I (excellent), with a radius of curvature longer than 2500 m, but a straight road is highly recommended.

I-6.3. After the system installation by the manufacturer or the vendor, a pre-calibration should be done using two test lorries (chosen according to 7.2.3.3 of the detailed specification), and one load per lorry, with the following test plan (8 runs):

- 4 runs at V_m,
- 2 runs at 1.2 V_m
- 2 runs at 0.8 V_m.

For a high-speed WIM system, V_m will be taken equal to 75 km/h. For a low-speed WIM system, V_m will be the recommended operation speed.

The static reference axle loads and gross weights should be given to the manufacturer or vendor, in order to adjust the system calibration.

I-6.4. After the pre-calibration, the test is carried out using the standard test plan N°3 (I-8.2). In addition to the 110 runs specified in I-8.2, two of the test vehicles will make 6 additional abnormal runs in order to check the ability of the system to detect such situation, and eventually to mark the wrong measurements with a violation code. These runs will be done as:

- 2-axle rigid lorry: 3 more runs, one with half of the vehicle (left or right half) outside the sensor(s), one run with the first axle passing on the sensor(s) and the second axle passing outside or partially outside the sensor(s), and one run with the lorry braking while passing on the sensor(s) (speed variation from 90 km/h to 60 km/h, or 12 to 5 km/h for a low-speed WIM system).
- 5-axle semi-trailer (with a tridem): 3 more runs, one with half of the vehicle (left or right half) outside the sensor(s), one run with the tractor passing on the sensor(s) and the semi-trailer (tridem) passing half outside the sensor(s), and one run with the lorry braking while passing on the sensor(s) (speed variation from 90 km/h to 60 km/h, or 12 to 5 km/h for a low-speed WIM system).

I-6.5. During the test, the manufacturer or vendor will not be allowed to access to the system.

I-6.6. The reference weights and static loads will be assessed according to the rules given in 9.6 of the detailed specification.

I-6.7. All the recorded data, except those marked with a violation code by the system, will be considered. The data analysis will be done as for an in-service verification (see I-7.2) according to the clauses of section I-8.3. The test conditions will be (I) (environmental repeatability) and (R1) (limited reproducibility). The results will be reported according to the Appendix IV format.

A second analysis will be carried out as for an initial verification (see I-7.1), by removing the mean bias on the gross weight for all the runs, applying by software a constant multiplicative factor on all the recorded axle loads. Then, the factor 0.8 mentioned in I-7.1.3 will be used to assess the accuracy classes for each criterion. The test report will present both analyses.

I-7 Initial and in-Service Verifications of a WIM System

I-7.1 Initial Verification

I-7.1.1. After installation and calibration of a WIM system, or during recalibration, a test may be carried out to assess its accuracy, **using the same data** used for the (re)calibration. This is an <u>initial verification</u>.

I-7.1.2. If the WIM system is calibrated using static calibration masses, <u>all the results</u> must be found within the interval $[-\delta/2; \delta/2]$ of the relevant accuracy class and criterion (single axle, axle group or gross weight according to the measuring scale length).

I-7.1.3. If the WIM system is calibrated using repeated runs of pre-weighed vehicles or instrumented vehicles, the confidence intervals given in Table 12 are modified using a width reduction such as $[-0.8\delta; 0.8\delta]$ for each relevant accuracy class and criterion. The required confidence level of this interval is given in chapter I-8.

I-7.2 In-Service Verification

I-7.2.1. An in-service verification may be done at any time during the lifetime of a WIM system. In this case, the sample of data used for the accuracy assessment must not have been used for any calibration or recalibration of the system.

I-7.2.2. If the WIM system is checked using static calibration masses, all the results must be found within the interval [-δ; δ] of the relevant accuracy class and criterion (single axle, axle group or gross weight according to the measuring scale length).

I-7.2.3. If the WIM system is checked using repeated runs of pre-weighed vehicles or instrumented vehicles, or using single runs of pre- or post-weighed vehicles from the traffic flow, the confidence intervals given in Table 12 are used for each relevant accuracy class and criterion. The required confidence level of this interval is given in chapter I-8.

I-8 Procedures to Check the Accuracy of a WIM System

I-8.1 General Rules

I-8.1.1. The assessment of the accuracy of a WIM system requires a test. This chapter deals with tests carried out using either repeated runs of pre-weighed vehicles. The use of single runs of pre- or post-weighed vehicles from the traffic flow is considered in the main document, chapter 11.

I-8.1.2. The more extensive the test plan (longer test period, higher number of vehicle types and runs), the higher the confidence of the conclusion. This means that the client risk (i.e. the risk of accepting a system in a higher class than it is) decreases as the test becomes more extensive, while the test cost increases. In this analysis the supplier risk linked to the statistical estimation of the mean bias is fixed at 5%.

I-8.1.3. In this specification, the client risk is governed by the probability of an individual error (with respect to the static load or weight) lying outside of the specified confidence interval. An upper bound of this risk is fixed by the specified values ($1-\pi_0$), where π_0 is the required confidence level.

In this appendix, this risk ($1-\pi_0$) is fixed at 5%, or 10% in one case (see I-8.5).

This risk is only assessed under the conditions of the acceptance test (see I-8.5); this means that the farther the test conditions are from the traffic conditions, the lower the real confidence and the higher the customer risk.

I-8.1.4. Depending on the test period length, the test may be carried out in (see definitions in the main document, section 11.1.5):

(I) environmental repeatability

(II) limited environmental reproducibility (not considered in this appendix)

(III) full environmental reproducibility (not considered in this appendix)

I-8.1.5. Neither recalibration nor component exchange should be done during a test period (see the main document, section 11.1.5 for further details).

I-8.1.6. According to the number of test (pre-weighed) vehicles, and load and speed cases, the test may be carried in (see definitions in the main document, section 7.2.3.2):

(r1) full repeatability

(r2) extended repeatability

(R1) limited reproducibility

(R2) full reproducibility (not considered in this appendix)

Some standard simplified test plans are given in section I-8.2.

I-8.1.7. Test vehicles are vehicles which are pre-weighed on an approved static scale or weigh-bridge, and perform repeated runs over the system. The static weighing operation must be made **carefully**, according to I-5.2.

I-8.2 Test Plans

Three main test plans are proposed, two of these being divided into two sub-plans, in order to comply with the customer requirement and resources. They are described in order of increasing cost and reliability. They all are in environmental repeatability conditions (I). The choice of test vehicles should be based on the most common types in the traffic flow.

The tandem or tridem axles should be equipped with air suspensions, in order to avoid gross errors on the static reference axle loads.

(i) Test Plan N° 1 - One Lorry

- a 2-axle rigid lorry only permits the checking of 2 criteria among the 4 (single axle and gross weight);
- a semi-trailer with tridem or tandem or some other vehicle types allow the checking of all the 4 criteria.

Test plan N° 1.1. One load, 10 runs, full repeatability conditions (r1) (Confidence Level π_0 = 95%)

This very short test is mainly recommended for periodical checks, carried out several times per year, or if only one type of vehicles is to be weighed by the system.

The test is carried out within a single day, according to Table 13:

It is recommended that the test vehicle is loaded to close to the mean gross weight of the same type of vehicle in the traffic flow.

Table 13: Test plan N°1.1

Test vehicle	Speed	Number of runs	
2-axle rigid lorry	$1.2V_m$	2 runs	--
or	V_m	6 runs	*7 runs*
5-axle semi-trailer	$0.8V_m$	2 runs	*3 runs*

V_m: mean lorry speed in the traffic flow - *last column, only if* $1.2V_m$ *exceeds the speed limit.*

Test plan N° 1.2. Two loads, 30 runs, extended repeatability conditions (r2) (Confidence Level $\pi_0 = 95\%$)

This short test is recommended for a yearly check of a WIM system.

The test is carried out within a single day, according to Table 14:

Table 14: Test plan N°1.2

Test vehicle	Speed	Load cases and number of runs			
		fully loaded		half loaded	
2-axle rigid lorry	$1.2\ V_m$	3 runs	--	3 runs	--
or	V_m	9 runs	*10 runs*	9 runs	*10 runs*
5-axle semi-trailer	$0.8V_m$	3 runs	*5 runs*	3 runs	*5 runs*

V_m: mean lorry speed in the traffic flow - *in italic, only if* $1.2V_m$ *exceeds the speed limit.*

(ii) Test plan N° 2 - Two Lorries

2 lorries are used: a 2-axle rigid lorry, and a semi-trailer with tridem, (or a rigid lorry with a trailer and a tandem or tridem axle, if the traffic flow contains a high proportion of this type).

Test plan N° 2.1. (confidence level $\pi_0 = 90\%$)

One load per lorry and 2 x 10 = 20 runs, limited reproducibility conditions (R1).

This test can be conducted for a newly installed WIM system, or after repair or modification of the system, if customer resources and time are limited; the confidence level is lower than for the other tests.

The test is carried out within a single day, according to Table 15:

Table 15: Test plan N°2.1

Speed	Test vehicles and number of runs			
	2-axle rigid lorry		5-axle semi-trailer (or road train)	
$1.2V_m$	2 runs	--	2 runs	--
V_m	6 runs	*7 runs*	6 runs	*7 runs*
$0.8V_m$	2 runs	*3 runs*	2 runs	*3 runs*

V_m: mean lorry speed in the traffic flow - *in italic, only if* $1.2V_m$ *exceeds the speed limit.*

It is recommended that the test vehicles are loaded to close to the mean gross weight of the same type of vehicles in the traffic flow.

If a road train is used instead of a semi-trailer, it is recommended that this vehicle should have at least one tandem or tridem axle.

Test plan N° 2.2. (confidence level $\pi_0 = 95\%$)

Two loads per lorry and 110 runs, limited reproducibility conditions (R1).

This test is recommended for a newly installed WIM system, or after repair or modification of the system.

The test is carried out within one to three consecutive days but under the same climatic conditions, according to Table 16:

Table 16: Test plan N°2.2

Test vehicle	Speed	Loading and number of runs			
		fully loaded		half loaded	
2-axle rigid lorry	$1.2V_m$	8 runs	--	5 runs	--
	V_m	14 runs	*20 runs*	10 runs	*13 runs*
	$0.8V_m$	8 runs	*10 runs*	5 runs	*7 runs*
5-axle semi-trailer (or road train)	$1.2V_m$	8 runs	--	8 runs	--
	V_m	14 runs	*20 runs*	14 runs	*20 runs*
	$0.8V_m$	8 runs	*10 runs*	8 runs	*10 runs*

V_m: mean lorry speed in the traffic flow - *in italic, only if* $1.2V_m$ *exceeds the speed limit.*

Remark: the required number of runs is based on the gross weight criterion. If only the single axles criterion (and eventually the axles of a group criterion), is (are) to be checked, the total number of runs may be reduced proportionally, in order to get 110 single axle (axles of a group) passes. But in this case the other criteria should not be checked

(iii) Test Plan N° 3 - Four Lorries

Four lorries, and 110 runs, limited reproducibility conditions (R1), (confidence level π_0 = 95%).

This test plan is the most representative, with a limited number of test vehicles, of the real traffic flow. Nevertheless it is a quite extensive test, which generally cannot be applied as a common acceptance test, but is recommended for new types of system or if several systems are tested together on the same test site.

The test is carried out within one or two consecutive days but under the same climatic conditions, according to Table 17:

Each test vehicle should be loaded to the mean gross weight of the same type of vehicles in the traffic flow.

The total number of runs of each type of lorry may be adapted to fit with the proportions in the traffic flow on the WIM site, with a total number equal to 110.

The test confidence may be increased (but also its cost) by splitting each set of runs (by vehicle type) into two different loads (full and half load, according to the expected proportions in the traffic flow).

Table 17: Test plan N°3

Test vehicle	Speed	Nb runs	Number of runs	
2-axle rigid lorry	$1.2V_m$ V_m $0.8V_m$	30	8 runs 14 runs 8 runs	-- *20 runs* *10 runs*
3-axle or 4-axle rigid lorry	$1.2V_m$ V_m $0.8V_m$	6	1 run 4 runs 1 run	-- *4 runs* *2 runs*
5-axle semi-trailer	$1.2V_m$ V_m $0.8V_m$	60	15 runs 30 runs 15 runs	-- *40 runs* *20 runs*
road train	$1.2V_m$ V_m $0.8V_m$	14	4 runs 6 runs 4 runs	-- *9 runs* *5 runs*

V_m: mean lorry speed in the traffic flow - *in italic, only if $1.2V_m$ exceeds the speed limit.*

The road train (rigid lorry with trailer) should be of the type which is the most common at the site.

If the proportion of one of the proposed vehicle types is negligible (or much smaller than the other ones) in the traffic flow at the site, this type may be excluded, but the total number of runs should be kept equal to 110.

I-8.3 Test Results Analysis

I-8.3.1. The level of confidence is generally fixed at 95%; in one case (test plan 2.1) it is only 90% to reduce the number of runs by a factor 6.

I-8.3.2. Before making the analysis, the numbers *n* of recorded gross weights, groups of axles, single axles and axles of a group must be counted. The number of gross weights should be equal to the value specified in the test plan; if this number is less than 95% of the specified value, the test must be continued or started again, in order to comply with this requirement.

I-8.3.3. The simplified procedure for assessing WIM system accuracy is described step by step below:

1. For each entity (gross weight, single axle, group of axles and axles of a group) the individual relative errors with respect to the static load (weight) or the accepted reference values are calculated:

$$x_i = \frac{(Wd_i - Ws_i)}{Ws_i} * 100 \quad \text{(in \%)}$$

where Wd_i and Ws_i are the in-motion measured value and the static (reference) value.

2. The mean *m* and the standard deviation *s* of the relative errors in each sub-population of x_i (same entity) are calculated.

3. For the considered accuracy class, $|m|/s$ and δ / s are calculated (δ is given in Table 12); in the case of an initial verification, δ is replaced by $0.80.\delta$ (see I-7.1.2).

4. In the diagrams given below, for each test plan and each sub-population size *n*, one curve delimits the "acceptance domain" and the "rejection domain".

For each entity (sub-population), if the point of coordinates ($|m|/s$;δ/s) in the relevant diagram is in the "acceptance domain", then the considered accuracy class is accepted; if not, the considered accuracy class is rejected; a lower class is considered and the process is repeated from step 3.

<u>Remark</u>: For the test plans N°1.1 to N°2.1, all the possible number *n* are given in the relevant diagrams (one curve for each value).

For the test plans N°2.2 and N°3, the possible numbers of *n* becomes too high, and one curve corresponds to each possible interval for *n*. For any modified test plan which provides a number n outside of these intervals, either:

- the curve of the closest interval below *n* should be considered (i.e. for the test plan N°2.2, if *n* = 150, the proposed intervals being [110-120] and [180-220], the first one should be taken into account), or
- the procedure described in the detailed specification, chapter 11 may be applied.

I-8.4 Graphs

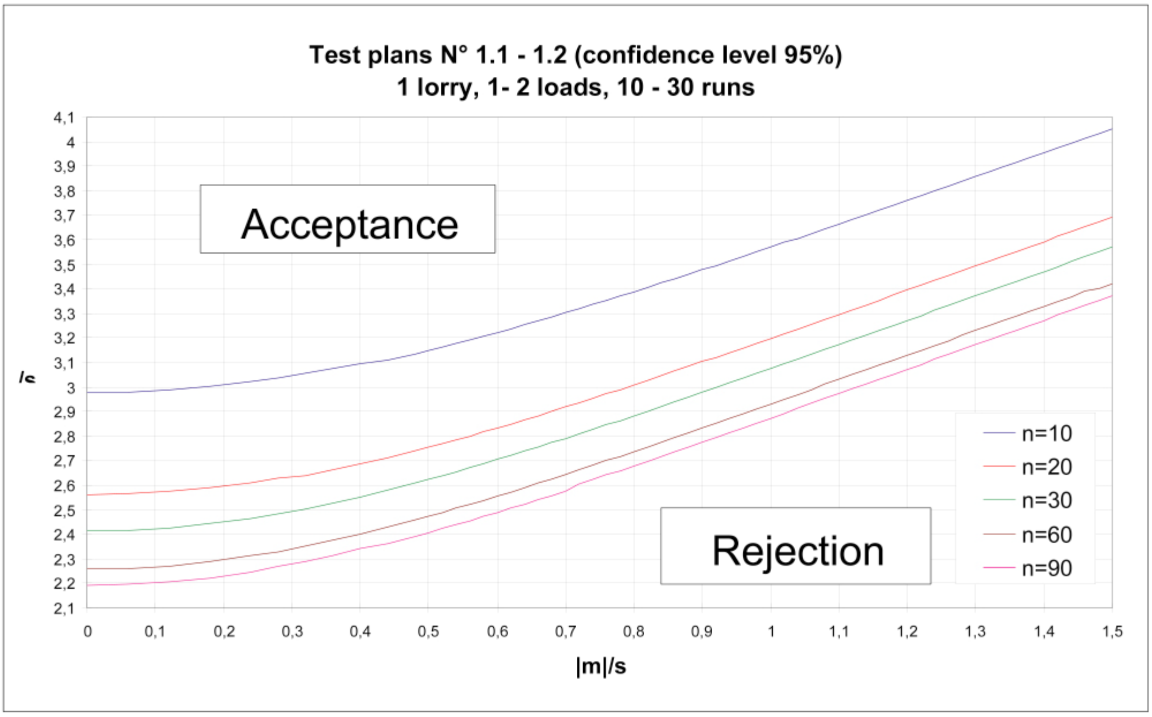


Figure 4: Diagram of the test plan N°1.1

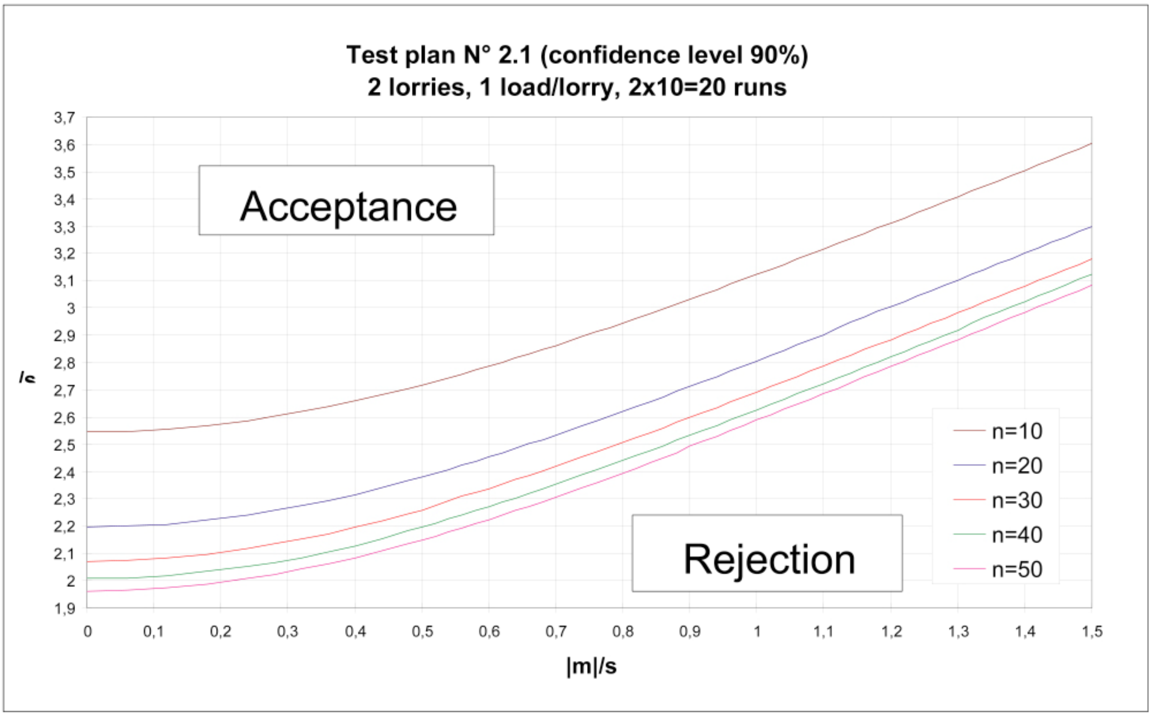


Figure 5: Diagram of the test plan N°2.1

Figure 6: Diagram of the test plan N°2.2

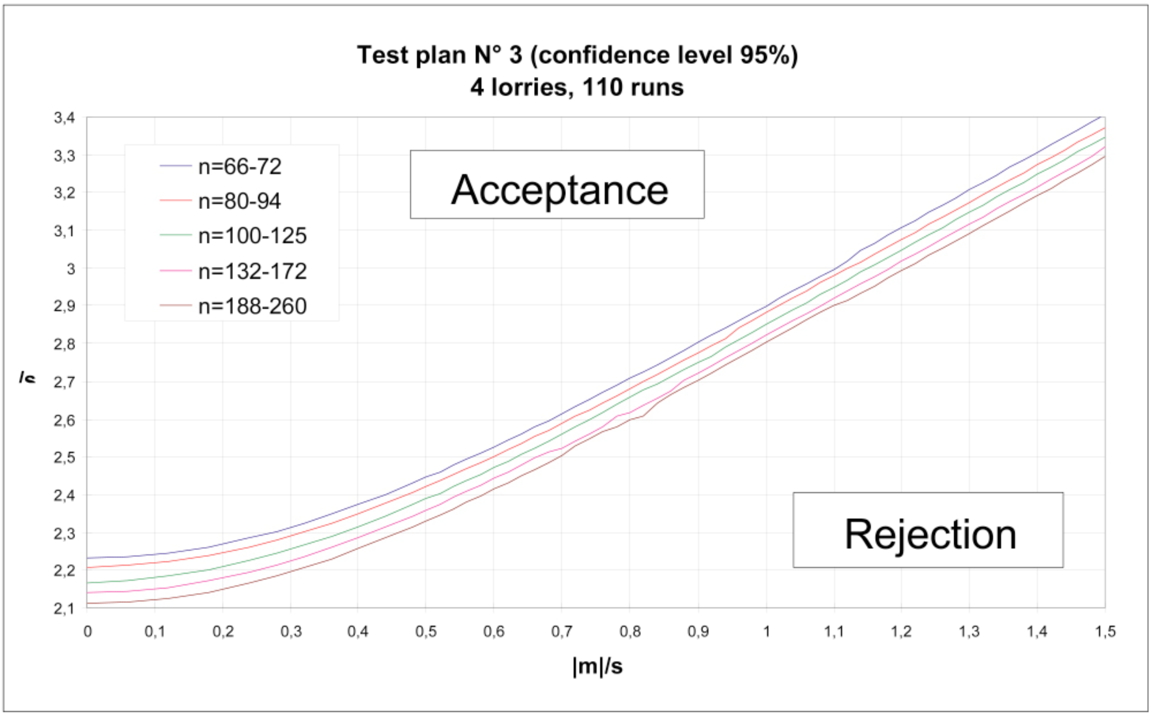


Figure 7: Diagram of the test plan N°3

APPENDIX II. SENSOR ACCEPTANCE AND INSTALLATION

II-1 Checking Before Installation

II.1.1. A quality assurance procedure must be provided by the supplier for the sensors and their characteristics.

II.1.2. Before the installation of any type of WIM sensor, it is recommended to check its performance with respect to the manufacturer's specification or claim. Such tests may be performed systematically by the customer, or by sampling if the supplier provides test charts for each sensor.

II.1.3. As a minimum it is recommended to check that each sensor provides a proper signal by a simple laboratory test.

II-2 Mechanical Checking

II-2.1 Case of Bar and Strip Sensors (Piezo-Electric, Piezo-Quartz, Capacitive, and Fibre Optic)

- Checking of the strip sensor state: no cracks, correct geometrical dimensions, etc.;
- Proper setting of resin (no subsidence when vehicles pass);
- Absence of deterioration's around the bars;
- If resin is used for the sensor mounting, the thickness exceeding the pavement surface must remain constant (in transverse direction), and not exceed 3 mm;
- Connecting cables correctly protected by electrical sheaths, especially at corners;
- Sufficient resistance against bending moment, according to the pavement deflection and the expected loads to be supported.
- The parallelism between bars or the angle with the road axis must also be checked, and more generally the compliance with the suppliers installation brochure.

II-2.2 Case of Mats (Capacitive or other)

- Check of the sensor and of the signal delivered by the wire; no visible physical damage;

- The sensor surface must be flushed to the pavement surface. In case of expected use of snow ploughs, the surface must be slightly (2 mm) lower;
- Proper setting of the resin;
- The resin surface must be flushed to the pavement surface;
- The connection wire should be properly protected against damage in service, preferably sing electrical sheaths.

II-2.3 Case of Strain Gauge or Load Cell Scales

to be completed later with contribution from Captels and Pietzsch

II-3 Electrical Checking before and after Installation

II-3.1 Case of Piezo-Electric Bars

6.3.1.1. ***Insulation resistance****:* this is measured using a megohmmeter, at a voltage of 50 V; the criterion of acceptance is a resistance $R > 10^9\ \Omega$.

6.3.1.2. ***Response of the cable****:* this is read directly from an oscilloscope, under the effect of an impact delivered by the operator (hammer, foot, shock device) or the passage of a vehicle.

For a class A(5), B+(7) or B(10) system, the homogeneity of the response along the bar may be tested by the use of a repeatable shock device, such as a FWD (Falling Weight Deflectometer) or a DYNAPLAQUE (a French portable calibrated shock device used in various countries), with an adapted plate to allow the application of the force to the sensor alone.

The procedure will then be as follows: n series of 3 successive shocks are applied at n points, distributed every 25 cm along the bar, and the means of the 3 measurements are calculated; the two extreme mean values are eliminated and the remaining series of (n-2) mean values are analysed (it produces 11 values for a 3.50 m bar); the bar can be regarded as satisfactory if the range of the mean values observed is within ± 10%. It is recommended to repeat these tests at another ambient temperature (difference of at least 10°C) to estimate the influence of temperature on the bar/pavement system and eventually to correct the signal for temperature effects.

II-3.2 Case of Piezo-Quartz Bars

to be completed later with contribution from Kistler

II-3.3 Case of Capacitive Strips

to be completed later with contribution from Golden River

II-3.4 Case of Fibre Optic Sensors

to be completed later with contribution from Alcatel

II-3.5 Case of Capacitive Mats

- Check the sensor signal by connecting to the electronics unit. The signal must be stable and within the limits specified by the manufacturer;
- Repeat this check after the installation.

II-3.6 Case of Strain Gauge or Load Cell Scales

to be completed later with contribution from Captels and Pietzsch

II-4 Installation recommendations

A WIM system installation (sensors and electronics) requires special procedures depending for example on the type of sensor, the structure of the road, the environmental conditions and the application.

It is obvious that general information should be given concerning the criteria for the site choice, with respect to the embedding and installation procedure of the sensors, etc. (see (METT-LCPC, 1993) for piezo-electric bars).

Nevertheless, the responsibility for a fair installation is the manufacturer's. He must have at his disposal the required information from the road manager, for example about the road structure, the environment and the climatic conditions during the installation.

For some types of sensors, such as piezo-electric and piezo-quartz bars or capacitive strips, the choice of resin to fix the sensor in the pavement may have some influence on the accuracy and has a strong influence on the sensor lifetime and installation delay; some recommendations are given for piezo-electric bars in (METT-LCPC, 1993).

References to some sensor installation guidelines or specification may be given here; contributions from various manufacturers would be welcome.

APPENDIX III. CALIBRATION METHODS

The calibration methods most commonly used are briefly described below, from the simplest to the most sophisticated; other methods may be considered.

<u>Description of common calibration methods</u>

We note:

- Wd_{ijk} = "dynamic" load (impact force) measured in motion of the vehicle *i*, the axle *j*, and the run *k*,
- Wd_{ik} = "dynamic" gross weight for the vehicle *i* and the run *k*, calculated by: $Wd_{ik} = \sum_j Wd_{ijk}$,
- Ws_{ij} = static load of the vehicle *i*, and the axle *j*,
- Ws_i = static gross weight of the vehicle *i*,
- n_i = number of runs of the vehicle *i*,
- p = number of test vehicles.

In the conditions (r2), it is recommended to consider the different configurations (loads and speeds) of the same vehicle as different vehicles for the data analysis.

Calibration coefficient: a calibration coefficient is defined as a multiplicative factor $\boldsymbol{C}$ to be applied to a raw recorded "dynamic" load Wd to get the final estimation of the static load (or the "calibrated" result) noted W: $W = \boldsymbol{C}.Wd$.

A calibration coefficient is intended to eliminate as far as possible any systematic bias in the WIM system, which may partially be induced by the pavement profile (spatial repeatability effect).

If the WIM system uses more than one sensor, at least one calibration coefficient must be computed for each of them.

In some "sophisticated" WIM systems, several calibration coefficients may be computed for each sensor, depending on the type of vehicle or on the axle rank (see ***2.*** and ***3.*** below).

For bridges, the calibration coefficient is replaced by a calibration curve, an influence line or surface.

Among the proposed methods outlined below, the first two (1.a and 1.b) are the most commonly used, while the third one (1.c) is often recommended; they all provide only one calibration coefficient by sensor.

1.a. Calibration on the mean bias: this method consists of calculating the calibration coefficient ***C*** such that for the mean bias of the relative errors for the gross weights of all the test vehicles measured in motion (one measurement for each run) is removed, each of them being accounted as many times as the lorry passed:

$$C = \frac{\sum_i n_i}{\sum_{i,k} \left(\frac{Wd_{ik}}{Ws_i} \right)} \tag{3}$$

This method provides an unbiased estimator of the gross weight. It is recommended in (r1).

1.b. Calibration on the total weight: this method consists of calculating the calibration coefficient ***C*** as the ratio of the total static gross weight of all the test vehicles (each of them being accounted for as many times as the lorry passed) to the total gross weight of these vehicles measured in motion (one measurement for each run):

$$C = \frac{\sum_i n_i Ws_i}{\sum_{i,k} Wd_{ik}} \tag{4}$$

This method provides an unbiased estimator of the total weight of all the vehicles. It is only recommended if the WIM purpose is the estimation of the whole traffic tonnage, such as in economical surveys of goods transportation.

1.c. Calibration on the mean square error (1): this method consists of calculating the slope of a regression line which passes through the origin in an orthonormal diagram plotting the individual "dynamic" gross weights versus the individual static gross weights of the test vehicles for each passage. It is based on the fact that a WIM system should provide "dynamic" loads which are proportional to the static loads. The calibration coefficient ***C*** is given by:

$$C = \frac{\sum_i n_i Ws_i^{\,2}}{\sum_{i,k} Ws_i Wd_{ik}} \tag{5}$$

This method may be applied for conditions (r2) to (R2), with more than 3 lorries (or loading cases); it minimises the mean square error of the individual gross weight measurements with respect to the static gross weights for all the vehicles passed, with the constraint that the "dynamic" gross weights are proportional to the static ones. It is recommended for most applications, when the purpose is the estimation of the individual lorry weights, because the estimator has a lower variance than the two previous ones and a very small bias.

1.d. Calibration on the mean square error (2): this method consists of calculating the slope and the ordinate at the origin of the regression line in an orthonormal diagram plotting the individual "dynamic" gross weights versus the individual static gross weights of the test vehicles for each passage. The mean square error should be smaller than with the previous method, but the proportionality between the "dynamic" loads and the static loads is no longer ensured, which is not in accordance with theory. The calibration procedure becomes: $W = \boldsymbol{C}.(Wd - b)$, with b and $\boldsymbol{C}$ given by***:***

$$C = \frac{\left(\sum_i n_i\right)\left(\sum_i n_i Ws_i^2\right) - \left(\sum_i n_i Ws_i\right)^2}{\left(\sum_i n_i\right)\left(\sum_{i,k} Ws_i Wd_{ik}\right) - \left(\sum_i n_i Ws_i\right)\left(\sum_{i,k} Wd_{ik}\right)} \tag{6}$$

and

$$b = \frac{\left(\sum_i n_i Ws_i^2\right)\left(\sum_{i,k} Wd_{ik}\right) - \left(\sum_i n_i Ws_i\right)\left(\sum_{i,k} Ws_i Wd_{ik}\right)}{\left(\sum_i n_i\right)\left(\sum_i n_i Ws_i^2\right) - \left(\sum_i n_i Ws_i\right)^2} \tag{7}$$

This method is not recommended in most cases because of the reason explained above. Furthermore, if applied, the b value should be rather small and independent of the calibration vehicle sample considered, which is not necessarily the case.

*In both methods **1.c.** and **1.d.**, the gross weights may be replaced by the axle loads and the formulas adapted. The calibration coefficients will then be slightly different. This is not highly recommended, because the individual axle loads are more significantly affected by the dynamic motion of the vehicles than the gross weights, and because the static axle loads are not well defined.*

2. Calibration by lorry type: this method provides one calibration coefficient for each type (silhouette) of lorry from the test sample, or for each class of silhouette (e.g., rigid lorry, tractor + semi-trailer, lorry + trailer). It is only applicable for conditions (R1) and (R2), and of interest if the WIM station software is able to manage such a set of calibration coefficients according to each lorry type. The same formulas as in ***1.a.*** to ***1.d*** may be applied, as many times as the number of lorry classes considered. The same remarks apply to each formula and procedure.

3. Calibration by axle rank: this method provides one calibration coefficient for each rank (and/or type) of axle within a lorry, taking into account the fact that the axle dynamic behaviour depends on their rank in the vehicle. It is only of interest if the WIM station software is able to manage such a set of calibration coefficients according to each axle rank. It is recommended to consider the following sub-populations, some of which may be merged for simplification:

- for the rigid 2-axle lorry: the front axles and the rear axles,
- for the rigid 3-axle lorry: the front axles and the rear tandem (sum of the two rear axles),
- for the semi-trailers: the front axles, the drive axles and the tandem or tridem of the semi-trailer (sum of the two or three rear axles),
- for the lorry + trailer: the front axles, the rear axles (or tandem or tridem) of the lorry, the axles of the trailer.

The formulas given above are again applied to each sub-population by replacing the gross weights by the axle loads. The same remarks apply to each formula and procedure.

Except for bridge WIM, all of these calibration methods are more efficient in cases (R1) and (R2) with a test lorry sample being representative of the expected traffic flow. In the case of (r1) or (r2) it is recommended to choose loads (gross weights and axle loads) which are representative of the load distribution encountered for the same type of vehicles as the test lorry in the traffic flow.

APPENDIX IV. STANDARD FORMAT, COMPUTER TOOLS

IV-1 Standard Results' Format and Computer Tools for Accuracy Assessment

IV-1.1 Data Presentation and Statistics Calculation

Figure 10 and Figure 11 gives a standardised table, designed under Excel, which contains the most useful information in order to apply this specification and to assess the accuracy of a WM system. A sample of this Excel sheet is available on floppy disk, or by Internet on the European WIM Web site (http:/www.zag.si/wim/specification).

The first part of the table gives the standard data delivered by the WIM system, which should be easily extracted from the original data files. The vehicles affected by a violation (error) code were eliminated, but accounted for, to be reported in the test report. The general heading only contains a summary of the required information listed in 12.1.18 of the specification. The successive columns contain:

- the sequential number of the vehicles (only lorries with a GW > 3.5 t are kept);
- date (given once per day, in Day/Month/Year) and time of passage (hh:mm:ss); for this application, it is not necessary to use hundreds of second;
- temperature, in °C;
- velocity in km/h;
- vehicle type, according to any classification (the COST 323 classification may be used by default);
- the gross weight and axle loads, by axle rank, and the group of axle loads (by rank), all measured in motion;
- the static reference values of these weights and loads.

N.B. the axle spacing is used in the pre-processing of the raw data to identify the single axles and axles of group, but are not necessary for the further accuracy analysis.

All the weights and loads are given in kg, but with a scale division of 100 kg according to the sensitivity and accuracy of the system.

The second part of the table gives the relative errors, automatically calculated by formula in the Excel sheet, and the axle type (single axles or axle of group). Finally, the statistics of the relative errors, as required in 11.4.5 and 11.4.6 are automatically calculated by formula, combining the individual relative errors and the type of axle information.

The small table of these statistics are the sufficient information needed to perform the accuracy calculation, using the test conditions (see IV-1-2).

IV-1.2 Accuracy Calculation

The accuracy calculation, according to the procedure detailed in the chapter 11, may be automatically done using the standardised Excel sheet given in Figure 12. The statistics calculated in IV-1.1 are introduced in the relevant cells, as well as the test conditions. The percentages of identified vehicles in the whole test sample are reported for information. If the system has a violation code, two percentages should be given, taking into account or not the vehicles identified but wrongly measured.

For an initial verification, where the same data sample is used to recalibrate the system, and thus the mean bias on the gross weight is (almost) removed, δ is automatically multiplied by k = 0.8 (see 10.1.3).

The built-in formula calculates the values of π_0, and using the solver with appropriate arbitrary initial values of δ_{min} automatically fulfils the table. The standardised graph is also provided, which shows both the δ_{min} and δ_c values for all the criteria.

This Excel sheet is also available on floppy disk, or by Internet (see IV-1).

Figure 10, Figure 11 and Figure 12 are at the end of the section IV-2.2.

IV-2 Example of Implementation of the Checking Procedures

In order to illustrate the procedure explained in chapter 11, an example is given hereafter.

IV-2.1 Calibration Plan

A WIM system was installed and calibrated during one and half day (environmental repeatability conditions (I)), following the procedure described in 7.2.3. The calibration plan was the following:

- two pre-weighed lorries were used, a 2-axle rigid lorry and a 5-axle semi-trailer;
- each of these test vehicles made several runs past the WIM site, at different speeds, and for the semi-trailer at different loads, according to Table 18; all together 115 runs were recorded;
- the WIM system was then calibrated on all these run results, with the formula (3) of the appendix III, using the gross weights;

- the initial accuracy verification is the done with these results, according to the procedure described in chapter 11.

According to this calibration plan, we are in the conditions of limited reproducibility (R1).

Table 18: Calibration plan with two pre-weighed test lorries

Test vehicle	**Speed (km/h)**	**Loading and number of runs**		
		Fully loaded	**Half loaded**	**Empty**
2-axle rigid lorry	80	10 runs	-	-
	65	20 runs	-	-
	50	10 runs	-	-
5-axle semi-trailer	80	10 runs	10 runs	5 runs
	65	10 runs	10 runs	5 runs
	50	10 runs	10 runs	5 runs

IV-2.2 Initial Verification and Accuracy Check

The results of the initial verification using the calibration sample data are summarised in Table 19.

The values of δ are taken from Table 5 for the classes retained, and multiplied by the reduction factor k = 0.8 (see 10.1.3). The theoretical probability π is used. The minimum required π_0 are either taken from Table 7 (conditions (I) and (R1)) and interpolated, or automatically by the Excel sheet of Figure 2. Values of δ_{min} obtained for $\pi = \pi_0$ are also given to be compared to k.δ.

It may be seen that the WIM system fulfils the requirements of class (C(15) in this initial verification, and even B(10) for the group of axles criterion (tridem here). Figure 8 show the results as well.

Table 19: Results of the initial verification

	Statistics of relative errors				**Accuracy calculation**					**Accepted class**
	Number	**Mean**	**Std deviat.**	π_o	**Class**	0.8×δ	δ_{min}	δ_c	π	
Criterion	***n***	***m*** (%)	***s*** (%)	(%)		(%)	(%)	(%)	(%)	
gross weight	115	-0.29	4.28	95.1	**C(15)**	12	9.3	11.7	99.0	**C(15)**
group of axles	75	0.23	6.01	94.6	**C(15)**	14.4	13.1	13.4	96.6	
single axle	235	-0.62	7.31	95.7	**C(15)**	16	15.9	14.9	95.9	
axle of group	225	0.26	6.96	95.7	**B(10)**	16	15.1	9.4	96.9	

Figure 8: Results of the initial verification

IV-2.3 In-Service Check of the WIM System

After the initial calibration, a test was performed to check the accuracy of the system in more realistic conditions, i.e. in full reproducibility conditions (R2). For that in-service checking, the test plan was to take about one hundred lorries from the traffic flow, with the help of the police during an enforcement period over three consecutive days (environmental repeatability conditions (I)). These lorries were pre-weighed on an approved static scale installed 5 km upstream of the WIM site. The axle loads were measured on this scale. Every pre-weighed lorry was then identified by its registration plate (and some visual description) and when passing on the WIM site (two operators were linked by radio).

The sample composition of these pre-weighed lorries was chosen in accordance with the traffic composition of this road, following a special agreement with the police. 86 lorries were weighed on the static scale and available for the test analysis.

The results of the test are summarised in Table 20 with the same presentation as in Table 19. The value of π_0 are taken from Table 7 (interpolated) or calculated.

The alternative method described in 11.4.7.2 is applied by comparing the value of δ_{min}, for which $\pi=\pi_0$, to the δ of the required class. δ_{min} gives the right accuracy level between two levels codified by letters. For two criteria (single axles and gross weight) the accuracy level is really in-between the conventional limits of classes B(10) and C(15). For the axle groups, it is closer to the class C(15) limit, while for the axles of group the value is just above the limit of the class B(10) (Figure 9).

Table 20: Results of in-service verification

	Statistics of relative errors				Accuracy calculation					
	Number	**Mean**	**Std deviat.**	π_o	**Class**	δ	δ_{min}	δ_c	π	**Accepted class**
Criterion	***n***	***m*** (%)	***s*** (%)	(%)		(%)	(%)	(%)	(%)	
gross weight	86	-2.27	6.09	92.6	**C(15)**	15	13.0	13.0	96.3	**C(15)**
group of axles	66	0.30	8.44	92.1	**C(15)**	18	17.1	14.1	93.6	
single axle	197	-3.92	7.66	93.7	**C(15)**	20	17.1	12.1	97.3	
axle of group	169	-0.19	10.07	93.5	**C(15)**	25	20.3	10.3	97.9	

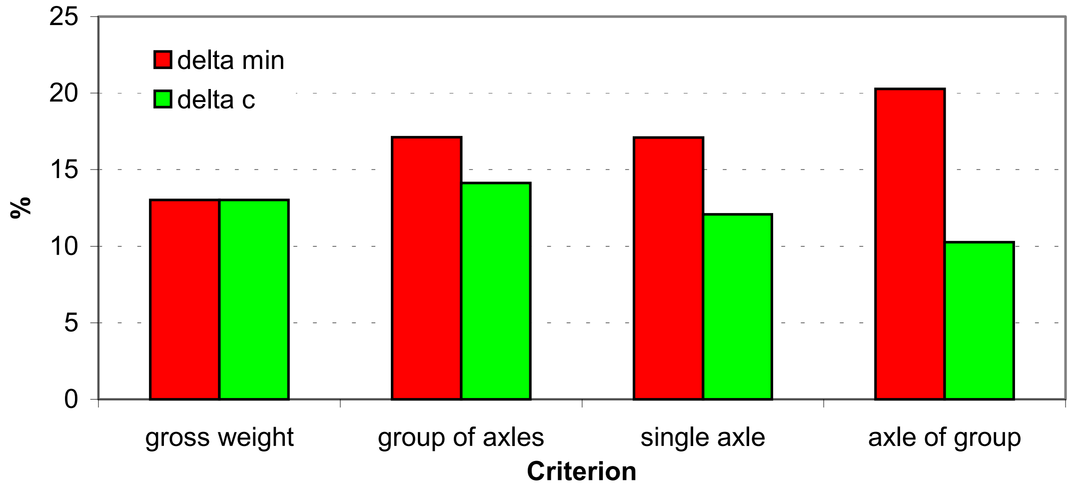


Figure 9: Results of in-service verification

The system is accepted in accuracy class C(15) for all criteria.

In comparison with the initial verification, the bias on the single axle loads and on the gross weights are respectively increased by factors of 5 and 10 (but the last one was very small), while the standard deviations of the axle group and gross weight samples increased by more than 40 %.

This example, based on true data, shows a typical difference between the two steps (initial verification and in-service checking).

System: "Name or manufacturer" **Location: "test site"** **Lane N°: kk**

RECORDED DATA

Period of the test: "from date1 to date2"
Test conditions: (I to III) and (r1 to R2) **Number of test vehicles: nnnn**

Load and weights may be expressed either in kg, 100 kg, tons or kN; the unit must be specified in the headings

N°	Date/ time	T (°C)	V (km/h)	Type	In motion loads/weights *Wd* (kg)										Static loads/weights *Ws* (in kg)									
					GW	A1	A2	A3	A4	A5	A6	…	GA1	GA2	GW	A1	A2	A3	A4	A5	A6	…	GA1	GA2
1	5/4/98 8:10:25	9,3	85	5	38000	6400	10600	7000	7000	7000			21000		39000	6500	10800	7300	7200	7200			21700	
2	8:11:23	9,5	89	5	39600	6200	13500	6900	6300	6700			19900		40200	6600	12100	7300	7000	7200			21500	
3	8:12:28	9,7	89	5	39400	5900	10300	9400	7300	6500			23200		38500	5900	9600	8700	7900	6400			23000	
4	8:13:06	9,9	88	5	40900	7100	10100	8200	8100	7400			23700		40500	6700	10100	7900	7900	7900			23700	
5	8:13:30	10,1	87	5	40000	8100	11700	7100	7000	6100			20200		39800	7500	11800	6900	6600	7000			20500	
6	8:13:56	10,1	90	5	30700	6700	12500	3600	4200	3700			11500		28200	6700	9900	3900	4000	3700			11600	
7	8:14:54	10,1	89	5	41300	6400	9800	8300	8600	8200			25100		42800	6100	10600	8700	8800	8600			26100	
8	8:16:09	10,1	79	6	36600	6500	12400	9000	8700						35700	6400	11100	9200	9000					
9	8:16:12	10,1	85	5	40500	6500	9200	8500	8100	8200			24800		39500	6500	9400	8100	8200	7300			23600	
10	8:16:32	10,1	88	5	42200	8200	13800	6900	6500	6800			20200		42000	7800	13400	7000	6900	6900			20800	
11	8:17:38	10,1	81	5	48300	8000	13000	8900	9200	9200			27300		48600	8100	13700	8900	8900	9000			26800	
12	8:18:28	10,2	88	5	33500	6100	5600	7300	7400	7100			21800		32600	6000	5200	7000	7200	7200			21400	
13	8:19:03	10,3	89	5	48700	7800	14200	9100	8500	9100			26700		46800	7200	14500	8400	8400	8300			25100	
14	8:19:50	10,4	86	5	37400	6400	8600	7600	7500	7300			22400		38600	6200	8300	8100	8400	7600			24100	
15	8:20:49	10,5	80	6	44900	6700	7200	8300	6400	7400	8900		16300		43900	6500	7500	8000	7100	7000	7800		14800	
16	8:21:03	12	88	5	39000	6200	10100	7500	7900	7300			22700		38400	6000	9700	7400	8000	7300			22700	
17	8:21:20	12	92	5	20200	5400	5300	3500	2900	3100			9500		20600	5200	5400	3400	3300	3300			10000	
18	8:22:29	12,3	86	5	37000	6100	7900	8400	7200	7400			23000		35000	6000	7400	7800	6800	7000			21600	
19	8:23:27	12,3	95	2	6800	2700	4100								6900	2900	4000							
20	8:23:33	12,4	88	5	43300	6900	11400	8800	8200	8000			25000		45400	6700	12100	8900	8900	8800			26600	
21	8:23:37	12,8	85	5	41500	6400	8800	7800	8200	10300			26300		40500	6200	9000	7300	8000	10000			25300	
22	8:25:13	13,4	89	6	42800	8400	12200	6700	7500	8000			18900		42900	7800	12300	6900	8000	7900			19200	
23	8:25:25	13,4	87	5	31300	6500	8800	5500	5000	5500			16000		29900	6300	8200	5200	5100	5100			15400	

Type*: the classification is that recommended by this specification; otherwise the vehicle categories should be given apart*
- axle loads are placed in columns A1 to A6, according to the axle rank; GA1 (and GA2 if needed) contains the group(s) of axle loads
- the type may be replaced by the number of axles, or this number may be added in an additional column
- for more than 6 axles, add columns after A6; for more than 2 axle groups, add columns after GA2

Figure 10: Standardised recorded data format and statistics – part1

STATISTICS

Cont'n

N°	Relative errors (%)										Type of axle (1=SA, 0=AoG)						
	GW	A1	A2	A3	A4	A5	A6	…	GA1	GA2	A1	A2	A3	A4	A5	A6	…
1	-2,56	-1,54	-1,85	-4,11	-2,78	-2,78			-3,23		1	1	0	0	0		
2	-1,49	-6,06	11,57	-5,48	-10,00	-6,94			-7,44		1	1	0	0	0		
3	2,34	0,00	7,29	8,05	-7,59	1,56			0,87		1	1	0	0	0		
4	0,99	5,97	0,00	3,80	2,53	-6,33			0,00		1	1	0	0	0		
5	0,50	8,00	-0,85	2,90	6,06	-12,86			-1,46		1	1	0	0	0		
6	8,87	0,00	26,26	-7,69	5,00	0,00			-0,86		1	1	0	0	0		
7	-3,50	4,92	-7,55	-4,60	-2,27	-4,65			-3,83		1	1	0	0	0		
8	2,52	1,56	11,71	-2,17	-3,33						1	1	1	1			
9	2,53	0,00	-2,13	4,94	-1,22	12,33			5,08		1	1	0	0	0		
10	0,48	5,13	2,99	-1,43	-5,80	-1,45			-2,88		1	1	0	0	0		
11	-0,62	-1,23	-5,11	0,00	3,37	2,22			1,87		1	1	0	0	0		
12	2,76	1,67	7,69	4,29	2,78	-1,39			1,87		1	1	0	0	0		
13	4,06	8,33	-2,07	8,33	1,19	9,64			6,37		1	1	0	0	0		
14	-3,11	3,23	3,61	-6,17	-10,71	-3,95			-7,05		1	1	0	0	0		
15	2,28	3,08	-4,00	3,75	-9,86	5,71	14,10		10,14		1	0	0	1	0	0	
16	1,56	3,33	4,12	1,35	-1,25	0,00			0,00		1	1	0	0	0		
17	-1,94	3,85	-1,85	2,94	-12,12	-6,06			-5,00		1	1	1	1	1		
18	5,71	1,67	6,76	7,69	5,88	5,71			6,48		1	1	0	0	0		
19	-1,45	-6,90	2,50								1	1					
20	-4,63	2,99	-5,79	-1,12	-7,87	-9,09			-6,02		1	1	0	0	0		
21	2,47	3,23	-2,22	6,85	2,50	3,00			3,95		1	1	0	0	0		
22	-0,23	7,69	-0,81	-2,90	-6,25	1,27			-1,56		1	0	0	1	1		
23	4,68	3,17	7,32	5,77	-1,96	7,84			3,90		1	1	0	0	0		

Statistics of the relative errors (%)				
	GW	SA	AoG	GA
number	23	52	60	21
mean	0,97	1,52	0,17	0,06
st. dev	3,22	6,31	5,88	4,77

GW= gross weight
SA= single axle
AoG= axle of a group
GA= group of axles

- the relative errors are calculated cell be cell from the previous part of the sheet using the formula: e=(Wd-Ws)/Ws
- the type of axle can be delivered by the WIM system, or derived from the axle spacing (AoG if the spacing is less than 2.2 m)
- the statistics of the relative errors are calculated using formula, which combine the relative errors and the type of axle cells

Figure 11: Standardised recorded data format and statistics – part 2

	A	B	C	D	E	F	G	H	I	J	M	O	P	Q
1	**Conditions [1]**	**Test plan**		**Env[t]**		**Initial verification (Yes=1, No=0):**					0			
2		rr1		I										
3														
4	**SYSTEM**	**Number**	**Identified**	**Mean**	**Std deviat**	π_o	**Class**	δ	δ_{min}	δ_c	π	**Accepted**		
5	***Entity***		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**		
6	**gross weight**	100	96,2	1,50	3,67	95,0	**B(10)**	10	8,5	8,5	98,0			
7	**group of axles**	50	96,2	2,00	5,78	93,9	**C(15)**	18	13,3	10,3	99,0	**C(15)**		
8	**single axle**	170	95,5	2,10	6,54	95,5	**B(10)**	15	14,8	9,9	95,7			
9	**axle of group**	120	96,0	2,50	9,72	95,2	**C(15)**	25	21,8	11,8	97,8			

10 (1)
11 "r1"=full repeatability
12 "r2"=extended repeatability
13 "rr1"=limited reproducibility
14 "rr2"=full reproducibility
15 "I"=environmental repeatability
16 "II"=environmental limited reproducibility
17 "III"=environmental full reproducibility

Users' instructions:

1. Enter the test conditions in cells B2 and D2, and put "1" in cell M1 if the same data sample was used for calibration (initial verification)

2. Enter the test statistics (on relative errors) in cells B6 to B9 and D6 to E9

3. (option) Initialise the expected values of δ_{min} in cells I6 to I9 ***(only if step 4. fails)***

4. Start the command "Tools/Solver/Solve/keep the results" - "Outils/Solveur/Résoudre/Garder la solution du solveur" , and then OK if successful

if the solver doesn't find an accepted solution, return to step 3. and modify the initial values of δ_{min}

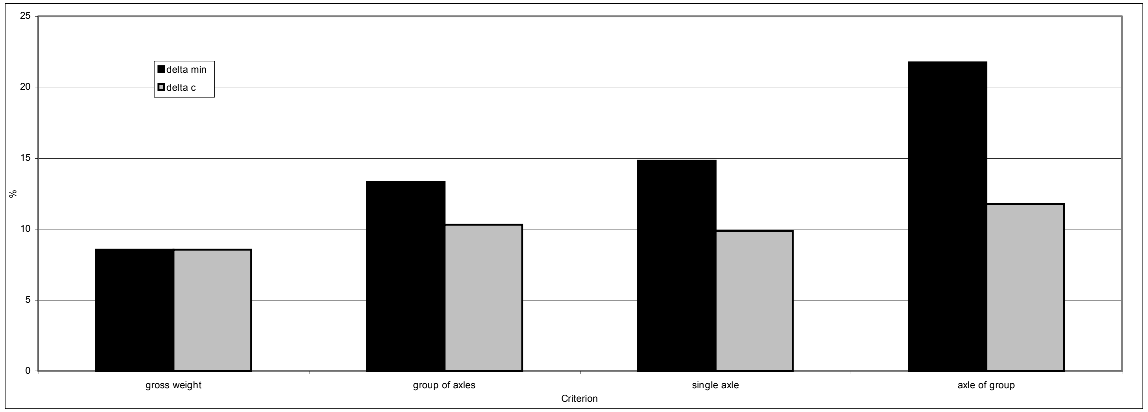


Figure 12: Standardised accuracy calculation sheet and presentation