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ASSESSMENT OF THE ACCURACY AND CLASSIFICATION OF WEIGH-IN-MOTION SYSTEMS
Part II - EUROPEAN SPECIFICATION

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Abstract

This is the second part of a two-part paper which addresses the issue of accuracy in weigh-in-motion (WIM) systems. The first part develops the statistical background necessary for any system of accuracy classification applied to a WIM system. This second part describes a draft European specification for the weigh-in-motion (WIM) of road vehicles, prepared by the COST 323 management committee. The philosophy behind the specification is outlined and thebasic structure detailed.

The specification gives an indication of what WIM accuracy might be achievable from sites with particular characteristics. There is a comprehensive review of methods of calibrating and testing WIM systems. Four types of calibration/test conditions are described for tests using statically pre- or post-weighed vehicles. Accuracy classes are defined on the basis of the width of the confidence interval within which the measured results lie. Confidence interval widths are specified for gross weights and weights of individual axles among other things The percentage of test results which are required to fall within the confidence intervals is a function of the test conditions and the number of test runs. Examples using real WIM data illustrate the use of the specification.

Keywords

Specification, Standard, Traffic, Load, Pavement conditions, Vehicle, Gross weight, Axle load, Weigh-In-Motion, WIM, Sensor, System, Calibration.

1. Introduction

There is considerable interest in Weigh-in-Motion (WIM) throughout Europe at present where there are in excess of 300 systems in operation. WIM systems currently exist in 15 countries in Western Europe and more than 5 in Eastern Europe and the number is increasing. The reasons are the many applications for which WIM data can be used. These are discussed in detail in COST 323 (1997b) but can be summarised as:

- Economical and geographical studies of freight movement
- Pavement aggressiveness and fatigue studies
- Bridge assessment and code calibration
- Enforcement of legal weight limits

Throughout Europe there are in excess of 15 WIM system/sensor manufacturers, including many of the pioneers who developed new technologies such as piezo-ceramic, piezo-quarz, capacitive and fiber optic sensors.

In order to facilitate the relationships between WIM users and suppliers, to clarify the real levels of accuracy and performance of WIM systems, and to provide a strong basis for calls for tender or acceptance tests, it has been decided to develop a harmonised European WIM Specification. The context of European legislation harmonisation, standardisation and codification (such as with the Eurocodes) is particularly favourable for such work at present. It requires close co-operation between several countries; an objective of the European COST (Co-Operation for Science and Technology) Transport programme is to facilitate such co-operation between experts and to provide a common technical background.

At the time of writing, there is no official European standard for WIM and few recent national specifications (METT-LCPC 1993, VIEA 1994, NWML 1995). Consequently there was a strong demand for such a document in the WIM industry and this task was one of the highest priorities of the COST 323 action on WIM of road vehicles, COST 323 (1993). Two years were spent initially analysing existing and emerging specifications (ASTM 1994, OIML 1996) and other technical documents (Gillmann, 1992), and preparing the table of contents. The European Specification was subsequently drafted between May 1996 and January 1997. It was then discussed with the European manufacturers and users' representatives. Comments were received and addressed in a revised draft published in June 1997 (COST 323 (1997a)). The main improvement for users was the addition of an appendix giving simplified requirements, not presented in detail in this paper, which contain only the most important clauses and some simplified rules. This draft was circulated widely by mail in Summer 1997 and positive comments were received.

2. Philosophy and Structure of Draft Specification

The final specification document consists of two parts, the main text and an appendix giving the simplified requirements. The main text is a comprehensive document with a number of mandatory clauses but considerable flexibility is allowed in means of testing of systems. In addition, there are informative clauses which are intended to provide the user with some background information about WIM or about the reasons for the mandatory clauses. In the present draft, the two types of clauses are mixed but the informative clauses are marked with a bar in the margin. The main physical, metrological and statistical background for the specification are presented in the first part of this paper. The simplified requirements, given in Appendix 1 of the specification, consist of a set of rules, tables and graphs for the calibration and testing of WIM systems. The rules, if satisfied, are sufficient to allow a system to be classified as being in compliance with the standard and of a certain accuracy class. Standard test plans are proposed, which may be used alternatively, depending on the available means and the user's requirements. Charts facilitate a quick and easy implementation of the specification with a pocket calculator. However, the appendix does not contain all methods by which WIM systems can be calibrated and classified.

Central to the specification is the definition of seven accuracy classes, A(5), B+(7), B(10), C(15), D+(20), D(25) and E. The latter is divided into further classes: E(35), E(40), etc.. The highest accuracy levels (A(5) and B+(7)) are recommended for legal purposes, such as overload enforcement, if current legislation applicable at the site allows the use of WIM for that purpose. The intermediate levels (B(10) and C(15)) are recommended for overload pre-selection, and for detailed traffic analysis involving the use of axle loads and gross weights. Such data might be used for applications in bridge and pavement engineering, design and maintenance. The lowest levels (D+(20) and D(25)) are mainly required for economical and technical studies and general traffic evaluation and management. Obviously, the rougher the pavement, the lower will be the accuracy of a WIM system. Therefore in some circumstances, users may accept a system in a lower class than desired in order to obtain measurements on a medium quality road. Classes E are applicable some low cost or portable WIM systems, or are encountered for common WIM systems installed on rough roads or with pavements in poor condition.

To be in a given class, there must be an acceptable level of confidence that WIM weights will be within a specified percentage of the reference (usually static) values. The numbers in brackets indicate the allowable relative error (in %) in gross vehicle weight but there are also specified error limits for the weights of groups of axles (i.e., successive axles with spacing less than 2 m), individual single axles and axles of a group taken individually.

The specification gives a detailed description of the means by which a WIM system can be calibrated, tested and classified in one of the accuracy classes. In addition, it provides an indication of what accuracy might be achievable from a site with particular characteristics as will be described below. There is also some discussion about data storage, processing and transmission.

3. Choice of WIM Site

The characteristics of a WIM site can significantly affect the accuracy of results. Road roughness, in particular, results in an excitation of the dynamics of passing trucks. Increased dynamic variation in applied force clearly tends to result in a reduction in the accuracy of static weight estimates. It has been well established in recent studies (Gyenes & Mitchell 1992, Cole & Cebon 1992, Barbour 1993, Barbour & Newton 1995, Jacob 1995, O'Connor et al. 1996, Jacob & Dolcemascolo 1997) that spatial repeatability exists, i.e., that road profiles induce a **characteristic** dynamic response from trucks. The result of this is that some parts of the road are repeatedly subjected to higher dynamic forces than others. The implications for WIM is that there can be a consistent bias in results related to the sensor location on the road. Unfortunately, it may not be possible to detect this without access to a large number of pre-weighed trucks. That makes the calibration difficult.

It has also been established (compare for example Barbour (1993) and O'Connor et al. (1996)) that patterns of spatial repeatability tend to be stronger in roads that are less even. Thus, an uneven road surface is likely to result in both a large dispersion in WIM weights relative to the static value and in a bias in the mean result. Nevertheless the 'statistical spatial repeatability' identified by O'Connor et al. (1996) may be corrected by means of a comprehensive calibration.

In addition to accuracy, site characteristics can significantly affect the durability of WIM systems. Properties such as deflection and rutting clearly influence the long term integrity of the system in its surroundings. Deep ruts may lead to brittle sensor failure and to shocks increasing the dynamic vehicle motions and affecting the accuracy. Large deflections may lead to sensor failure by fatigue or brittle failure, but can also affect the repeatability of the measurement. Pavement cracking also frequently causes sensor failure.

			WIM Site Class		
			I (Excellent)	**II (Good)**	**III (Acceptable)**
Rutting (3 m - beam)		Rut depth max. (mm)	≤ 4	≤ 7	≤ 10
Deflection (quasi-static) (130 kN - 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) (50 kN - 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)(1)	9 - 10	7 - 8	5 - 6

(1) *The APL is a car-towed device used to measure longitudinal profile in the short (SW), medium (MW) and long wavelengths (LW) respectively.*

Table 1 - Classification and Criteria of WIM sites

The standard defines three classes of WIM site based on rutting, deflection and evenness limits as presented in Table 1. An indication is then given in Table 2 as to the accuracy class that is likely to be achievable at a site of a given class. Thus, for example, a user with a class III site can see that Class C(15) accuracy can probably be achieved but that Class B(10) or better is unlikely. This is in accordance with the results of tests carried out in various countries and under various pavement conditions, reported by Jacob et al. (1995), Caprez et al. (1997) and Blab & Jacob (1997).

Accuracy Class	WIM Site Class		
	I (Excellent)	II (Good)	III (Acceptable)
class A(5)	Sufficient	Insufficient	Insufficient
class B+(7)	Sufficient	May be Sufficient	Insufficient
class B(10)	Sufficient	Sufficient	Insufficient
class C(15)	More than Sufficient	Sufficient	Sufficient
class D+(20)	More than Sufficient	More than Sufficient	Sufficient
class D(25)	More than Sufficient	More than Sufficient	Sufficient

Table 2 - WIM Accuracy Class Likely to be Achievable in given WIM Site Class

In addition to the site classification system, other site properties are specified such as road geometry and pavement layer thickness. Some environmental factors are also considered. For example, it is specified that the system must function correctly for relative humidities as high as 90% and must be insensitive to salt and water exposure.

For bridge and culvert WIM systems, criteria are given for ‘optimal’ and ‘acceptable’ bridge forms, spans, skews and surface evenness.

4. Calibration

4.1 Introduction and methods

A principal problem with the accuracy of WIM systems is that a dynamic measurement is usually used to determine static axle weights. Static calibration methods are possible for systems which use strain gauges, load cells, piezo-quartz or fibre-optic sensors and some guidance for such methods is given in the specification. However, these are not applicable to all types of sensor. A further difficulty with static calibration is that strip sensors behave differently under static vertical loads than they do under a tyre travelling at speed.

In addition to static calibration methods, some guidance is given for the use of impacting devices such as the Falling Weight Deflectometer and for the implementation of automatic self-calibration procedures (Stanczyk, 1991).

However, pre-weighed calibration trucks are favoured above all other methods because they are simple, direct and applicable to all forms of WIM. Such methods can partially remove the effects of spatial repeatability if the calibration truck or trucks are subject to the same repeatability effect as vehicles in the normal traffic flow. However, patterns of spatial repeatability have been shown by O'Connor et al. (1996) to be sensitive to speed and are known to be different for different trucks of the same class.

The specification defines four levels of repeatability/reproducibility test conditions as follows:

Full Repeatability Conditions (r1): One vehicle passes several times at the same speed, load and lateral position.
Extended Repeatability Conditions (r2): One vehicle passes several times at different speeds, different loads and with small variations in lateral position (in accordance with typical traffic).
Limited Reproducibility Conditions (R1): A small set of vehicles (typically 2 to 10), representative in weight and silhouette of typical traffic, is used. Each vehicle passes several times, at different combinations of speed and load and with small variations in lateral position.
Full Reproducibility Conditions (R2): A large sample of vehicles (some tens to a few hundred), taken from the traffic flow and representative of it, is used for the calibration.

Calibration under full repeatability conditions is not recommended and is anticipated only in special circumstances, because the relative variability is much lower than under normal weighing conditions. Calibration under extended repeatability conditions is allowed if the client approves. It is required in such circumstances that the vehicle be typical of the traffic being weighed and that it be driven in fully loaded, half loaded and unloaded conditions. At least ten runs are required in total to get an estimation of the standard deviation of the relative errors, at two or three speed levels representative of the site. Speed ranges of 70 and 95 km/h are mentioned for motorways and 50, 70 and 90 km/h for other roads.

Calibration under limited or extended reproducibility conditions is recommended. For the former, at least three or four test vehicles representative of the traffic flow silhouettes (rigid truck(s), tractor with semi-trailer and truck with trailer) are suggested with heavier vehicles driven both fully and half loaded. While not of general interest, it is allowable to have different calibration coefficients for different vehicle types and for different axles in vehicles. The use of instrumented vehicles is discussed if the WIM system is to be used to estimate dynamic rather than static forces.

4.2 Calculation of Calibration Coefficient

Four methods are outlined for the calculation of the calibration coefficient, C. It is defined as the constant of proportionality between the inferred static weight of axle j and vehicle i, Ws_{ij}, and the measured dynamic (WIM) weight Wd_{ij}:

$$Ws_{ij} = C.Wd_{ij} \qquad (1)$$

The most commonly used method consists of calibrating on the mean bias of all runs of the calibration trucks. An unbiased estimator for gross vehicle weight (GVW), for n_i

runs of the i^{th} calibration vehicle with gross static weight Ws_i, is obtained using the coefficient:

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

where Wd_{ik} is the measured dynamic GVW for the k^{th} run of vehicle i. If an unbiased estimator of the traffic tonnage for the site is required, equation (2) can be replaced with:

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

For full repeatability conditions, equations (2) and (3) give the same calibration coefficient.

For most applications, when the estimation of individual truck weights is required, it is recommended to calibrate using a linear regression on GVW through the origin. The calibration coefficient is then:

$$C = \frac{\sum_i n_i \left(Ws_i \right)^2}{\sum_{i,k} Ws_i \, Wd_{ik}} \tag{4}$$

This method may only be used for conditions other than full repeatability.

4.3 General Recommendations for Calibration

The specification recommends that newly installed WIM systems to be carefully calibrated, and the temperature to be recorded during the calibration. Such a calibration constitutes an initial verification, which also allows the assessment of the system accuracy (see section 5.1). It is recommended that operational WIM systems be recalibrated regularly (e.g. once or twice a year) and the accuracy reassessed, by in-service verification (see section 5.2). Some procedures are proposed for the detection of calibration drift through analysis of the recorded data, e.g., through comparison of some statistics with given target values (Gillmann (1992)). Another effective calibration procedure is automatic self-calibration introduced in France in the early 1980’s and described by Stanczyk (1991). It consists of continuous recalibration to obtain correspondence between some recorded statistic and a stated target values, which is a function of the site traffic. This procedure can be most effective and valuable but it requires a good knowledge of the traffic patterns and the target values must be carefully chosen according to local conditions. Periodical checks must also be carried out to detect any malfunctioning of the equipment.

5. Accuracy Classification

The WIM system accuracy classification is based on comparisons of measured results against reference values which, it is anticipated, would generally be determined by statically weighing trucks. To comply with a given accuracy class, the calculated probability that individual results are within the confidence interval [$Ws(1-\delta)$, $Ws(1+\delta)$], or that individual relative errors are within the confidence interval [$-\delta,+\delta$] must exceed a specified minimum, π_0. The confidence interval width, δ, is a function of the accuracy class and the specified values are given in Table 3 for each entity (gross weight, single axle, group of axles and axle of a group taken individually). The minimum probability is a function of the test conditions (repeatability or reproducibility, environmental variability) and the sample size (see section 5.3). The statistical background and the origin or proof of the procedures and various formulas presented in section 5.4 are given in Part I of this two-part paper.

Type of measurement	**Domain of use**	**Confidence interval width δ (%) for Each Accuracy Class**					
		A (5)	**B+ (7)**	**B (10)**	**C (15)**	**D (25)**	**E**
1. Gross weight	greater than 35 kN	5	7	10	15	25	> 25
2. Group of axles	greater than 20 kN	7	10	13	18	28	> 28
3. Single axle	greater than 20 kN	8	11	15	20	30	> 30
4. Axle of a group	greater than 20 kN	10	15	20	25	35	> 35
Speed	greater than 30 km/h	2	3	4	6	10	> 10
Inter-axle distance		2	3	4	6	10	> 10
Axle/vehicle count		1	1	1	3	5	> 5

Table 3 - Tolerances of the Accuracy Classes (Confidence Interval Width for Relative Errors)

5.1 Initial Verification and Accuracy Classification after Calibration

After installation or some modifications of sensors, hardware or software, repair or part replacement, a WIM system must be (re)calibrated. In most cases, the calibration procedure provides data which may be used for an accuracy classification. That is an 'initial verification', in which the same sample is used for calibration and for accuracy assessment. Thus, as it is after calibration, the mean bias should be zero or very small depending on the method used to calculate the calibration coefficient (see section 4.1). To be accepted in an accuracy class defined by δ, the specification requires that the confidence interval becomes [$-k.\delta,+k.\delta$] for the relative errors at a level of confidence greater than π_0. If the calibration is made using repeated runs of pre-weighed trucks, *k* is taken equal to be 0.8. The specified minimum probability, π_0, is as given in Table 4 (see section 5.3) if the calibration is carried out over a short time period (e.g. 1 or 2 consecutive days). It is recommended that a sufficient number of vehicles or runs be used to result in a value of π_0 in excess of 90% for standard application, but this percentage may be increased to 95% or more for particular applications or at the request of the customer. The procedure for the assessment of the accuracy class is described in section 5.4.

In particular cases, if the system is calibrated using calibration masses (such as would be possible with bending plates or load cells), the metrological rules of OIML (1996) require that $k = 0.5$ and $\pi_0 = 100\%$.

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

Table 4 - Minimum levels of confidence π_0, of the centred confidence intervals (in %) case of a test under 'Environmental Repeatability' (I)

5.2 Accuracy Classification for In-Service WIM Systems

In-service verification of WIM systems should be carried out periodically depending on changes in the conditions of operation (traffic, environment, drift of the response, etc.), or in case of any doubt about the results. Such a verification may be done at any time in the lifetime of the WIM system. The specification does not allow the system to be recalibrated during an in-service test and the bias may not therefore be removed. *Thus the test data sample cannot be used for any recalibration before the accuracy classification.*

If the system is classified using calibration masses, the metrological rules of OIML (1996) require that 100% of the relative errors are in the interval $[-\delta, +\delta]$ of the relevant accuracy class and for the criterion (entity) being checked.

If the WIM system is checked using pre-weighed or post-weighed test vehicles, the specified minimum level of confidence π_0 is dependent on the environmental and test conditions, as explained in section 5.3. After such an in-service verification, and if a large bias is found which leads to a lower accuracy class than expected, a recalibration may be carried out. Then the principles of section 5.1 must be applied for the assessment.

5.3 Test Plans and Required Confidence Levels

This section is applicable when the accuracy test is carried out using pre-weighed or post-weighed test vehicles. The static weighing of these vehicles should be made on an approved static scale, with a specified accuracy, according to the general rules described in the first part of this paper. The more extensive the test plan and longer the test period, the higher the number of vehicle types and passes which ultimately results in a higher confidence in the conclusion. The customer risk, i.e., the risk of accepting the system to be in a higher class than appropriate, is governed by the probability of an individual error lying outside of the specified confidence interval [$-\delta,+\delta$]. An upper bound of this risk is given, according to the first part of this paper, by ($1-\pi_0$). The lower this risk is made, the longer and more extensive will be the required test. The customer can control the risk by selecting an appropriate value for π_0. The supplier risk α, i.e., that of a system being assessed to be in a category lower than appropriate, is linked to the statistical estimation of the mean bias, and is fixed at 5%.

Three environmental conditions are defined which the test organisation may choose:

Environmental Repeatability (I): 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.

Limited Environmental Reproducibility (II): 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.

Full Environmental Reproducibility (III): 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 temperature, climatic and environmental conditions vary during the measurements and all the site seasonal conditions are encountered.

During the whole test period, no recalibration or any manipulation, software adaptation or part exchange may be conducted on the WIM system. Only the systems equipped with an automatic self-calibration procedure are continuously recalibrated, and in this case neither the software nor the target values may be modified during the test period.

The test plan describes the types, number, loads and speeds of the vehicles and passes used for the test. Some standard test plans are proposed in the specification (Annex 1, simplified rules), while the general procedure may be applied with any test plan.

For Environmental Repeatability conditions, the minimum levels of confidence, π_0, are as specified in Table 4. For limited and full Environmental Reproducibility conditions, lesser values for π_0 are required as can be seen in Tables 5 and 6. For sample sizes (n) not mentioned in these tables, the figures may be interpolated.

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

Table 5 - Minimum % levels of confidence, π_0 , of the centred confidence intervals case of a test under 'Limited Environmental Reproducibility' (II)

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

Table 6 - Minimum % levels of confidence, π_o , of the centred confidence intervals case of a test under 'Full Environmental Reproducibility' (III)

5.4 Procedure for the Assessment of the Accuracy of a WIM System

It is assumed in the following that an accuracy test is carried out using pre-weighed or post-weighed vehicles. For each entity - gross weight, single axle load, etc. - the sample of the relative errors of all the measured values is denoted (x_1, x_2,...,x_n). The sample statistics to be calculated and used in the proposed procedure are the mean (bias) m, the standard deviation s and the number of values, n. A lower bound π of the probability that an individual relative error falls within the specified interval $[-\delta,+\delta]$ is calculated and compared to the specified limit π_o. According to the theory developed in the first part of this paper, an upper bound on the customer risk, π, for $\alpha = 0.05$, is given by:

$$\pi = \Phi(u_1) - \Phi(u_2) \qquad (5)$$

where:

$$u_1 = \frac{\delta - m}{s} - \frac{t_{n-1,0.975}}{\sqrt{n}}$$

and:

$$u_2 = \frac{-\delta - m}{s} + \frac{t_{n-1,0.975}}{\sqrt{n}}$$

The function Φ is the cumulative distribution function of a Student variable, and $t_{n-1,0.975}$ is a Student variable with n-1 degrees of freedom.

If n is greater than 60, the cumulative distribution function Φ in equation (5) may be approximated by the cumulative distribution function of a standardised Normal variable. For large samples of data, i.e. when n exceeds $10/(1-\pi_o)$, the probability (level of confidence) can be statistically estimated by the sample proportion, π', of x_i being within the confidence interval $[-\delta,+\delta]$. However this approximation does not account for the uncertainty of the mean estimation, and generally provides a higher value than π. The supplier risk is reduced, but the customer risk is increased.

The final acceptance test is:

- if $\pi \geq \pi_o$, the system is accepted in the accuracy class of tolerance δ for the criterion considered;

- if $\pi < \pi_o$, the system cannot be accepted in the proposed accuracy class, and the acceptance test is repeated with a lower accuracy class (a greater δ).

An alternative approach is to calculate the lowest value for δ, denoted δ_{min}, such that $\pi = \pi_o$. Then the test consists of comparing δ_{min} to the value specified in Table 3 for the proposed accuracy class and criterion.

The simplified procedure proposed in Appendix 1 of the specification consists of the use of charts which are applicable for some standardised common test plans. The acceptance test then becomes very simple, and consists merely of checking if the point with co-ordinates ($|m|/s$, δ/s) is in an acceptance domain. If not, δ must be increased and the test repeated.

6. Example

To illustrate the procedures outlined in Section 5, an example is presented of the accuracy classification process.

6.1. Calibration Plan

A WIM system was installed and calibrated within a day using two pre-weighed trucks, a 2-axle rigid truck (T2) and a 5-axle articulated truck (T2R3). Both of the test vehicles made several runs past the WIM site, at different speeds and, for the T2R3, at different loads, as presented in Table 7. The WIM system was then calibrated on all of these run results using the gross weights.

Test vehicle	**Speed** (km/h)	**Loading and number of runs**		
		fully loaded	half loaded	empty
T2	80 65 50	10 runs 20 runs 10 runs		
T2R3	80 65 50	10 runs 10 runs 10 runs	10 runs 10 runs 10 runs	5 runs 5 runs 5 runs

Table 7 - Calibration plan with two pre-weighed test trucks

6.2. Initial Verification after Calibration

The initial verification is performed from the calibration results, following the procedure described in Section 5.1. According to the calibration plan, the conditions are those of Limited Reproducibility (R1) and Environmental Repeatability (I). Table 8 summarises the test results:

- the statistics m, s and n of the relative errors are given in columns 2, 3 and 4,
- the values of $k.\delta$ with k=0.8 are given in columns 5 and 6, with δ taken from Table 3 for classes B(10) and C(15),
- the minimum required level of confidence π_o taken (by interpolation) from Table 4 is given in column 7,

- the π values given in columns 8 and 9 are the calculated levels of confidence (lower bound) evaluated from equation (5), using m, s and δ for the required accuracy class,
- the lowest value δ_{min}, such that $\pi = \pi_o$, is given in column 10,
- the accuracy class for the entity specified in column 1 is given in column 11.

				0.8 ***δ*** (%)		***π_0***	π (%)		δ_{min}	**class**
Unit	***m*** (%)	***s*** (%)	***n***	**B(10)**	**C(15)**	(%)	**B(10)**	**C(15)**	(%)	acc.
Single axle	- 0.62	7.31	230	*0.12*	*0.16*	*95.7*	86.7	**95.9**	15.8	**C(15)**
Axle group (tridem)	0.23	6.01	75	*0.104*	*0.144*	*94.6*	86.2	**96.6**	13.2	**C(15)**
Axle of a group	0.26	6.96	225	*0.16*	*0.20*	*95.7*	**96.9**	99.3	12.8	**B(10)**
Gross weight	- 0.29	4.28	115	*0.08*	*0.12*	*95.1*	90.4	**99.0**	9.3	**C(15)**

Table 8 - Results of the initial verification (in bold, the accepted levels of confidence)

In order to be classified in a particular class, the π value must exceed the target value π_0, or the value δ_{min} must exceed the product, $k.\delta$, for the proposed class. It can be seen that the WIM system fulfils the requirements of Class C(15), except for the axle of a group load criterion for which Class B(10) is acceptable.

6.3. In-service Check of the WIM system

After some time, an in-service test was performed to check the accuracy of the system under more realistic conditions, i.e., in full reproducibility (R2) conditions. The test plan consisted of taking about one hundred trucks from the traffic flow during an enforcement period over three consecutive days (Environmental Repeatability conditions (I)). These trucks were pre-weighed on an approved static scale installed 5 km upstream of the WIM site where the axle loads were measured. Each pre-weighed truck was then identified by its registration plate and correlated with the data obtained from the WIM site.

The sample composition of the pre-weighed trucks was chosen in accordance with the traffic composition of the road, following a special agreement with the police. Because of the traffic conditions, only 86 trucks from a total of 101 weighed on the static scale were available for the test analysis; 14 trucks by-passed the WIM system (the road has two lanes in each direction), or left the road between the static weighing area and the WIM site.

The results of the test are summarised in Table 9. The values of π_o are still taken (by interpolation) from Table 4, while δ values are used instead of $k.\delta$.

It can be seen that the WIM system again fulfils the requirements of Class C(15), even if it is very close to Class B(10) for the axle-of-a-group criterion. In comparison with the initial verification, the bias on the single axle loads and on the gross weights have increased by factors of 5 and 10 respectively, while the standard deviations of the axle group and gross weight samples increased by more than 40 %. The values of δ_{min} increased by 8% to 58% compared to those of the initial verification, while the tolerances δ are 25% higher (k = 0.8). However the π_o values are approximately 2 points lower because the test is in reproducibility conditions, (R2) instead of (R1).

This example, based on true data, demonstrates the difference between an initial verification and an in-service check.

				δ (%)		π_0	π (%)		δ_{min}	**class**
Unit	***m*** (%)	***s*** (%)	***n***	**B(10)**	**C(15)**	(%)	**B(10)**	**C(15)**	(%)	acc.
Single axle	- 3.92	7.66	197	*0.15*	*0.20*	*93.7*	89.3	**97.3**	17.1	**C(15)**
Axle group (tridem)	- 0.30	8.44	66	*0.13*	*0.18*	*92.1*	80.0	**93.6**	17.3	**C(15)**
Axle of a group	- 0.19	10.07	169	*0.20*	*0.25*	*93.5*	93.2	**97.9**	20.2	**C(15)**
Gross weight	- 2.27	6.09	86	*0.10*	*0.15*	*92.6*	81.5	**96.3**	13.0	**C(15)**

Table 9 - Results of in-service verification (in bold, the accepted levels of confidence)

7. Conclusions

This paper provides a summary of the current draft of the new European WIM specification. This document meets the requirements of most users and customers and will facilitate their relationships with the manufacturers and suppliers. It is complementary to the currently drafted OIML recommendation which applies where weighing is for legal purposes and to fully controlled low-speed WIM.

Similar accuracy classes are defined in both documents. However, it can be seen that the classification system presented in this paper is based on an elaborate statistical approach, which has been developed to address the issues inherent to WIM. While this may at first, appear rather complex, it is quite comprehensive and allows great flexibility for the user. The complexity is eased by the use of examples and may be avoided through application of the simplified procedure, not detailed here, but described in Appendix 1 of the specification.

Useful information and procedures are also described for WIM system calibration and for acceptance testing, both for the case of an initial verification and for an in-service check. The proposed tools and framework are sufficiently general and flexible to be adapted to expected future technical developments in WIM devices.

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