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COMPARISON OF METHODS FOR THE WEIGHING TEST IN CALIBRATION OF HIGH CAPACITY NON-AUTOMATIC WEIGHING INSTRUMENTS

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Abstract: This paper presents the results obtained from the comparison of different techniques for the weighing tests for the calibration of high capacity weighing instruments, in order to evaluate their use as a function of the amount of available weights and the required uncertainty of the instrument in their normal use.

Keywords: Mass, Weighing instruments, substitution weights.

1. INTRODUCTION

In calibration of high capacity non-automatic weighing instruments a common problem is the amount of available mass standards (or weights) additionally to the difficult of handling and transporting large weights.

This work presents the uncertainty comparison of different procedures for the weighing tests in calibration of a truck scale. The main difference of these procedures is based on the amount of standard weight used.

There is not any standard, guideline or recommendation in Mexico or at international level about the required uncertainty for the calibration of those instruments; therefore it is a choice of the user which is the suitable uncertainty for the calibration of his own weighing instrument.

The calibration tests were done following the guidelines of EA-10/18 [1].

2. PURPOSE

The purpose of this study is to estimate the uncertainty of different calibration methods for high capacity non-automatic weighing instruments as a function of the amount of mass standards used and the characteristics of the weighing instruments such as repeatability and sensitivity.

All tests were done in two phases:

- Adjusted instrument
- Instrument misadjusted intentionally on its characteristic response (linearity) but not the eccentric load indication neither the repeatability.

It was decided to make the test methods for the adjusted instrument and repeat them for the same instrument misadjusted intentionally in order to evaluate the sensitivity of the test methods for the evaluation of the characteristic response of the high capacity non-automatic weighing instruments.

The weighing test methods evaluated were:

i. Mass standards
ii. Substitution loads
iii. Combinatorial Technique

3. WEIGHING INSTRUMENT TESTED AND MASS STANDARDS

The truck scale tested is located in Rancho Monte Carlo in Torreón Coahuila, Mexico.

The scale tested has the following characteristics (see fig. 1):

Brand:	Revuelta
Model:	RCC-1880-VR
Serial number:	19645-C.780R
Range:	80 000 kg
Type:	Truck scale
Resolution:	10 kg
Accuracy Class:	OIML Medium III [2]
Load receptor Dimensions:	18 m x 3 m
Points of support:	8

For the calibration were used eighty mass standards with the following characteristics,

Nominal value: 1 000 kg
Accuracy class: OIML M_1 [1]
Density: 4 782 kg/m^3

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[1] The Mexican Standard NOM-038-SCFI-2000 [5] allows the construction of weights of large nominal value made of steel box filled with metallic material.

Fig. 1. Truck scale tested.

Fig. 2. Mass standards used.

4. TESTS

The tests were done for the adjusted and misadjusted weighing instrument. The calibration tests performed were the following:

- Eccentric loading test
- Repeatability test
- Weighing test

The differences among test methods are focused in the weighing tests which were done with different amount of mass standards and substitution weights and the number of measurements done.

4.1 Eccentric loading test

The eccentric loading test was done using a vehicle with load (approx. 26 000 kg). The vehicle was placed in three positions along the load receptor of the scale, at the center of the load receptor and at the ends of the load receptor of the truck scale.

The load was placed within the point of support of the scale in order to avoid a malfunction or damage of the instrument. The effect of the eccentric loading is calculated from the following formula,

$$\Delta I_{ecci} = \left(I_i - I_1\right) + \delta_{res} \tag{1}$$

where,

I_i	is the indication of the weighing instrument when a the load is placed at the end *i* of the load receptor
I_1	is the indication of the weighing instrument when a the load is placed at the centre of the load receptor
δ_{res}	is the correction due to the resolution of the scale with zero as mean value.

4.2 Repeatability test

The repeatability test was done using a vehicle with load (approx. 26 000 kg) and the same vehicle with tow (approx. 51 400 kg). For this test each load was placed three times at the centre of the load receptor.

From the three indications for each load I_j the standard deviation for the load *j* is calculated using formulas (2) and (3). The repeatability of the scale is calculated with formula (4), which considers the contribution of the resolution.

$$s\left(I_j\right) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(I_{ji} - \bar{I}_j\right)^2} \tag{2}$$

$$\bar{I}_j = \frac{1}{n}\sum_{i=1}^{n} I_{ji} \tag{3}$$

$$s_{Scale} = \sqrt{s\left(I_j\right)^2 + \left(\frac{d}{\sqrt{12}}\right)^2} \tag{4}$$

where,

n	is the number of repetitions, three for this exercise
I_{ji}	Is the repetition *i* of the indication with the load *j* on the load receptor
d	is the resolution of the scale

4.3 Weighing test

For the weighing test, three methods were applied.

4.3.1 Weighing test with mass standards

The weighing test was done with eighty mass standards of 1 000 kg placed one by one in the load receptor.

The results of this exercise were taken as reference values in order to evaluate the others weighing test methods.

4.3.2 Weighing test using substitution loads

For this exercise, there were used m = 16 000 kg in mass standards (16 pieces of 1 000 kg each), and loaded vehicles in order to have loads close to the following values,

$Q_1 \approx$ 16 000 kg
$Q_2 \approx$ 32 000 kg

$Q_3 \approx 48\,000$ kg
$Q_4 \approx 64\,000$ kg
The weighing sequence was the following,
i. m
ii. Q_1
iii. $Q_1 + m$
iv. Q_2
v. $Q_2 + m$
vi. Q_3
vii. $Q_3 + m$
viii. Q_4
ix. $Q_4 + m$

4.3.3 Weighing test applying the combinatorial technique [4]

This exercise was done using $m = 8\,000$ kg as mass standards, and four loaded vehicles with the following approximate mass values,
$R_1 \approx 17\,000$ kg
$R_2 \approx 13\,200$ kg
$R_3 \approx 10\,460$ kg
$R_4 \approx 5\,730$ kg

The goal of this method is to have the 2^n combinations of loads. For this exercise and taking 5 individual loads (taking the mass standards as one of them) there were 32 combinations of load.

5. ERRORS OF INDICATION

5.1 Rounding error of the indication

In order to reduce the uncertainty due to the resolution of the scale, there were applying small extra weights in steps of $d_T = d/10$, for this exercise $d_T = 1$ kg.

The corrected indication due to the rounding error (I_L) is calculated by the following formula,

$$I_L = I + \frac{d}{2} - n d_T \tag{5}$$

where,

I is the indication of the scale
n are the number of small extra weights placed in the load receptor
d_T is the value of the small extra weights

5.2 Buoyancy correction

Even when the calibration of the scale was done in conventional mass, all indications of the scale were corrected by the buoyancy effect by the following formula,

$$\delta m_B = m_c\left(\frac{\rho_{aCal} - 1{,}2}{\rho_m}\right) \tag{6}$$

where,

m_c is the conventional mass of the mass standard placed in the load receptor
ρ_{aCal} is the air density during the calibration
ρ_m is the density of the mass standard or the substitution weight

5.3 Inverse of the sensitivity of the weighing instrument

The inverse of the sensitivity of the scale was evaluated for the weighing test in order to correct the mass difference (given in indications of the scale) between the mass standard (or known mass) and the unknown mass or load.

The impact to the uncertainty due to this factor is directly proportional to difference between the indication of the load and the indication of the mass standard.

The inverse of the sensitivity is evaluated several times for the weighing test using the following formula,

$$S^{-1} = \left(\frac{m_c}{\left(I_{x+m} - I_x\right) + \delta_{Ecc} + \delta_{\mathrm{Re}\,p} + \delta_{Round}}\right)\cdot\left(1 - \frac{\rho_{aCal} - 1{,}2}{\rho_m}\right) + \delta_{\mathrm{Re}\,p\left(S^{-1}\right)} \tag{7}$$

where,

I_{x+m} is the indication of the weighing instrument when a load x and the mass standard are on the load receptor
I_x is the indication of the weighing instrument when the load x is on the load receptor
δ_{Ecc} is the correction due to the eccentric load of the scale with zero as mean value.
$\delta_{\mathrm{Re}\,p}$ is the correction due to the repeatability of the scale with zero as mean value.
δ_{Round} is the correction due to the rounding error of the indication with zero as mean value.
$\delta_{\mathrm{Re}\,p\left(S^{-1}\right)}$ is the correction due to the repeatability (or dispersion) of the sensitivity evaluations. This correction has zero as mean value.

5.4 Evaluation of the error of indication

The error indication for the weighing test is calculated from the next formula,

$$E = I_L - m_c + \delta m_B + \delta_{Ecc} + \delta_{\mathrm{Re}\,p} + \delta_{Round} \tag{8}$$

For the weighing test using substitution loads and applying the combinatorial technique, it is necessary to evaluate the conventional mass of the load x, $m_C\left(Load\ x\right)$, see formula (9).

$$m_C\left(Load\ x\right) = \frac{m_c\left(\dfrac{\rho_{aCal} - 1{,}2}{\rho_m}\right) + \Delta I \cdot \bar{S}^{-1}}{\left(1 - \dfrac{\rho_{aCal}}{\rho_{(Loadx)}}\right)} \tag{9}$$

$$\Delta I = I_x - I_{m_c} \tag{10}$$

where,

$\rho_{(Loadx)}$ is the mean density of the load x

ΔI is the mass difference between the mass standard and the load i reading in indications of the weighing

$\bar{S}^{-.1}$ is the mean value of the inverse of the sensitivity of the scale

6. EVALUATION OF THE UNCERTAINTY OF THE ERROR

The uncertainty of the error of the indication is evaluated according GUM's method [6] applied to formula (8) as the mathematical model,

$$u(E) = \sqrt{\sum_{i}^{n} \left[c_i \cdot u(x_i)\right]^2} \qquad (11)$$

$$c_i = \frac{\partial E}{\partial x_i} \qquad (12)$$

where,

c_i is the sensitivity coefficient due to the input quantity i

$u(x_i)$ is the standard uncertainty of the input quantity i

7. FORMULA TO DESCRIBE ERRORS IN RELATION TO THE INDICATIONS IN USE

In order to derive a formula to describe errors in relation to the indication in use $I_{(use)}$, with the following form,

$$E_i = a_0 + a_1 I_{(use)i} + a_2 I_{(use)i}^{\ 2} \qquad (13)$$

where the indication in use has the following form,

$$I_{(use)} = I + \delta m'_B + \delta_{rep} + \delta_{ecc} + \delta_{res} \qquad (14)$$

where,

$\delta m'_B$ is the buoyancy correction due to the density difference between the mass standards used in the calibration and the unknown material.

The relation between the Indications and the errors could be expressed as,

$$X\beta = Y - \varepsilon \qquad (15)$$

where,

X is the matrix of the indications of the weighing instrument

β is the vector of the fitting coefficients

Y is the vector of errors (related to the indications calculated in chapter 5)

ε is the vector of errors (of fitting)

Equation (15) could be solved by Gauss Markov approach [7],

$$\hat{\beta} = \left(X^T \Phi^{-1} X\right)^{-1} X^T \Phi^{-1} Y \qquad (16)$$

where,

$\hat{\beta}$ is the estimate of the fitting coefficients

Φ is the covariance matrix, where was introduced the combination of the variance of the errors and the variance of the fitting [7,8]

The covariance matrix of the fitting coefficients $\mathrm{cov}(\hat{\beta})$, was calculated from the following expression,

$$\mathrm{cov}(\hat{\beta}) = \left(X^T \Phi^{-1} X\right)^{-1} \qquad (17)$$

Last matrix has in its main diagonal the variance of the fitting coefficients. The uncertainty of the indications errors evaluated by the formula (13) is evaluated by GUM method.

The variance of the adjusting coefficients (a_0, a_1 and a_2) and variance of the indication in use are the contributions to the uncertainty for the indications errors of the weighing instrument in use.

8 RESULTS

In Fig. 3 and 4 are the graphs of the indication errors of the truck scale under test for the 1st experiment (adjusted instrument), and in Fig. 5 and 6 are the graphs of the indication errors for the truck scale under test for the 2nd experiment (misadjusted instrument).

Errors of indication calculated from the formula (13) for substitution loads method and combinatorial technique were compared against mass standards method by the criterion of normalized error (En) [9]. All methods could characterize the indication error within uncertainty interval. The level of uncertainty depends on factors as repeatability, eccentricity, sensitivity of the instrument and the amount of mass standards used as well as indications difference between the mass standards and the loads.

If the repeatability, the eccentricity or the uncertainty of the sensitivity of the scale increases, then the uncertainty of the indication errors increases proportionally too.

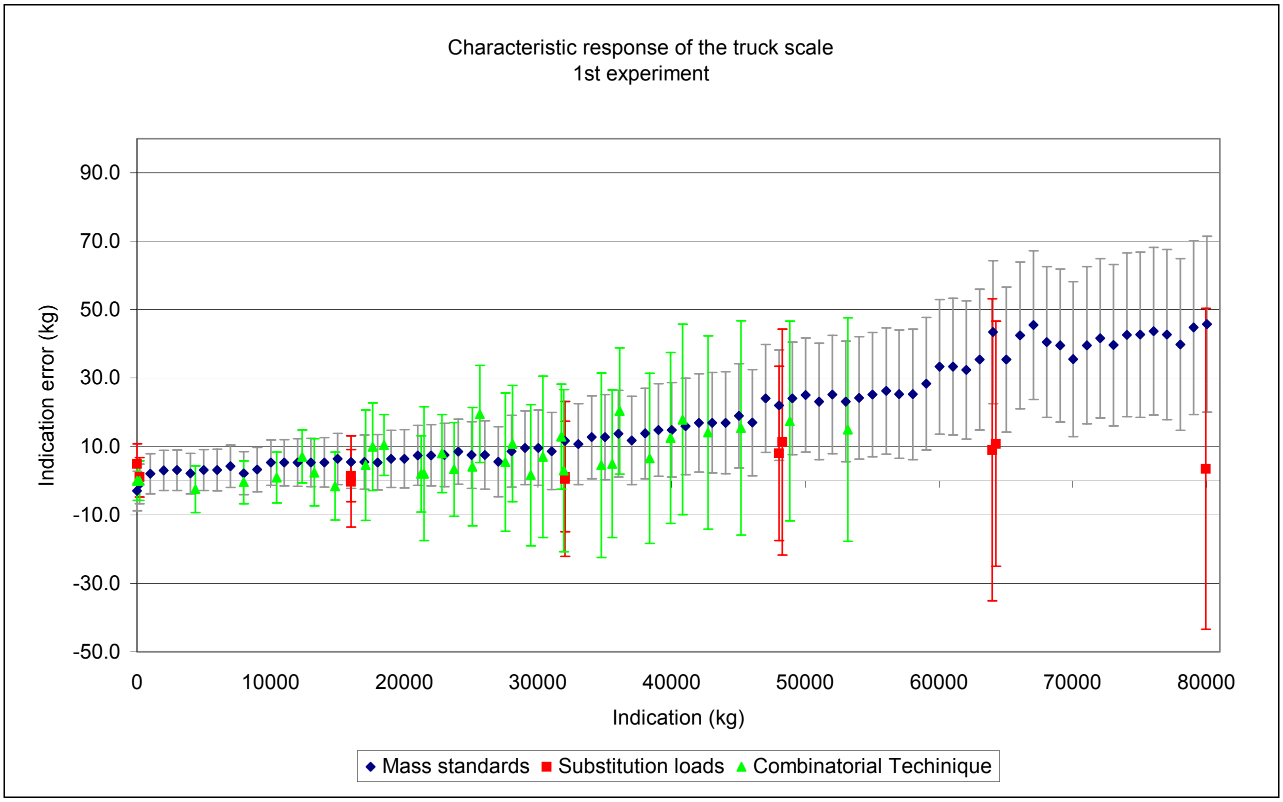

Fig. 3. Errors of the indication for the adjusted instrument.

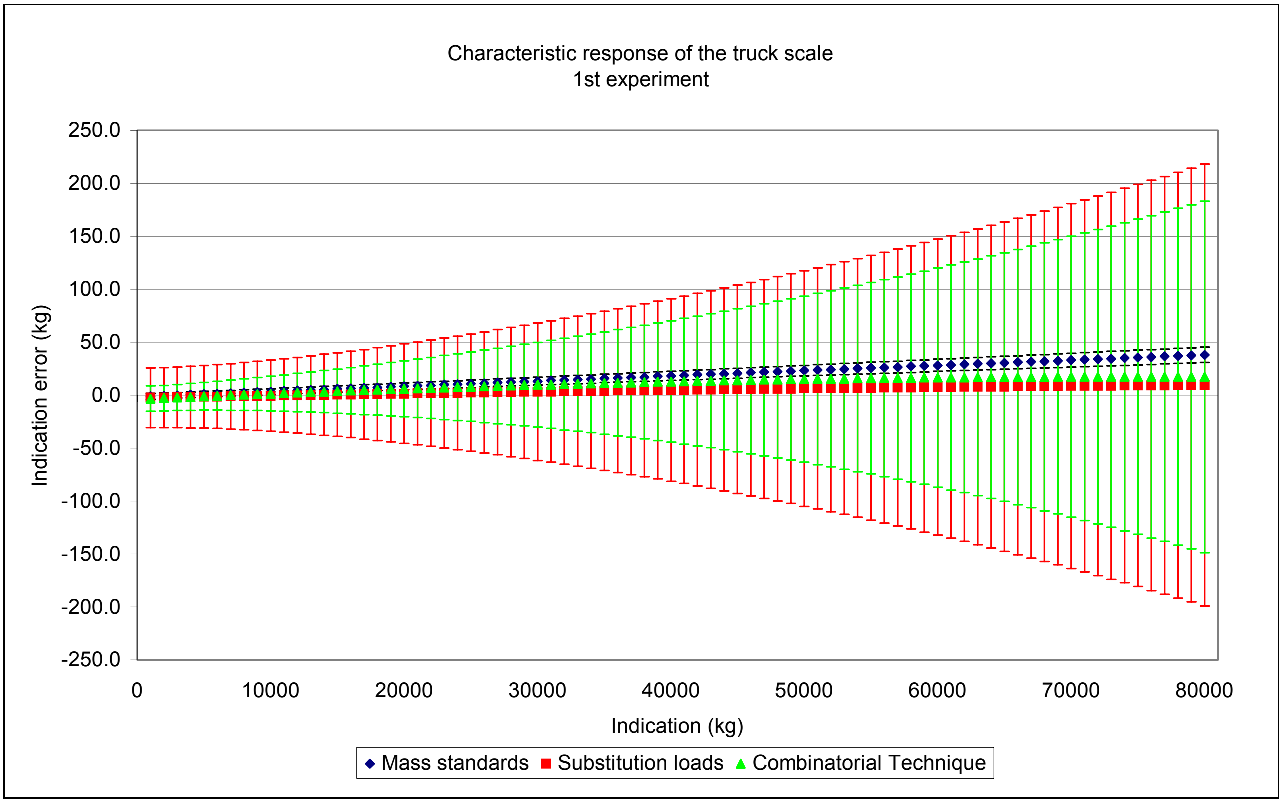

Fig. 4. Graph of the errors of the indication of the truck scale calculated by second order formula. The uncertainty of the indication in use was not considered for this evaluation. The correlations between adjusting coefficients (a_0, a_1 and a_2) were not considered.

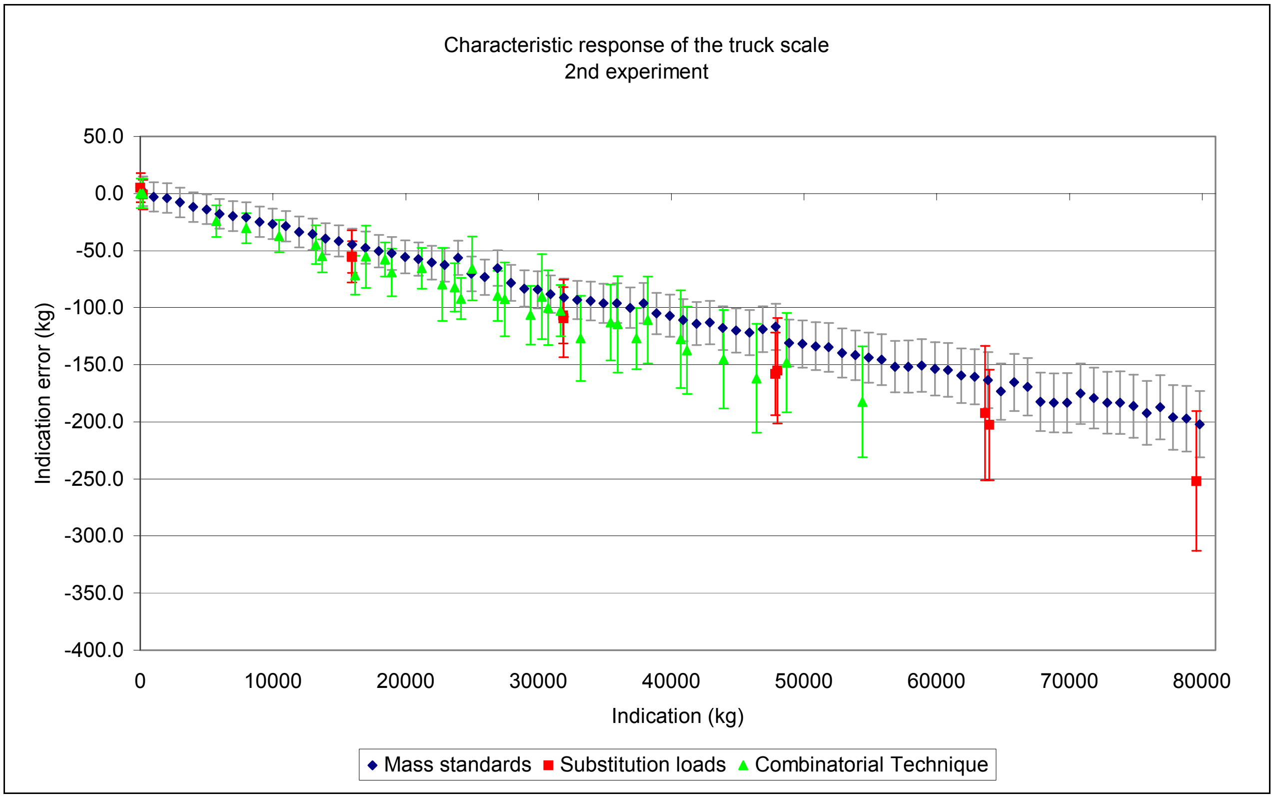

Fig. 5. Errors of the indication for the misadjusted instrument.

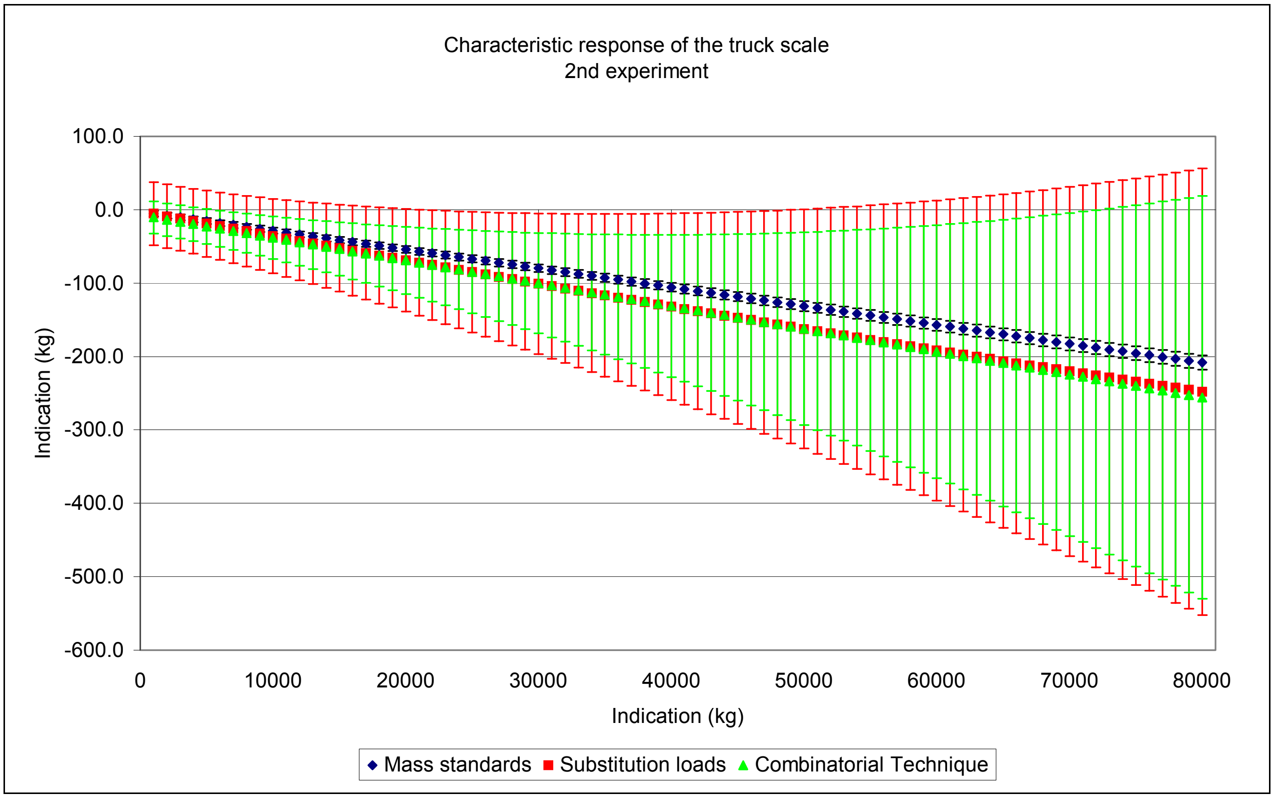

Fig. 6. Graph of the errors of the indication of the truck scale calculated by second order formula. The uncertainty of the indication in use was not considered for this evaluation. The correlations between adjusting coefficients (a_0, a_1 and a_2) were not considered.

Table 1. Errors of the indication evaluated by formula (13) for the adjusted instrument.
The uncertainty of the indication in use was not considered for this evaluation.

	Mass standards		Substitution Loads			Combinatorial Technique		
Indication	Errors	Uncertainty	Errors	Uncertainty	En*	Errors	Uncertainty	En*
8 000	2	3	-1	32	0,10	0	15	0,13
16 000	6	3	1	41	0,14	4	22	0,09
24 000	10	3	2	54	0,15	8	31	0,08
32 000	14	4	3	69	0,15	10	43	0,09
40 000	18	4	5	86	0,15	13	57	0,09
48 000	22	5	6	106	0,15	15	74	0,10
56 000	26	5	7	128	0,15	16	93	0,11
64 000	30	6	8	152	0,14	17	115	0,11
72 000	34	7	9	179	0,14	17	139	0,12
80 000	38	7	9	209	0,14	17	166	0,12

Table 2 Errors of the indication evaluated by formula (13) for the instrument intentionally misadjusted.
The uncertainty of the indication in use was not considered for this evaluation.

	Mass standards		Substitution Loads			Combinatorial Technique		
Indication	Errors	Uncertainty	Errors	Uncertainty	En*	Errors	Uncertainty	En*
8 000	-23	4	-29	48	0,12	-32	27	0,32
16 000	-44	4	-56	61	0,19	-57	38	0,33
24 000	-64	5	-82	80	0,22	-81	54	0,31
32 000	-85	5	-107	102	0,22	-106	74	0,29
40 000	-106	6	-132	127	0,21	-131	97	0,26
48 000	-126	7	-156	156	0,19	-156	124	0,24
56 000	-147	7	-180	187	0,18	-181	155	0,22
64 000	-167	8	-203	223	0,16	-206	191	0,20
72 000	-188	9	-226	261	0,15	-231	230	0,19
80 000	-208	10	-248	304	0,13	-256	275	0,17

* Normalized error [9]. The normalized errors were calculated taking as reference the errors evaluated by mass standards method.

9 CONCLUSIONS

Metrological characteristics of the weighing instruments such as repeatability, eccentricity and sensitivity should be introduced in the evaluation of the error's uncertainty, and it is very important to have a good estimation of those values in order to have a good estimation of the errors too.

When substitution loads are used, it is recommended to follow as much as possible the clause 3.7.3 of OIML R76 [2], in order to keep under control the error's uncertainty.

Selection of the calibration method for truck scales should be based on one hand on the comparison of the required uncertainty (for the normal use of the instrument) and the calibration uncertainty, and on the other hand on the available mass standards (weights), substitution mass and the metrological characteristics of the weighing instrument under calibration.

Indication errors and their associated uncertainties obtained from substitution loads method and combinatorial technique methods were calculated with the same formulas and under the same assumptions.

The significant difference between the substitution loads method and combinatorial technique is the number of indications taken which represents the degrees of freedom for the characterization of the characteristic response of the scale.

The goal of all calibration methods (specially the weighing test) should be to reach, as much as possible the maximum capacity of the weighing instrument.

It was presented a Gauss Markov approach [7] for calculating the adjusting coefficients of the formula (13). The Gauss Markov approach gives a good estimation of the variance values of the adjusting coefficients of the formula (13).

The covariance values among the adjusting coefficients were not taken into account in order to have a conservative estimation of the uncertainty of the indication errors calculated by formula (13).

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