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KEY FACTORS IN ROAD VEHICLES WEIGH-IN-MOTION

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Abstract: the present paper shows the advantages and disadvantages of road vehicles weighing. By considering the use of Weigh-in-Motion (WIM) instruments and applying the Monte Carlo`s simulation method, it is possible to demonstrate some factors that actually interfere in the measurement process of road vehicles weighing. This process is one contribution to metrology for the sustainable development, as long as it collaborates for the maintenance, life time and security of the highways.

Keywords: weigh-in-motion, vehicle, highways, metrology, security.

1. INTRODUCTION

The deterioration of highways has been excessive, reducing consequently its life time and, in addition, hindering the production flowing. One of the main factors of deterioration of the highways is the overload of road vehicles, which transport loads above the settled weight limit for effective legal control. In order to inhibit this weight excess it has commonly been used the weigh-in-motion instrument for the checking of road vehicles [1].

The wegh-in-motion instrument is basically an equipment capable to measure the representative total vehicle weight force, through the sum of all axles weights.

Road vehicle weighing is used to monitor vehicles that are travelling in highways, aiming at the purpose of tariffs payment by highways users and supervising this measurement [2]. But, this dynamic weighing presents a higher uncertainty comparing with the static one, because in the first one some other factors interfere during the measurement process. The study of these factors is the core objective of this paper.

For the checking of some of these factors, tests were performed in a typical outdoors installation, used for official verifications on weight excess. Data obtained during the measurements were analyzed regarding the uncertainties aspects, via Monte Carlo's method. According to [3] this method provides guidance on the evaluation of measurement uncertainty in situations where the conditions for the applicability of the rule of propagation of errors and related concepts is not fulfilled or it is unclear whether it is fulfilled. It can also be used in circumstances where there are difficulties in applying the rule of propagation of error, because of the complexity of the model, for example. This guidance includes a general alternative procedure, consistent with the GUM (Guide for Uncertainty Measurement), for the numerical evaluation of measurement uncertainty, suitable for implementing by computer.

Afterwards it can be noticed that the main factors in weigh-in-motion are as follows: configuration of the vehicles, with reference to suspension and articulation types, speed and the installation of the WIM instrument.

2. PROPOSITION

This paper intends to show the key factors that actually interfere in the use of WIM instruments on the process of road vehicles weighing .

3. METHODS

It was analyzed the outdoors operation of WIM instruments in different conditions of use[4], implemented for the vehicles weight measurement in highways. In this case it is considered the following variables: speed, road pavement type in which the instrument is installed, the different types of trucks including the high load ones, load compositions, and weighing instruments types. The results achieved shall be treated by the Monte Carlo's simulation method. Following these studies, it can be said that the variables are integral parts of the whole process and should be taken into account during the measurement process.

Trying to prove the need for considering the factors related to the vehicle configuration and tire conditions of the vehicles in highways, dynamic weighting tests have been accomplished in a scale located in BR 316 highway, Piauí, in 2005.

For the measurements of performance, different vehicle types have been considered, approaching most of brazilian vehicle classification. Analysis have been made of the behavior of new vehicle types having larger capacity, with normal permission of use, at the measurement moment:

- Highway, simple Track: width = 7,20 m (in two lanes of 3,60m/each); shoulders: Type I - width = 5,00m (2,50m on each side);

- Speed: taking into account the speed range operation capacity of the instrument considered: low, average and maximum values.

- Vehicle: to characterize most of the vehicle types used for the road transportation, five types have been used.

Types of vehicles, according to the following description and Figure 1:

V1: 3C - Three axles.
V2: 3C - Three axles (higher configuration to the previous one).
V3: 2S3 - Five axles - with towing cart.
V4: 3T4 - Seven axles – "double train" for bulk loads
V5: 3T4 - Seven axles - with towing and clamp. - "double train" tank.

- Load: intending to analyze the measurement capacity of the equipment in different application levels, reference [5], weight limits and vehicles dimensions of the, shipments have been divided into the range (in ton) below, correlated with the previous item numbering:

V1: 12t to 16t,
V2: 22t to 26t,
V3: 32t to 36t,
V4: 42t to 46t,
V5: 52t to 56t.

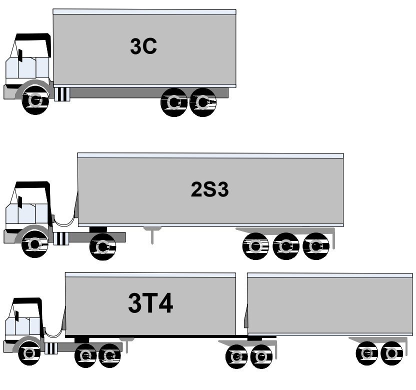

Figure 1 - Representation of the vehicle types used in the test.

The vehicles crossed over the full platform of the weighing instrument in which controlled speed achieved up to 12km/h, establishing a comparison between the measurements average and reference values, obtained in an instrument for static weighting for each type of vehicle used. To check the characteristics of measurement reproducibility, the standard deviation of each group of measurements has been considered. Partial results of the measurement of the total weigh-in-motin for four different configurations types of road vehicles and another carrying liquid material (e.g. water), are presented in the Table 1.

V1 - vehicle with 3 axles
V2 - vehicle with 3 axles
V3- vehicle with 5 axles
V4- vehicle with 7 axles
V5- vehicle with 7 axles, transport of liquid material

Table 1 – five different road vehicle weigh in motion

Vehicle type/ Parameter	V1	V 2	V 3	V 4	V 5
Average kg	12109,3	23004,0	34797,3	41713,0	51730,7
$\overline{Sx}$ kg	466,5	188,2	307,0	1355,1	612,0
$\overline{Sx}$ %	3,85	0,82	0,88	3,25	1,18
True value	12340kg	22840kg	34560kg	46340kg	52870kg
Erros %	1,87	0,72	0,69	9,99	2,15

$$average : \bar{x} = \frac{\sum_{n} x_i}{n} \quad (1)$$

n = number of measurements performed for each vehicle = 15

X_i = vehicle measurement in movement

Sx = standard deviation for the average value

True value = it corresponds to the measured value in a static weighing instrument.

$$error\% = \frac{(average - truevalue)}{truevalue} 100 \quad (2)$$

In this case, 15 measurements were conducted in each vehicle in the same weighing receptor, speeds ranging up to 12km/h. In this example, it has been noticed the need for an instrument adjustment with respect to vehicles V1,V4 and V5, due to errors higher than the admissible 1% for this instrument type. The difference between the errors for the 5 types of vehicles requires the need to take into account the influence of vehicles types and loads used in the measurement, especially for the adjustment of the instrument.

4. RESULTS

Listed in Table 2 are the reference values obtained in a static weighing instrument, when there are no interferences from dynamic factors, relative to vehicle movement.

Table 2 - Imput simulation values

Vehicle	Type	Load
V1	3C	12340kg
V2	3C	22840kg
V3	2S3	34560kg
V4	3T4	46340kg
V5	3T4	52870kg

The Table 3 shows the average of dynamic values, and uncertainties are presented in kg and %, obtained with weighing instrument installed in highway.

Table 3 - Uncertainty results obtained in the simulation

Average [kg]	U [kg]	U [%]
V1=12109,3	240,55	1,99
V2=23004,0	98,59	0,43
V3=34797,3	159,40	0,46
V4=41713,0	699,97	1,68
V5=51730,0	316,42	0,61

Table 4 – Results considering the error contribution due to the standard mass (relative to the true reference value - see Table1) and its measurement uncertainty (Table 3).

Vehicle	Error [%]	Results [%]
V1	1,86	3,85
V2	0,72	1,15
V3	0,69	1,15
V4	9,99	11,67
V5	2,16	2,77

However, during test performance vehicle V4 has shown operational problems in one of its suspensions, strongly affecting the measurements results.

5. DISCUSSION

The WIM instrument is used to check weight in highways. It is important to check the weight excess of the trucks in highways[6]. Different researchers have studied dynamic measurement systems. Accordingly [7], they have studied the tire influences on vehicle force transmission to the pavement. According to[8], they have developed a measurement system to weigh vehicles using the average, obtained from weighing signal sent to the scale, using mathematical algorithms to estimate the mass of the vehicle, and a weighing method which performs accurate mass measurement under vibration similar to the moving conditions. As in [9], they studied calibration processes making use of force transducers. In accordance to [10], they have studied high-speed weighing processes based in Non-Linear Regression Gauss-Newton method.

In reference [11] it has been shown that the platform system should not have an evenness higher than 3 mm in 8 m length before and after the weighing platform, just to avoid distortion measurements. To inhibit these problems, strain gauges are strongly recommended to be used (i.e., horizontal and vertical pressure sensor), and also the use of specific algorithms, with parameters adapted to the real situation are suggested. The signal processor analyzes it and compares it with the measured values. Different techniques such as: The maximum measurement value, the minimum square method, the error estimating algorithm, and the Kalman filter method have been applied to the WIM instrument. However, most of WIM systems imposes speed operation restrictions. But, according to the author of this paper, the system itself is not speed sensitive. The method consists of two steps: the mathematical weighing parameters estimation and, via these parameters, the weight calculation.

In this test the uncertainty level achieved, ranges from 0,43% to 1,99%, and the results from 1,15 to 11.67, for different vehicle types configuration, proved the need to adjust the WIM instruments to on site operation conditions, taking into account several vehicle groups. The active suspension influences have been demonstrated in V4 results, showing a very large variation.

The weighing system vibration caused by the vehicle displacement forces, working in severe conditions of use, are noticed and interferes in the measurement value when using the WIM. These problems can be noticed when there exists bad vehicles suspension, and the equipment is unstable and the assembling is not leveled

Therefore, these results show that the models proposed by other authors should be reflecting the need for the design to be suitable to the real situation, where it is in fact installed, considering the local variables, such as pavement structure, vehicles configuration, and an efficient maintenance program so that the weight value has shown a very good approach to the real value.

Legal metrology purpose is to verify if instruments comply to metrological characteristics stated for the intended use. In Brazil this is an attribution of Inmetro, which is the National Institute of Metrology, Normalization and Industrial Quality.

6. CONCLUSION

The WIM systems use in road vehicles has pointed out the advantage of a quick identification of the vehicles that represent the weight excess. On the other hand, it presents the disadvantage of when working in severe conditions of use, needs a rigorous maintenance and metrologic control programs.

This paper also analyzes the use of WIM instruments in studies of modern vehicles reaching up to 57t, the so called *"double-trains"*.

Therefore, the contribution has been given for the use and metrological control of these instruments, realizing the weight surveillance of vehicles, contributing to increase pavement life time and reducing traffic accidents as well. This method represents a very important application of legal metrology for a sustainable development.

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