16th IMEKO TC4 Symposium
Exploring New Frontiers of Instrumentation and Methods for Electrical and Electronic Measurements
Sept. 22-24, 2008, Florence, Italy

Analysis of Reliability for the Weigh-in-motion Vehicles with Monte Carlo Simulation Modelling

Luciano Bruno Faruolo, M.T.[1], Marina Rodrigues Brochado, D.Sc[2],Adriana da Cunha Rocha, D.Sc[3].

[1]INMETRO, National Institute of Metrology, Normalization and Industrial Quality,
Av. Nossa Senhora das Graças, 50 - Prédio 11 - Sala 8 - Dimas
CEP 25250-020 Xerém - Duque de Caxias - RJ
Tel: + 55 21 2679-9136 Fax: + 55 21 2679-6194
lbfaruolo@inmetro.gov.br

[2]CEFET-RJ Federal Center of Technology, Rio de Janeiro, Brazil, Av. Maracanã, 229 Bloco E Sala 505
Maracanã – CEP 20271-110
Tel: 55 21 2566-3057 Fax: + 55 21 2568-1548
marina@cefet-rj.br

[3]INMETRO, National Institute of Metrology, Normalization and Industrial Quality,
Av. Nossa Senhora das Graças, 50 - Prédio 3 - Sala 22 - Lafor
CEP 25250-020 Xerém - Duque de Caxias - RJ
Tel: + 55 21 2679-9037 Fax: + 55 21 2679-1505
acrocha@inmetro.gov.br

Abstract- The load transported by road vehicles is subject of concern for the traffic authorities worldwide. The weight excess in vehicles has a direct impact on society, because of the detrimental effect on roads life time. The damaged roads lead to a higher number of accidents and deaths, damage vehicles and cause delays on trips. The technology for the identification of the force exerted by a vehicle on the road is the main factor for controlling the road usage. Measuring instruments have been installed along the roads to monitor the vehicles load and to check the associated parameters established in the national specific legislation. The analysis of reliability of the measuring instruments is very important as the accuracy is relatively different among the instruments used. This work evaluates the reliability of road vehicles weight measuring procedures for the weigh-in-motion system, by a developed model applied to an exploratory research in two weighing stations, using statistical tools, reliability analysis and making use of Monte Carlo method for the uncertainties evaluation. This model is capable of improving the process accuracy contributing for the reduction of damages caused by the weight excess of road vehicles.

I. introduction

A. Presentations

This work approach considers the dynamic mass measurement using weigh-in-motion systems with Monte Carlo Simulation. Also, automation has been used for acquiring and process test data.
There is a very brand new condition of use for roadways, considering the new characteristics of traffic, due to the exportation increase and the actual composition of vehicles up to nine axles, with a higher load capacity. The deterioration of highways has been excessive, reducing 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, the weigh-in-motion instrumentation has commonly been used for the verification of road vehicles [1]. The weigh-in-motion instrument is basically an equipment capable of measuring the representative total vehicle weight force through the sum of all axles weights. Road vehicle weighing is used to monitor vehicles that are traveling in highways. This monitoring is important because allows the traffic authorities to charge the correct tariff in respect to the vehicle weigh and the distance traveled by this vehicle with this specific load [2]. But, this dynamic weighing presents a higher uncertainty when compared with the static one, because in the first one some other factors interfere during the measurement process. These factors must be measured for the instrument qualification. The model of Analysis of Reliability for the Weigh-in-motion (WIM) Vehicles with Monte Carlo Simulation Modeling is the main purpose of this paper.

B. Review of previous work

The WIM instrument is used to check weight in highways. It is important to verify the weight excess of the trucks in highways to prevent damage to these highways[6]. Different researchers have studied dynamic measurement systems. They have studied the tire influences on vehicle force transmission to the pavement [7]. According to Ono et. al [8], a measurement system to weigh vehicles has been developed using the average, obtained from weighing signal sent to a 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 Kumme [9], calibration processes making use of force transducers have been studied. High-speed weighing processes based in Non-Linear Regression Gauss-Newton method have also been investigated [10].
It has been shown [11] that the platform system should not have an evenness higher than 3 mm in 8 m length before and after the weighing platform in order to avoid distortions in measurements. To inhibit these problems, strain gauges are strongly recommended for use (i.e., horizontal and vertical pressure sensor). Also the use of specific algorithms, with parameters adapted to the real situation are suggested. The signal processor analyzes and compares those algorithms 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.
The main factors in weigh-in-motion are as follows [12] configuration of the vehicles, with reference to suspension and articulation types, speed and the installation of the WIM instrument. Some proceedings for calibration can be used depends of application [13]. The road project have been revised on the traffic characteristics were modified from a previous situation at design [14].

C. Proposal

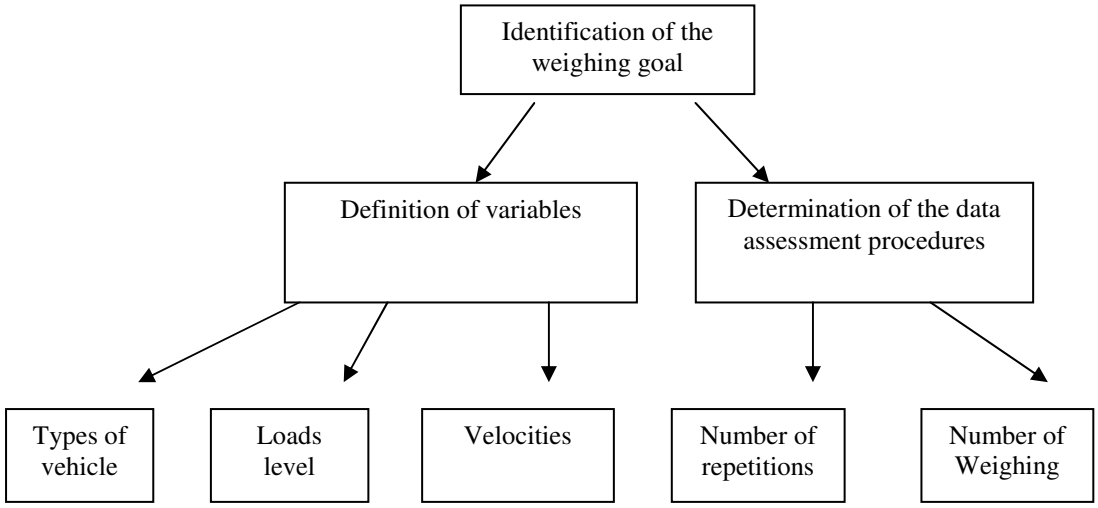
This paper proposes a new method for analyzing the reliability in instrument operation in mass control road vehicles. The paper presents a model with a method describing the key factors that have been applied in this function. The Monte Carlos's method applied in uncertainly measurement shows the possibility to study the performance of the instrument in different conditions that represent the real instrument characteristics. This model represents an important advance in the metrology control instrument and in the development instrumentation using sensors and transducers. Also, this approach can be used for calibration system identification and control of the overload trucks in highways.

II. Approach to the problem

The mass measurement of moving vehicles in real road conditions is a hard task to be reproduce in laboratory, mainly due to the difficulty of accounting for all the complexes variables that a *in situ* measurement presents. Therefore, in this work, the *in situ* mass measuring was preferred rather than an attempt to laboratory testing.
Figure 1 shows the real system used in a weighing station for verification vehicles weigh limits in roads. The method developed for analysis of reability was applied, in order to assess the dynamic weighing reliability of moving vehicles. The vehicle weighing takes place alongside the road, followed by fiscal transit agents. The speed limit for this procedures does not exceed 6 km/h.

Figura 1 – Road weighing station

As mentioned previously, the model applied on this work, make use of the Monte Carlo Method [15] [16], using a set of chosen parameters that influence the testing directly [17].



These parameters can be listed as:

- Vehicle Type;
- Velocity;
- Load

The main vehicles type weighed are listed below and depicted in figure 2:

- Truck 3c,
- Semi-trailer 2s3,
- Bi-train, 3t4,

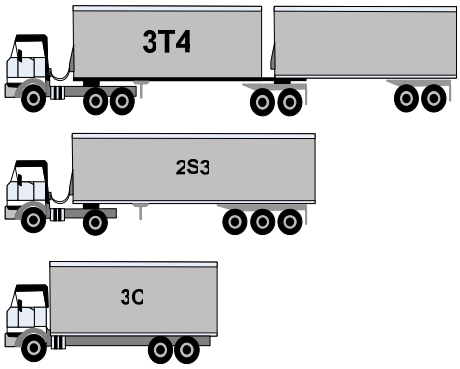


Figure 2 – The different types of vehicles tested.

The velocities used for the test were 2 km/h, 4 km/h e 6 km/h, and the load condition was split into "loaded" and "empty".
For the development of the model, up to 1100 measurements were performed, in order to reach the appropriate uncertainty measurement that could be used to represent the real variation of the influence of factors such as pressure of tires and the suspensions. The model developed for calculating the uncertainty budget is presented by the equation below:

$$E = \overline{x_d} - R \tag{1}$$

E = measurement error

$\overline{x_d}$ = weigh vehicle average

R = reference value of static scale.

The uncertainty related to the error is then a sum of all contributions from equation 1:

$$U = k\sqrt{u_1^2 + u_2^2 + +u_3^2} \tag{2}$$

Listed:

u_1 = repeatability

u_2 = reference standard

u_3 = resolution

U = uncertainty of measurement

k = coverage factor

Once the model was established, the Monte Carlo Method was used to calculate the uncertainties. For this matter, the variation of the central value was taken as 10%. Repeatibility was a constant concern through the measurements. Normal distribution was adopted in regard to the uncertainty, although the resolution contribution adopted was the rectangular one.

III. Results end Discussion

This work demonstrates that the efficiency to control mass of trucks can be improved using this method of uncertainty calculation. The previous uncertainty value of 1,49% with a clear improvement was decreased to 0,56%. Previous studies using only mean values and regression were not able to calibrate the instrument to the real vehicles traffic characteristics. The methods that considered the vehicles types and different loads represents the real characteristics of these instruments.

The method presented on this work can be related with the results simulations of the real weighing data, generating very low errors value. This is due to the high interactions values produced by the Monte Carlo Method (which uses more than 100.000 interactions). Despite that fact, the dispersion of real values should not be discarded for reliability assessment and regulation issues. The results analysis aimed the simulation of real data by a variation of the initial conditions within a 10% range and through higher interactions. Results showed the influences of moving vehicles weighing that can be considered for the reliability assessment of weighing instruments and processes.
The model used can thus be applied in weighing instruments calibrations and identification of eventual adjustments aiming the better performance of the weighing systems. These aspects represent the possibilities of use of this model for reliability assessment for instrument selection, according to their performance regarding the deviations and errors accounted during the weighing process.

IV. Conclusions

The tests results indicate the need of adjusting the instruments of dynamic weighing for the real conditions of service, i.e., taking into account the types of vehicles that circulate on the roads.
The use of electronic weighing instruments leads to a concern on the quality of the AD/DA conversion, which is fundamental for the process performance. The model for assessing data influences the tests result.
This works presents thus, a model to be applied in calibration processes in instruments used for monitoring and policing traffic control. This model is capable of improving the process to inhibit the damage on the road pavement. The simulation model can be used in different situations when instruments are been used for checking the force exerted from the vehicle to the road. It can also be applied as an important tool for legal metrology and in specific application conditions**.**

References

[1] L.B. Faruolo, J.L Fernandes, M.R Brochado. “Tendencies for the Control of the Weight of Vehicles in the Highways”, ENQUALAB, São Paulo, Brasil, 2006.
[2] Dodoo, Nii Amoo and Thorpe Neil “A New Aproach for Allocating Paviment Damage Between Heavy Goods Vehicles for Road-user Charging”, Elsevier, 2005.
[3] Guide to the Expression of Uncertainty in Measurement, Supplement 1- Numerical Methods for the Propagation of Distributions, 2004.
[4] L.B. Faruolo, J.L. Fernandes “The mass measurement in-motion using strain gage", 8 COTEQ, Salvador, Brazil, 2005.
[5] Determination N 184 of Contran – Brazilian National Council of Traffic, 2005.
[6] L. B. Faruolo, "Analysis of the System of Measurement of the Weight of Vehicles In Montion In the Highways", ENQUALAB - REMESP, São Paulo, Brazil, 2005.
[7] J. Hyunz-gyn ; T. R Way; B. Loygren; M. Landstrom, ; A. C Bailey.; E. C. Burt..; T. P. Mc.Donald, “Dynamic Load and Inflation Pressure Effects on contact pressures of a Foresty Forwarder Tire”, Journal of Terramechanics, 8p, 2004.
[8] T. Ono, K. Fukuda,. K..Yoshida, H.Uozumi, e H.Tottori, , “Mass-estimation Methods for In-motion Vehicles Using Axle Whinghing System”, IMEKO - International Measurement Confederation, Tampere, Finland, 1998.
[9] Rolf Kumme, “The Determination Of The Efective Dynamic Force For The Calibration Of Force Transducers, With Due Regard To The Distribuition Of Mass And Acceleration” , IMEKO,1996.
[10] M. Danaci, “New approaches for high speed and Accurate Weight measurements”, IMEKO, Stambú, Turkey, 2001.
[11] M.Niedzwiecki e A Wasilewski, “Application Of Adaptive Filtering To Dynamic Weighing Of Vehicles” Pergamon, 1996.
[12] L.B. Faruolo, J.L. Fernandes, M. R. Brochado “key factors in road vehicles weigh-in-motion, XVIII IMEKO, Rio de Janeiro, Brazil, 2006
[13] COST 323 – European specification on weigh-in-motion of road vehicles, draft2.2, EUCO-COST/323 1997

[14] L.B. Faruolo, J.L. Fernandes, M. R. Brochado " Análise do efeito do peso de veículos nas estradas" XIV Congreso Panamericano de Engenieria Trafico e Transporte, Las Palmas de Gran Canária, Espanha, 2006

[15] Cox. M. Harris P. Sierbert "Evaluation of uncertanily based on the propagation of distributions using Monte Carlo simulation, Measurement techniques, 2003.

[16] Moscati G., Mezzalira, L. G. e Santos, F.D. Incerteza de medição pelo método de monte carlo, no contexto do suplemnto 1 do GUM, Enqualab, São Paulo, 2004.

[17] Luciano Bruno Faruolo , "Analysis of Reliability for the Weigh-in-motion Vehicles", master teses In Technology, CEFET-RJ Federal Center of Technology, Rio de Janeiro, Rio de Janeiro, 2007.

***