

CORRECTION OF WIM MEASUREMENTS BY THE SLIMAX METHOD

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ABSTRACT

Since the introduction of WIM to South African roads, all calibration methods have aimed at the correction of systematic error. However, the random-error component in WIM measurements, particularly those done at high speeds, is equally important, because of its amplification when loading characteristics such as the proportion of overloaded heavy vehicles and E80 are evaluated from the dynamic forces measured by WIM. Even though the WIM equipment may be calibrated to produce accurate average axle loads, the random error results in over-estimation of the above characteristics because of a fourth-power function used in the calculation of E80, and the bloated right-hand tail of the axle-load distribution from which overloading is evaluated.

A method called SLIMAX has been devised to arrive at realistic estimates of static axle loads from the WIM-measured dynamic ones. This is done by the elimination, or significant reduction, of systematic and random errors of WIM measurements.

To demonstrate the working and outcome of the SLIMAX Method, raw WIM-measurements on axle loads were used from the Cedara permanent WIM station on the N3 National Road north of Pietermaritzburg. Over one million heavy vehicles were used in the analysis. The distributions of the raw, adjusted and corrected axle loads are presented graphically. A comparison is made of the characteristics derived from these distributions, such as the percentage of overloaded heavy vehicles and E80 per heavy vehicle.

The above comparisons show that, even with the systematic error eliminated and the static tonnage thus being estimated correctly, the random error causes over-estimation of both the E80 and the magnitude of overloading. The bias, however, can effectively be corrected by means of software. The SLIMAX Method may appeal to practitioners concerned about the quality of WIM measurements, as a relatively simple and practical way of restoring the justification and credibility of WIM-measured results.

RATIONALE

Four types of axle-load distributions are taken into consideration, viz.

- The true (but unknown) distribution of static axle loads of heavy vehicles that travelled in a given lane during a given period of time.
- The distribution of raw axle loads as measured by WIM in the same space and period; this distribution is burdened by systematic and random errors committed by the WIM equipment.
- The distribution of adjusted axle loads – a distribution from which the systematic error has been eliminated.
- The distribution of corrected axle loads, which is free, or almost free, of both the systematic and random errors of WIM measurement – a ‘slimmed’ distribution that imitates the distribution of true axle loads.

The basic premise is that a WIM-measured axle load X_{wim} can be adjusted into X_{adj} by multiplying X_{wim} by a constant factor k , which removes a systematic influence such as calibration error. This adjusted axle load X_{adj} can then be converted into corrected axle load X_{corr} by suppressing the random error of WIM measurement e_{wim} .

The model thus is:

$$X_{\text{corr}} = X_{\text{wim}} \cdot k + e_{\text{wim}} \quad (1)$$

The distribution of corrected axle loads is obtained from the raw one in two steps.

Firstly, all raw axle loads are multiplied by an adjustment factor k that eliminates the systematic error of WIM measurement. The factor is established during calibration, when a sample of WIM measured axle loads is compared with the weighbridge-measured counterpart. The adjustment factor is calculated from the condition that the sum of adjusted axle loads be equal to the sum of weighbridge-measured axle loads. Statistically speaking, the distribution of adjusted axle loads has a correct mean, although it is relatively dispersed (broad) due to the dynamic forces being measured.

Secondly, the distribution of adjusted axle loads is 'slimmed up' into a less dispersed distribution – the distribution of corrected axle loads, which imitates the true one. The key to the slimming is information on the dispersion of errors e_{wim} expressed in terms of their variance, V_{wim} , (variance is a statistical measure of scatter), with which given WIM equipment registers static axle loads as dynamic forces. The variance of the distribution of adjusted axle loads V_{adj} is the sum of the above variance V_{wim} and the variance V_{true} of the true (but unknown) distribution of static axle loads:

$$V_{\text{adj}} = V_{\text{wim}} + V_{\text{true}}, \quad (2)$$

from which it follows that:

$$V_{\text{true}} = V_{\text{adj}} - V_{\text{wim}} \quad (3)$$

V_{adj} is known from the adjusted axle loads and V_{wim} can be deduced from the calibration of WIM equipment or its accuracy specification. V_{true} , the sought variable, is then found from the above equation and used as the variance of the distribution of corrected axle loads V_{corr} . Once the distribution of corrected axle loads is constructed, important loading characteristics, such as the percentage of overloaded heavy vehicles, E80 and Extra E80, can then be derived from this distribution.

Eq.4 does the actual translation of raw axle loads into their corrected counterparts. While preserving the shape of the distribution of adjusted axle loads, the reduction in the variance of corrected axle loads is achieved by means of moving the adjusted values towards their mean, in a proportional manner.

$$c_i = k \left(M_r + (r_i - M_r) \sqrt{1 - \left(\frac{SEA}{k SD} \right)^2} \right) \quad (4)$$

where

c_i	corrected axle load
k	adjustment factor eliminating the systematic error
M_r	mean raw axle load
r_i	raw axle load to be corrected
SEA	square root of V_{wim}
SD	standard deviation of raw axle loads

The theory behind the method (Slavik, 1998) was published in detail in 1998. Since then software that is compatible with the South African Traffic Data Standard (Schildhauer, 1999) has been developed and used on experimental basis. Recently the method has been computerized and used at several WIM stations placed along the N3 Toll Road and the N4 Toll Road in the Maputo Corridor, to study the influence of law enforcement on the extent of overloading.

APPLICATION

To demonstrate the working and outcome of the SLIMAX Method, raw WIM-measured axle loads were used as obtained at the Cedara permanent WIM station from 1 January 2002 to 31 December 2002. The station is situated about 18 km north of Pietermaritzburg, on the N3 National Road, which is a four-lane freeway with concrete surface. The station has been in permanent operation since October 2000. The WIM sensors were placed in both outer lanes, to weigh and register majority of the heavy-vehicle axle loads on the road. The 2002 data entail 1,13 million heavy vehicles, 5,73 million heavy-vehicle axles, and 36,3 million tons of axle loads. In 2002 the Cedara WIM station recorded good (verified) data 99,25 % of the time. Only good data – altogether 239 Mb - were used in the analysis.

As mentioned above, the SLIMAX Method requires the values of factor k and the value of variance V_{wim} . The k factors were derived from a sub-population of 920 6-axle and 7-axle trucks weighed during a special survey, at the Midway static weighbridge (off the N3 Freeway, about 60 km north of the Cedara WIM station), in the week from 22 to 28 November 2001. The total mass weighed statically was 41 270 tons. At the same time, the Cedara WIM recorded the corresponding tonnage. To bring the WIM-measured total tonnage to the statically measured 41 270 tons, the individual WIM-registered axle loads at Cedara had to be increased. The required increase was +22,15 % in the northbound direction and +27,60 % in the southbound direction. The corresponding k factors, particular to the Cedara WIM station, were thus taken as 1,2215 and 1,2760 respectively.

SLIMAX 2, v2.3, ©2002, M Slavik (ms1af)

CONTROL | SUMMARY | COMPARE | TONS | 24h TRAFF | VEHFLOW | HHVOL | SPEED% | 7 DAYS | 24h HV | AXFLOW | HV | E80 | % PLD | PLD <X | OFFENCES

Site identification text: Cedara, Both directions, 2002

Period to examine, YYMMDD: First day: 020101 Last day: 021231

Lanes from which loop-count sum records are expected: 1 2 3 4 5 6 7 8

Lanes from which individual HV records are expected: 1 2 3 4 5 6 7 8

HIGHLIGHTS

%EGR Loops, %	99.78
ADT, vehs/day	24988
ADTT, HV/day	3523
Percentage HV, %	14.10
HV: %S %M %L	29.2 21.4 49.4
%EGR WIM, %	99.25
Overloaded HV, %	23.73
E80/day	8959.8
E80/HV	2.88
Extra E80, %	8.20

CORRECTED AXLE LOADS:

Average axle load, t	6.332
St. dev. of axle loads, t	2.006
St. error of WIM, t	1.378

List of files to examine:

- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020131.rsa
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020228.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020331.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020430.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020531.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020630.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020731.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020831.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20020930.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20021031.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20021130.RSA
- C:\Papers\8thWIM-SlimAx\CedaraRSA\flat\CDR20021231.RSA

Grace given before prosecution: 0 % 5 % 10 % 15 %

Check min. HV mass Make CleanFile Do all in ONE GO

WIM:

1	2	3	4	5	6	7	8
k	1.2215	1.000	1.000	1.2760	1.000	1.000	1.000

Damage exponent: 4.2 WIM measurement error SEA, t: 1.378

1213515 rec. in 34.66s. Files examined: 12 of 12

TRACE: OFF ON

Help | Select input files | Abort | Evaluate

Taskbar: Start | Tempor | Novell GroupWise - M... | Slavik1 - 815HVVD.d... | C++Builder 5 | SlimAx 2.3 | 15:04 PM

Screen shot 1. Control panel with input.

The value of variance V_{wim} was derived from the specification of the WIM equipment. The Cedara WIM uses DAW100 bending plates manufactured by PAT Germany. This equipment qualifies as Type II WIM system according to the American standard (ASTM, 2002), which allows a maximum axle-load error for this

type of device of $\pm 30\%$. The $\pm 30\%$ tolerance has been interpreted as a 95% confidence interval, which means that one standard deviation of error is $30\% / 1,96 = 15,31\%$. When this figure is applied to the load of greatest interest, which is the legal axle-load limit of 9,0 t, we obtain $9 \cdot 0,1531 = 1,378$ t. The value of 1,378 t is thus the square root of V_{wim} called WIM measurement error SEA, which is required as an input parameter by SLIMAX. Provision is made in the input to enter values of SEA appropriate to individual WIM circumstances.

The input arrangement is apparent from the screen shot as shown.

The SLIMAX program is very fast – the processing on an ordinary PC of the 239 Mb of data – 1,214 million records – took about 35 seconds.

OUTPUT

The most important output items are three axle-load distributions shown in Figs 1, 2 and 3. When looking at these distributions one should notice the following:

The distribution of raw axle loads as shown in Fig.1 is centered on the mean axle load of 5,079 t. Its dispersion is indicated by the standard deviation $SD = 1,958$ t.

The distribution of adjusted axle loads as shown in Fig.2 centers on the mean axle load which is 6,332 t, and is thus shifted to the right. Because of the large adjustment factors – 1,2215 and 1,2760 – it has a larger dispersion than the distribution of raw axle loads; the standard deviation is 2,433 t.

The distribution of corrected axle loads as shown in Fig.3 has the same mean as the distribution of adjusted axle loads – 6,332 t, but is ‘slimmer’, i.e. dispersed less – its standard deviation is only 2,006 t.

(At this point we could check the compliance with Eq.2: $V_{true} = V_{adj} - V_{wim}$.)

With V_{corr} taken as V_{true} : $V_{true} = 2,006^2 = 4,02$; $V_{adj} = 2,433^2 = 5,92$; $V_{wim} = 1,378^2 = 1,90$.

Indeed: $4,02 = 5,92 - 1,90$.)

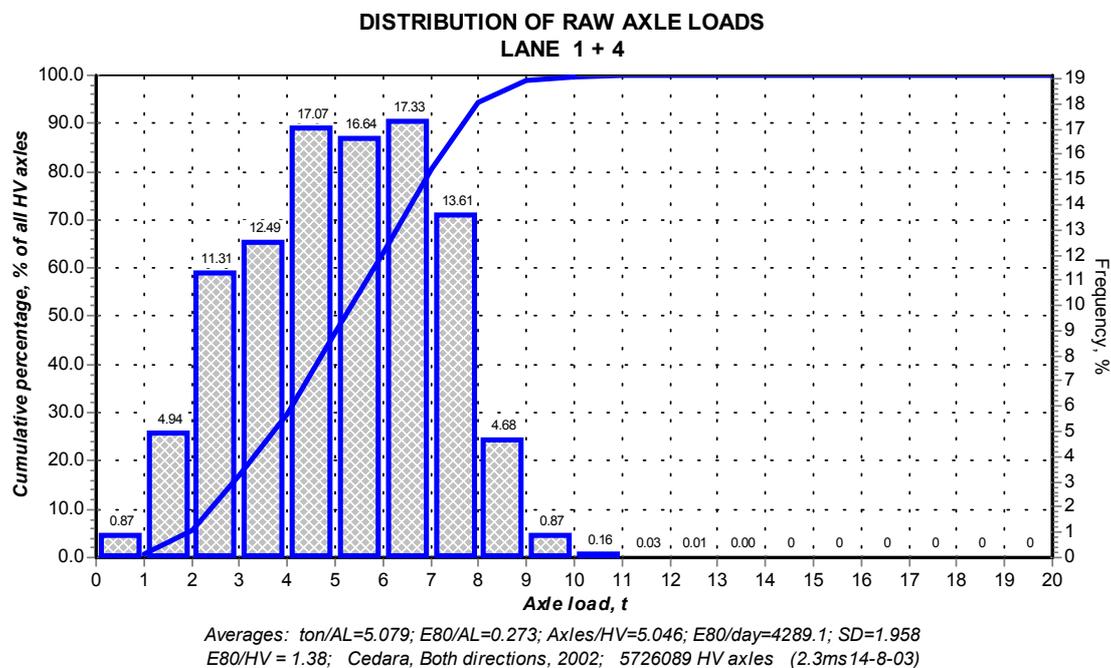


Figure 1. Distribution of raw axle loads.

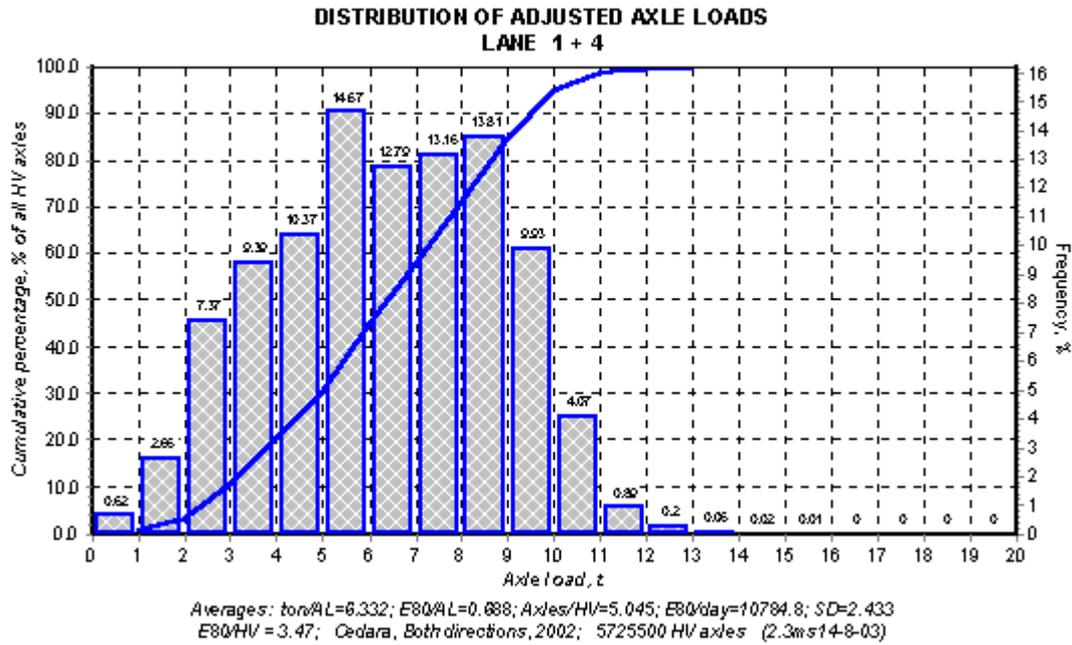


Figure 2. Distribution of adjusted axle loads.

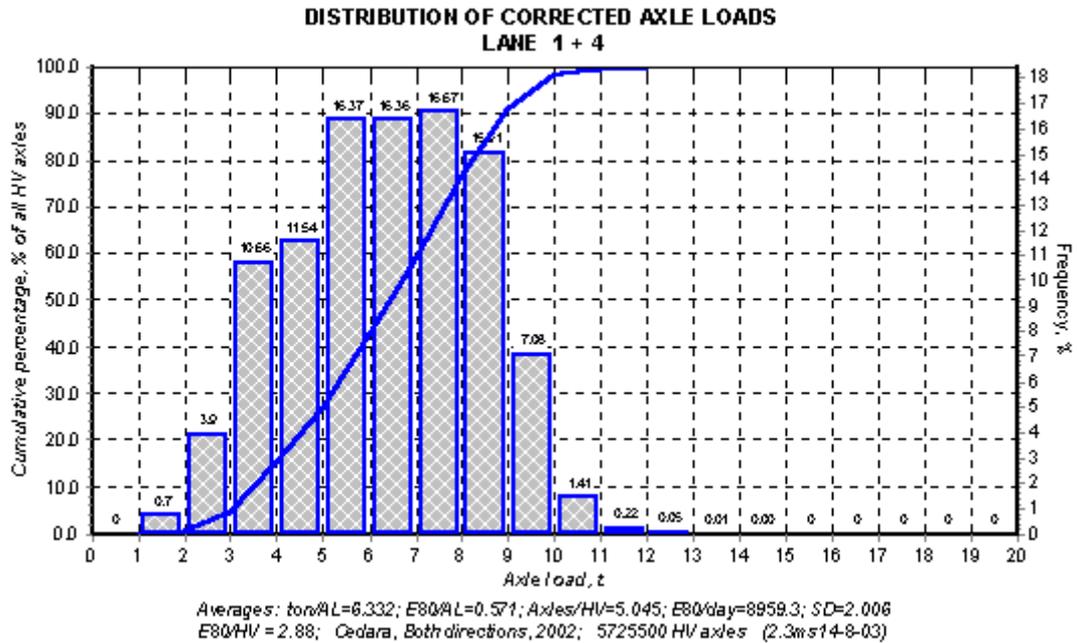


Figure 3. Distribution of corrected axle loads.

Various traffic and loading characteristics, such as the percentage of overloaded axles, average E80 per heavy vehicles and others are then derived from these distributions. For the user's convenience the program compiles a table in which comparison is made between the characteristics derived from the raw, adjusted and corrected distributions.

The comparison table is shown in Screen Shot 2 in which these abbreviations are used:

HV	heavy vehicles
E80	eighty-kN equivalent axle loads
XE80	extra E80 (those contributed by axle overload above 9 t)
%OLHV	percentage of overloaded heavy vehicles
%XE80	XE80 as a percentage of all E80
AL	axle load
SEA	square root of V_{wim}

SLIMAX 2, v2.3, ©2002, M Slavik (mslaf)
 Site : Cedara, Both directions, 2002
 First day of the period to examine : 1 Jan 2002
 Last day of the period to examine : 31 Dec 2002
 Number of days in the above period : 365
 ID numbers of examined lane(s) : 1 2 3 4
 Individual HV records expected from : 1 4
 Syst. error correction factors k : 1.2215 1.2760

Axle loads:	Raw	Adjusted	Corrected
HV	1134884	1134835	1134835
E80	1565515	3936440	3270310
XE80	29672	696447	268108
%OLHV	2.08	33.36	23.73
E80/HV	1.38	3.47	2.88
%XE80	1.90	17.69	8.20
Mean AL, t	5.079	6.332	6.332
St.dev. of AL, t	1.958	2.433	2.006
WIM error SEA, t	0.000	0.000	1.378

Screen shot 2. Comparison of characteristics obtained from raw, adjusted and corrected WIM measurements.

The above comparison reveals several interesting facts:

- There is a calibration error - with the current calibration the Cedara WIM under-measures axle loads.
- When the calibration error is eliminated, the average axle load increases from 5,079 t to 6,332 t. This has a very serious impact on the estimated overloading - 33 % instead of 2 %. Equally serious is the impact on the estimated average E80 per heavy vehicle – 3,5 instead of 1,4. This means that the raw WIM measurements are only usable after an adjustment, to compensate for the influence of systematic error.
- When the adjusted WIM measurements are corrected - to compensate for the influence of random error, the picture changes; although the average axle load after correction stays the same – 6,332 t – the estimates of overloading and E80 are reduced. According to the above table, a realistic estimate of overloading is about 24 %, whereas the estimate of E80 per heavy vehicle drops from 3,47 to a more realistic level of 2,88 E80/HV.

DISCUSSION

An acid test of the SLIMAX method would be a comparison between the corrected and true axle loads. Unfortunately, this comparison could not be done - it was neither practical nor possible to weigh almost 6 million axles on a weighbridge. Several small samples of axles were used previously to gauge the degree to which the SLIMAX Method can imitate static axle loads – the results were encouraging, the method always made a step in the right direction. Should there be a research exercise done anywhere, with hundreds or thousands corresponding static and WIM-measured axle loads, the author would be most grateful to receive such data and analyze them by the method.

CONCLUSION

WIM measures dynamic axle loads that are then used to estimate static loads. The dynamic loads measurement is subject to both systematic and random errors. Although these errors may be large, WIM measurements should not be regarded as useless. The so-called raw axle loads – those measured – can be

corrected and trustworthy results thus obtained. The correction, which is a simple linear transformation, is based on the knowledge of both the systematic and random error of the WIM scale used. This information is available from WIM calibration and/or from WIM manufacturer's specification. Since the SLIMAX correction procedure takes into consideration not only the properties of the WIM equipment used, but also factors such as the condition of road surface, the composition of truck traffic and the loading of trucks it is highly site-specific and appropriate.

ACKNOWLEDGEMENT

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