

# Evaluation of Factors Affecting WIM System Accuracy

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## Summary

This paper was presented at the second COST 323 WIM conference in Lisbon 1998. It describes all factors affecting the accuracy of LS- and HS-WIM systems and of static wheel load scales. Similarities as well as the differences are presented. The static wheel load scales are used as a basis, because they are widely used and accepted for law enforcement purpose.

The most important result of this paper is the table with the achievable accuracy. The figures given as well as the rest of the text are approved by the scientific committee of COST 323 and therefore can be considered as correct.

## Zusammenfassung

Das vorliegende Papier wurde an der zweiten COST 323 WIM Konferenz in Lissabon 1998 präsentiert. Es beschreibt alle Faktoren, welche die Genauigkeit von Wägungen während der Fahrt bei niedrigen und hohen Geschwindigkeiten, wie auch mit statischen Radlastwaagen beeinflussen. Die Gemeinsamkeiten, wie auch die Unterschiede werden herausgearbeitet. Die statischen Radlastwaagen werden als Basis verwendet, weil sie als anerkanntes Mittel für die Durchsetzung der Gewichtslimiten gelten und weltweit eingesetzt werden.

Das wichtigste Resultat ist die Tabelle mit den erreichbaren Genauigkeiten. Die angegebenen Werte wie auch der übrige Text wurden durch das wissenschaftliche Komitee von COST 323 überprüft und können somit als korrekt betrachtet werden.

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# Evaluation of Factors Affecting WIM System Accuracy

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### Abstract

This paper describes all factors affecting the accuracy of LS- and HS-WIM systems and of static wheel load scales. Similarities as well as the differences are presented. The static wheel load scales are used as a basis, because they are widely used and accepted for law enforcement purpose.

**Keywords:** Law enforcement, static weight, gross weight, axle load, platform scale, wheel load scale, WIM system, type approval, centre of gravity, axle suspension, vehicle oscillation, system accuracy.

### Résumé

Ce papier décrit tous les facteurs influençant la précision du pesage en marche à basse et à haute vitesse et du pesage avec des indicateurs de charge de roue statique. Les choses en commun, même que les différences sont présentées. Les indicateurs de charge de roue servent comme base, parce qu'ils sont utilisés et acceptés dans le monde entier pour la répression de la loi.

**Mots-clés:** Répression de la loi, poids statique, poids total, charge par essieu, pont bascule, indicateur de charge de roue, pesage en marche, approbation du type, centre de gravité, suspension d'essieu, oscillation du véhicule, précision totale.

### Zusammenfassung

Das vorliegende Papier beschreibt alle Faktoren, welche die Genauigkeit von Wägungen während der Fahrt bei niedrigen und hohen Geschwindigkeiten, wie auch mit statischen Radlastwaagen beeinflussen. Die Gemeinsamkeiten, wie auch die Unterschiede werden herausgearbeitet. Die statischen Radlastwaagen werden als Basis verwendet, weil sie als anerkanntes Mittel für die Durchsetzung der Gewichtslimiten gelten und weltweit eingesetzt werden.

**Schlüsselworte:** Gesetzesvollzug, statisches Gewicht, Gesamtgewicht, Achslast, Brückenwaage, Radlastwaage, Wägung in Fahrt, Bauartzulassung, Gewichtsschwerpunkt, Achsaufhängung, Fahrzeugschwingung, Gesamtgenauigkeit.

## **1. General and historical background**

Law enforcement is always based on limits for the static weight. This approach is appropriate for all legal needs except for the determination of the damage potential of heavy vehicles. It is rather related to the maximum force a wheel applies to the road surface during travelling (cue: road friendly suspension). Nevertheless there are some good reasons to use static weight limits also in view of road protection. Probably the most important is, that the truck operator has virtually no opportunity to check the impact forces of his vehicle during travelling. On the other hand he faces absolutely no problems keeping the gross weight within the limits, but there is somewhat more trouble checking the axle weights.

Years ago the weight enforcement was performed on platform scales that the whole vehicle could fit onto. Only the gross weight was determined with a rather high precision, completely independent of the type of vehicle, its maintenance condition and the way the vehicle was stopped on the platform.

To overcome the disadvantage of stationary weigh stations (bypassing, no spot checks possible, etc.), portable wheel load scales were developed. Because each wheel is measured individually more information is available, i.e. wheel and axle loads as well as the gross weight. The precision of these instruments is somewhat lower compared to platform scales. But depending on how many scales are used, additional errors may occur because of weight transfer between axles, especially when weighing trucks with three or more axles, using only two pads in an axle by axle mode, TRRL/LMP (1988), Scheuter, F. (1997).

With portable static wheel load scales enforcement is possible at almost any place, provided that the suitable measuring procedure is applied, Scheuter, F. (1997). The disadvantage, that the measurement takes some time (the vehicle has to be stopped on the scale) has led to the idea of using low and high speed WIM systems as well for law enforcement. The following sections show what errors might occur, in comparison to static wheel load scales. This comparison gives a good overview of WIM capabilities in respect to a well known and world-wide accepted technology. The goal is to give assistance in setting up rules for tolerance deductions, which are absolutely necessary to avoid the risk of failing in legal proceedings.

## **2. Error influences**

### **2.1 General**

According to the above, the error of any weighing equipment is the difference between the indicated weight and the „real static weight“, which is defined as the weight under perfect conditions, meaning an absolutely level site, the suspension of the vehicle in an average, frictionless position, no braking. Any type of weigh sensor or scale only can measure what it „feels“. The difference between the indication of the sensor and the applied load (or the load the sensor feels) is the intrinsic error of the instrument. The difference between the applied load and the „real static weight“ might be called error due to „external factors“.

In the following text the expression WIM is used for both low and high speed WIM if not specifically indicated.

### **2.2 The accuracy of the sensor (intrinsic error)**

The intrinsic error can be determined using a test machine or dead weights. Depending on the technology it may be influenced by the following factors: temperature, excentric loading,

tilting, bending, lateral forces, repeatability, creep, warm up, moisture, electromagnetic susceptibility, etc.

Equipment for law enforcement must usually be type approved and individually tested before being put into operation.

Type approval: One or more samples are tested under laboratory conditions to find out the performance of the measuring system. The procedure consists of many tests to prove that the indication is correct under all relevant conditions. All results must comply with legal regulations.

Putting into operation: The equipment to be put into operation is tested under simplified conditions, preferably at ambient temperature at least at one location of the platform. Depending on the results the type approval reveals, other tests may also have to be performed, e.g. with excentric loading.

In the European Union static scales must comply with the regulation 90/384/EEC. It is assumed, that all requirements are met, if the scale is tested successfully by a notified body according to the standard EN 45501 (1992), which is based on the OIML recommendation No. 76. Regulations for WIM systems are in progress, COST 323 (1997).

### **2.3 The combined influences of vehicle, site and sensor (external factors)**

#### ***Tilting***

Tilting has two effects:

- Tilting of the *vehicle* causes a displacement of the centre of gravity and thus a load shift towards the lower wheels.
- Tilting of the *sensor* leads to a lower indication, because it only registers the force component perpendicular to the sensor surface. This effect is very small. At 5% slope the error is only -0.12% of the measured weight!

Therefore weighing on a slope shows different results than on a level site. A slope in the driving direction results in load transfer towards the lower axle(s). This transfer is compensated for 100%, so that the calculated gross weight will not be affected. A slope crosswise results in a load transfer towards the lower wheels. This transfer is also compensated for 100%. If a full axle sensor is used no error occurs. When using a half sensor (determination of the axle weight by multiplying the measured wheel load by two) considerable errors may be avoided by adapting the calibration factor correspondingly or by using a specific correction.

#### ***The vehicle suspension***

The load on a wheel or an axle is directly related to the compression of the spring of the suspension. If the compression is different than average the sensor will not feel the correct load and thus measure an incorrect weight.

The stiffer the spring the higher the effect. In the case of a rear axle of a truck a rough calculation shows that the load rises by approximately 100 kg per mm compression (Assumption: empty truck: 2t axle load; fully loaded: 12t; difference 10t; compression of the suspension unloaded to fully loaded: 100mm; Spring rate: 10.000kg/100mm = 100 kg/mm).

Using WIM systems, specially HS-WIM, this effect occurs in cases where the sensor surface is lower or higher than the road surface (the body of the truck doesn't follow the axle movement) or as a result of an oscillation of the vehicle body.

Using static wheel load scales the effect occurs only when weighing a vehicle with three or more axles with an incorrectly levelled sensor. The effect is usually smaller than when using WIM, because most modern multi-axle systems are of the „balancing type“, so that a incorrect level doesn't affect the compression of the spring very much and because the vehicle body easily follows the axle movement. A further improvement is possible by measuring axle groups or the whole vehicle in one operation (number of scales as number of wheels), because the differences compensate for each other, so that the group and the gross weight are not influenced, Scheuter, F. (1997)

### ***Friction in the suspension***

Two types of friction occur: mechanical and hydraulic. The direction of both types of friction forces is opposite to the actual vertical movement of the axle. The magnitude of the mechanical friction depends on the construction of the suspension and on its maintenance, and is virtually independent of the velocity of the axle movement. Hydraulic friction occurs in shock absorbers together with a certain amount of mechanical friction. The magnitude of the hydraulic friction depends on the construction of the shock absorber and of the damping fluid used. The hydraulic friction force generally increases linearly with the velocity of the axle movement.

Modern suspensions are more likely to show hydraulic than mechanical friction because they are often equipped with shock absorbers and because vehicle manufacturers try to suppress mechanical friction, which is the main source of wear (abrasion of material).

When measuring a wheel the friction may result in a higher or lower weight, depending on the actual direction of the axle movement the moment it passes the WIM sensor, or on how the vehicle came to rest on the static scale.

Friction is an advantage when using WIM systems as vehicle oscillation is damped.

Static weighing of vehicles with three or more axles is influenced by mechanical friction only, because there is no axle movement producing hydraulic friction. As described in section above, an improvement is possible by measuring axle groups or the whole vehicle in one operation so that group and gross weight are not influenced.

### ***Brake reaction forces***

Using WIM systems no braking is necessary. So principally there is no influence on the accuracy.

Static weighing is influenced by braking if vehicles with three or more axles are weighed. Depending on how the braking forces are transferred to the vehicle chassis, additional force components may have an effect unless the brake is not released. To prevent such errors the brake has to be released for a short time to relax the suspension. But there still might be some residual friction forces which were induced by braking. Refer to section above.

### ***Vehicle oscillation***

The largest possible errors for WIM systems are caused by vehicle oscillation. There are two main movements, the oscillation of the body with a natural frequency of 1..3 Hz, depending on the loading and the axle oscillation with approximately 10 Hz, Baur, M. (1988), Huhtala, M. (1998). The error occurs because no commercially available WIM sensor is long enough to measure the axle load during one full period of the lowest frequency (necessary sensor length for 10 km/h: 3m, for 100 km/h: 30m!). Depending on the actual amplitude of the oscillation

the moment the axle passes the WIM sensor the measured weight will be higher or lower than the real static weight.

Due to the fact that the axle frequency is virtually a constant value its influence can be reduced by offsetting the left and the right sensor by half a wave length. This measure is useful if the speed of the vehicle is assumed to be constant. The offset is calculated by the equation  $\Delta l = v/(2 \cdot f_{\text{axle}})$ . For a speed  $v$  of 10 km/h (2.8m/s) the offset is 0.14m, for 100km/h accordingly 1.4m.

Multi sensor WIM systems may reduce the influence of vehicle *and* axle oscillations significantly, (Siffert, 1997). An other approach is to correct the measured weight by calculating the dynamic portion of the load. More information and references are given in Ma, S and Caprez, M (1995).

The magnitude of the possible error depends on the speed, on the damping quality of the suspension and of the evenness of the road surface, Forschungsgesellschaft...(1983) .

Obviously the static wheel load scales are not affected, because the operator is obliged to take the reading after the load has stabilised.

### ***Tyre tread***

The tyre tread may have an influence on strip sensors if its design shows cross grooves (winter tyres). Depending on where the cross groove is located while the wheel passes the sensor strip the measured weight will be higher or lower than the real static weight. The magnitude of the effect depends on the dimension of the groove and of the strip width (length in driving direction).

### ***Aerodynamic forces***

Aerodynamic forces in the vertical direction are rather small compared to the vehicle weight. Only crosswind can have an influence because it results in load transfer towards the leeward wheels. If a full axle sensor is used no error occurs because the load transfer compensates from one side to the other. When using a half sensor (determination of the axle weight by multiplying the measured wheel load by two) considerable errors are possible.

### ***The sensor installation (levelling)***

Incorrect sensor levelling results in errors due to the characteristics of the vehicle suspension. Refer to section vehicle suspension and friction above

### ***The site and access evenness***

Access and site unevenness result in vehicle oscillations, refer to the corresponding section above and to COST 323 WIM Specification (1997) and to incorrect levelling of the sensor, see above.

When using static wheel load scales the result is influenced by the unevenness one vehicle length in front and behind the scale. The effect is the same as described for incorrect levelling in the section above.

## 2.4 The influence of the driver and the operator

If no special measures are taken a WIM system may be bypassed. If the system is used for law enforcement a driver knowing that his vehicles is overloaded, will try to reduce the measured weight by bypassing the sensor partially, without attracting the operator's attention. For the operator (if there is one, automatic preselection) it is quite difficult to notice whether the tyre has passed properly within the active area of the sensor. The drivers also will try to reduce the measured weight by accelerating or braking at the appropriate moment.

Various means to detect by-passing are available: Off side sensors, video surveillance, markings, kerbs, etc. Braking or accelerating may also be detected using appropriate sensor configurations.

Theoretically, weighing on static wheel load scales can not be influenced by the driver, because the operator is responsible for correct weighing conditions (wheels correctly placed on the sensor, released brakes). Nevertheless some drivers will do their best to disturb the measurement.

## 3. Review of the error influences and achievable accuracy

Table 1 shows the typical intrinsic sensor accuracy for different types and their dependency on external factors. Except for the sensor accuracy no figures are given, because most errors appear as a combination of different factors and/or no exact values are available.

**Table 1** - Typical sensor accuracy and dependency on external factors

Weighing System Configuration	Weight Measured	Intrinsic Sensor Error	Tilting Longitudinally	Tilting Crosswise	Access Evenness	Site Evenness	Sensor Levelling	Crosswind	Vehicle Suspension Quality	Braking	Vehicle Speed	Excentric Loading	Tyre Tread
Platform Scale	Gross	<.5	-	-	-	-	-	-	-	-	-	-	-
Set of 6 Static Wheel Load Scales	Axle	.5	x	-	-	x	x	-	x	x	-	-	-
	Gross		-	-	-	-	-	-	-	-	-	-	-
Set of 2 Static Wheel Load Scales I	Axle	.5	x	-	-	x	x	-	x	x	-	-	-
	Gross		-	-	-	x	x	-	x	x	-	-	-
Full Plate WIM	Axle	1-	x	-	x	x	x	-	x	-	x	-	-
	Gross	2	-	-	x	x	x	-	x	-	x	-	-
Half Plate WIM	Axle	1-	x	x	x	x	x	x	x	-	x	x	-
	Gross	2	-	x	x	x	x	x	x	-	x	x	-
Strip WIM	Axle	2-	x	-	x	x	x	-	x	-	x	-	x
	Gross	10	-	-	x	x	x	-	x	-	x	-	x

Based on Table 1, on HAENNI's experiences with static and dynamic sensors and on publications (e.g. Forschungsgesellschaft...(1983) , TRRL/LMP (1988), COST 323 Post proceedings (1995)) the following over all accuracy ranges may be established. For easier comparison with the actual law enforcement rules the „*maximum permissible error band*“ (*mpe*) definition is used for the accuracy figures.

**Table 2** - Typical over all accuracy of various weighing systems (gross weight)

System	Accuracy (mpe)	Notes
Platform scale	< 0.5 %	Very accurate measurement of the gross weight.
Set of 6 wheel load scales	1%	Most accurate way in mobile weighing, but labour intensive and slow. Almost independent of external factors.
Set of 2 wheel load scales	1...3%	Axle by axle weighing, most convenient way in static mobile weighing. 1% relates to a good site and modern vehicles in good shape, Broster, C. (1996), 3% with the same material on an average site with vehicles in poor condition, Scheuter, F. (1996).
Full plate low speed WIM	1...5%	1% relates to a „perfect“ fixed installation with vehicles in good shape, 5% to a good mobile system with access ramps on an average site and vehicles in poor condition.
Full plate high speed WIM Half plate high speed WIM	10..30% 15..30%	10% /15% relates to a site with a very good evenness and vehicles in good shape, 30% to an average site and vehicles in poor condition.
High speed strip WIM	15..40%	15% relates to a highly sophisticated sensor, a site with very good evenness and vehicles in good shape, 40% to an average site and vehicles in poor condition.

#### 4. Conclusion

- For law enforcement high accuracy is required to avoid inadequate high tolerance deductions. This would lead to a practical increase of the weight limits. Even if a WIM system is used for preselection only, the accuracy must be high to guarantee that only overloaded vehicles are selected.
- The long term stability of the system must be good to prevent failing in legal proceedings.
- The highest accuracy is achieved with static scales and weighing in one operation or with a highly sophisticated low speed WIM in conjunction with a perfect measuring site.
- The higher the speed the more important a perfect site is. It must be recognised that a measuring site may deteriorate quicker than a static scale or the WIM sensor itself.
- A check or a repair of a static scale is much simpler than of a fixed-installed WIM system. Therefore the reliability of a fixed-installed WIM system, including the pavement in front and behind the sensor, must be significantly higher.
- Regulations for WIM systems must be incorporated into existing transport law.

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## Typical Errors of Weighing Systems (Gross weight)

Error Definition: according EN45501 (OIML76)

