Sources of Error in Dynamic Weight Measurement

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Author: F. Scheuter

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Summary

This article has been written for the **Traffic Technology International** magazine 1997.

It summarises the error sources of dynamic measurement in respect to static weighing with portable wheel load scales.

Accuracy figures for WIM systems are stated as follows:

approx. ± 1%:	Axle weight scales with load cells, max. 5 km/h, perfect surface before and after the scales.
approx. ± 5%:	Scales sensor in plate form, max. 20 km/h, perfect surface before and after the scales.
approx. ± 10%:	Scales sensor in plate form, max. 100 km/h, very good surface before and after the scales.
approx. ± 15%:	High-grade weight sensor in strip form, max. 100 km/h, good surface before and after the scales.
approx. ± 25%:	Simple piezo cable, max. 100 km/h, good surface before and after the scales.

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Sources of error in dynamic weight measurement

The increasing spread of weigh-in-motion systems worldwide has brought with it a new set of difficulties which must be addressed in order to achieve accurate results

Felix Scheuter, Haenni & Co Ltd, Switzerland

In the past years there has been a steadily increasing interest in Weigh-In-Motion (WIM) systems. The reasons for this are found in the efficient recording of weight and also the need for more statistical data. Up until the 1960s, the platform scale was considered the sole usable means for determining the weight of goods vehicles. The introduction of portable static wheel-load scales led in grand style to a considerable rationalisation of weight enforcement, because with this equipment quick measurements could be made practically anywhere. However, there were problems with the accuracy of the results, and this was frequently – and falsely – attributed to the scales.

On closer examination it was established, in most cases, that the errors arose from faulty use, such as the omission of levelling in the sequential measurement of multiple axle systems. Today these problems are known to the users and such errors are avoided. The use of portable static wheel-load scales for weight enforcement has become a generally recognised method. Their accuracy lies only slightly below that of platform scales, providing that the product used is of corresponding quality, i.e. that it has been approved in accordance with the OIML (Organisation Internationale de Métrologie Légale).

MODERN-DAY WIM PROBLEMS

These days, with the increasing spread of WIM systems, one perceives difficulties similar to those experienced earlier with the portable wheel-load scales. The errors of that time are not repeating themselves, but new ones are occurring. In addition, for many users knowledge regarding the achievable precision of WIM systems is still rather patchy. On the one hand there are potential customers who require precision in the order of one per cent, and that also at high speeds. On the other hand there are frustrated users of WIM systems who consider the results achieved as absolutely unusable. Where does the truth lie? To get to the bottom of this one must delve into the theory of scales.

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A vehicle has a certain mass, also designated as weight. This is independent of whether the vehicle is stationary or moving. However, all known scales are based on the principle of force measurement – i.e. the force created by the mass – and the acceleration of gravity is measured. If additional acceleration arises, then measurement errors will occur. Therefore with a conventional (static) scale the weight applied must first be brought to rest before a reading can be taken. For obvious reasons this is not possible in the case of dynamic vehicle scales.

Nevertheless, there are possibilities for weighing the mass of a vehicle during its journey with a reasonable level of accuracy. There are two approaches:

- Avoidance of vertical vehicle oscillations. This state is reached if the driver has the impression that the vehicle seems at standstill with running engine. To make this possible, it is necessary to have a perfectly even road surface, an in-built scales sensor precisely flush with the surface and perfectly balanced wheels. Alternatively, there can be a drastic reduction of the vehicle speed. The poorer the surface, the slower the vehicle must move.
- Measurement of the vehicle over a longer stretch so that an average

value can be determined, corresponding to the effective mass. Unfortunately this approach, at least at present, is only suited for research purposes because the length of such a sensor must amount to about 30m. This figure is yielded from the fact that the structure of a fully laden lorry oscillates up and down about once a second (natural frequency 1Hz). In order to form a correct average value, a measurement must be made for at least the duration of one oscillation. At 100km/h a vehicle covers about 30m in this period of time!

In order to give a picture of the size of measurement errors due to vehicle oscillation, the various factors of influence are listed in Table 1[1].

The table shows that in principle good results can only be achieved with the best possible road quality and with vehicles with good suspension systems. This points up the first fundamental point of dispute. The manufacturer of the weighing system is himself responsible for the accuracy of the sensor, but has only a very restricted influence on road quality and its deterioration over the course of time, and certainly has no influence on the quality of the lorry travelling on it.

Here we find ourselves in the same situation as with the portable static wheel-load scales, i.e. the accuracy of the results is dependent on the one hand on the equipment, and on the other hand on the way in which it is used. In most countries the portable static wheel-load scales have been put to the acid test under laboratory conditions in accordance with OIML regulations, so that in general no doubt exists about their properties.

These days most users employ the equipment correctly, so that large errors due to ground unevenness, level differences and vehicle properties are extensively avoided. In various countries, differing opinions have developed regarding the estimation of the residual measurement uncertainty, but the end effect is that they are very similar. These estimations are used in weight enforcement, among other purposes, to make an appropriate deduction so as to ensure that a driver is never penalised for a higher weight than the actual one. Here are some examples of how the deductions are determined:

- Deduction of the tolerance in service of the wheel-load scales. This includes the possible errors of the scale itself (tolerance at first calibration), as well as the additional error to be expected by imperfect measurement conditions;
- Deduction of a percentage figure (1 to 2 per cent), which covers all error possibilities;
- Deduction of the calibration tolerance of the scales; additional deduction of a percentage figure for taking into consideration imperfect conditions of use.

By this approach, straightforward operation is possible in a way that effectively precludes challenging the results in court.

The same pattern can also be used for the WIM systems. The difference lies in that additional error influences arise while others drop out. To these must be added the influence of the vehicle oscillations, caused by ground unevenness, speed and vehicle properties. On the other hand all friction influences in the spring system, as well as influences due to the brakes, drop out. A commonality exists in that all errors occurring can once again be divided into two categories: errors due to the measuring equipment itself and those due to its mode of use. Therefore for a correct estimation of the errors, both types must be taken into consideration.

The accuracy of the measurement equipment itself should be apparent from the data sheets provided by the manufacturer. Unfortunately, these statements are frequently unclear. There are manufacturers who specify an accuracy that, by reason of the excellent value, is immediately recognised by the specialist as the accuracy of the sensor, but for the less experienced user it gives the illusion of accuracy in the installed state, while this accuracy which is only achievable under absolutely perfect conditions. Other manufacturers only specify the overall accuracy, because they know the properties of their sensors only from practical experiments in a built-in state, or because they hold the view that the entire stretch of road in which the sensor is installed should be regarded as the measurement system.

This approach to the matter is totally legitimate, although it requires the manufacturer to specify unequivocally the conditions of use (evenness of the road, speed, vehicle quality). However, with a view to an unequivocal disclosure of the cause of errors it is preferable to specify the precision of the sensors themselves, and the influences when in use, in the form of tables or illustrations, for example as part of the operating instructions. The advantage of this approach is

High accuracy WIM systems are now available but legal requirements restrict police to static scales

Speed (km/h)	Road quality	Vehicle quality	Influence of error up to approx.
5	very good	high	1%
	average	low	8%
50	very good	high	2%
	average	low	30%
100	very good	high	3%
	average	low	40%

Table 1: Influence of vibration exciting factors on precision of measurement

that the responsibility is divided between manufacturer and the user in accordance with their possible fields of action.

MEETING REQUIREMENTS

Depending on what information the user is interested in, the overall system must satisfy differing requirements. Where the mass flow must be determined, it is important that the measured weights concur on average with the actual weight. The sensor must be calibrated correctly, be stable over a long period of time, be temperature-independent and durable. No special requirements are placed on the quality of the road because vehicle oscillations are balanced statistically.

Where the static weight of the individual vehicle must be determined (weight enforcement or pre-selection for weight enforcement, statistical distribution of the effective axle and vehicle weights), it is important that each individual measurement be precise, which can be achieved by: a more precise sensor, better installation and minimal vehicle oscillations (drastic speed reduction and/or perfect surface).

approx. ± 1%	Axle weight scales with load cells, max. 5 km/h, perfect surface before and after the scales.
approx. ± 5%	Scales sensor in plate form, max. 20 km/h, perfect surface before and after the scales.
approx. ± 10%	Scales sensor in plate form, max. 100 km/h, very good surface before and after the scales.
approx. ± 15%	High-grade weight sensor in strip form, max. 100 km/h, good surface before and after the scales.
approx. ± 25%	Simple piezo cable, max. 100 km/h, good surface before and after the scales.

Table 2: Achievable accuracies with today's WIM technology

Where the mechanical loading of the road must be determined, it is also important that each individual measurement be precise. However one must clearly understand that such a measurement precisely made only permits an assertion for the spot in which the sensor is installed. An extrapolation to other positions on the road is only permissible if the road quality there is identical. Installed in a good stretch of road, fewer high peak loads are yielded than in a poor stretch of road, by reason of the differing magnitudes of the vehicle oscillations.

To sum up, it can be stated that with the WIM systems available today the accuracies shown in Table 2 can be achieved, varying with the type of installation and the sensor. There are today suitable systems available for all current applications, although on legal grounds in most countries the police must still use static scales for weight inspection. ■

Reference

1 *Forschungsgesellschaft für Straßen und Verkehrswesen, 'Bemerkungen zur Erhöhung der zulässigen Gesamtgewichte von Nutzfahrzeugen aus der Sicht der Straßenbeanspruchung', Forschungsarbeit aus dem Straßenwesen Nr. 99, Kirschbaum Verlag 1983.*