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► **To cite this version:**

David Bétaille, Bernard Jacob. Direct enforcement of overloads: extensive full-scale tests and certification procedure of wim systems. XXVIIth World Road Congress, PIARC, Oct 2023, Prague, Czech Republic. 13 p. hal-04486068

HAL Id: hal-04486068

<https://univ-eiffel.hal.science/hal-04486068v1>

Submitted on 1 Mar 2024

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DIRECT ENFORCEMENT OF OVERLOADS: EXTENSIVE FULL-SCALE TESTS AND CERTIFICATION PROCEDURE OF WIM SYSTEMS

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ABSTRACT

Overloaded road vehicles induce road unsafety, deterioration of infrastructure and unfair competition in freight transport. The European Directive 96/53 (revised 2015/719) regulates commercial vehicle weights and dimensions for international traffic and requires Member States to carry out checks and report on them.

Weigh-in-motion (WIM) systems currently detect overloaded vehicles to screen them prior enforcing them on approved static scales. The work carried out since 2015 in France paves the way for direct enforcement of overloads by WIM, which would make it possible to enforce 200 times more of overloaded vehicles, with less staff and resources. This will ensure a better compliance, and ensure a greener and fairer transport market, and increased road asset durability and road safety.

The French Ministry of Transport is in charge of the deployment of direct enforcement, in partnership with the Ministry of the Interior for legal issues, and with the Legal Metrology (Ministry of Economy) and its National Metrology and Testing Laboratory (LNE) for certification. The Université Gustave Eiffel and the Cerema carried out research and development works and tests, on open road and on a closed test site, to prove the feasibility of direct enforcement by WIM and prepare a type-approval procedure.

The work has focused on assessing the accuracy and reliability of marketed WIM systems. The paper summarizes the main results obtained both with reference and instrumented vehicles and with vehicles from the traffic flow. The aim is to get a right balance between almost no false positive, which would lead to wrong fining, and the lowest tolerance on overloads. The impact of the heavy vehicle dynamics on weighing was assessed, by testing with an instrumented truck, to confirm physical modelling and check that the certification in the required accuracy classes could be achievable..

Extensive tests have been carried out over more than 4 years on the motorway A4 (operated by SANEF) in eastern France. Static weighs were used as references to assess the accuracy of WIM systems. WIM manufacturers providing systems based on piezo-quartz sensors by Kistler were pre-qualified, with respect to the accepted tolerances and levels of confidence.

A certification procedure including type-approval, initial and in-service verification, has been developed, based on the OIML recommendation R-134, with a few proposed and justified derogations. A test site, Transpolis near Lyon, was pre-qualified for the type-approval tests.

The results show that marketed WIM systems meet the OIML class 10, for fully loaded or overloaded trucks, and the class 5 is achievable for the heaviest trucks. The class 10 is also achievable for the gross weights of the light commercial vehicles (LCVs, below 3.5 t). The certification procedure is now being approved by the LNE.

1. INTRODUCTION

The overloading of road vehicles is a main cause of road unsafety, deterioration of infrastructure and unfair competition between transport modes and companies. The driving codes and the European Directive 2015/719 regulate the weights and dimensions of commercial vehicles and an enforcement policy and controls are carried out, and required from the Member States by the European Commission.

Weigh-in-motion (WIM) equipment has been used in France since 2010 on the national road network and the concessionary motorway network, to screen overloaded vehicles and fine them after a double check in static or at low speed on a certified scale. The screening in the traffic flow proved its effectiveness since more than 95% of the vehicles identified by the WIM systems are actually overloaded. The improved accuracy and reliability of WIM systems now indicate that they may be used for automated controls and fining of overloads. That would make it possible to control around 200 times more vehicles than by stopping the vehicles, without increasing the dedicated staff. This could also contribute to a better compliance with regulations, to a fairer transport market, to an extended durability of road assets, and to a better road safety.

WIM systems are already used for direct enforcement in Czech Republic and Hungary in the EU. Several European Member States are actively working to enable WIM systems to be used for automated control of overloads, including Belgium, Germany and France (among others).

2. PROPOSED TYPE-APPROVAL PROCEDURE

Much of the research and development effort is currently focused on validating the accuracy and reliability of WIM systems, with the required tolerances. Metrological procedures for type-approval, initial verification and in-service inspection should be developed, following the OIML recommendation R-134. The aim is to get the right balance between no false positive, to avoid wrongly fining legally loaded vehicles, and the minimization of the tolerance accepted onto overloads.

In France, the Ministry in charge of Transport (DGITM, General Directorate for Infrastructure, Transport and the Sea) is the prime contractor for the project and its technical deployment, in partnership with the Ministry of the Interior (Home Office), which supervises the legal aspect of direct enforcement. Scientific and technical work and tests are carried out by Université Gustave Eiffel (formerly IFSTTAR) and by Cerema (East and Centre-East). The legal metrology organization is represented by the National Metrology and Testing Laboratory, which supervises and validates certification procedures.

2.1. Procedure, methods and OIML R-134 exemptions

Statistical approach following the COST323 (COST323, 2002) and metrological approach according to the OIML R-134 (OIML, 2006) have been considered during the research investigations towards the certification procedure. Despite COST323 is not legally relevant for direct enforcement, it provided a fruitful part of the assessment and of the feasibility study to prove the achievable performance of WIM systems. And OIML R-134 recommendations have definitely been chosen as guidelines. The COST323 approach based on tolerance intervals and confidence levels, was complemented by the metrological approach based on maximum permissible errors (MPE), the latter being finally specified in the procedure.

Specifications apply to high-speed WIM systems using road sensors installed on road pavement and operating in free traffic flow. The OIML R-134 addresses the accuracy of gross vehicle mass (GVM) and axle loads, with the following classes:

- GVM: classes 2, 5 and 10, with two additional classes proposed in the on-going revision of the recommendation, 15 and 20. The figures are the (relative) maximum permissible error for in-service inspection;
- axles loads: D, E, F and an additional proposed class G, with relative MPEs of 4, 8, 16 and 32%. These values also apply to in-service inspection, for any reference vehicle except a 2-axle rigid lorry for which half of these MPEs apply.

The reference weights aforementioned come from vehicles weighed in static on an approved axle scale.

Table 1 shows the targeted accuracy classes for various categories of heavy vehicles. In addition to GVM and axle loads, the tridem group of axles is concerned. During the certification procedure, only reference vehicles close to or above the maximum permitted weight will be used, since only overloads are targeted. The Ministry of Transport is expecting to enforce at least similar overloads as static controls today, which means keeping the weighing tolerance below 5%. This tolerance is relaxed for LCVs and light trucks, because the commercial impact or infrastructural damage are limited, and the accuracy is lower.

Table 1: Targeted accuracy classes for different trucks and LCVs (vans)

Category of vehicles	Max permitted GVM	Test range	Lower/targeted accuracy class
Van	3,500 kg	≥ 3,500 kg	20/10
2-axle rigid*	19,000 kg*	≥ legal limit	10
3-axle	28,000 kg	≥ 28,000 kg	10/5
4-axle rigid	32,000 kg	≥ 32,000 kg	5
4-axle articulated	38,000 kg	≥ 38,000 kg	5
5 and more axles	40,000 or 44,000 kg	≥ 40,000 kg	5
Axles	Max permitted load	Test range	Lower/ targeted accuracy class
Single axle	13,000 kg	10,000-25,000 kg	F/E
Tridem axle	27,000 kg	≥ 24,000 kg	F/E

* There are several legal limits in this category

2.2. Ratio between the MPEs for initial and in-service verification

The ratio r between the MPE for type-approval test and initial verification and the MPE for in-service verification is still under discussion within the TC9SC2p11 committee in charge of the revision of the R-134. In most of the current OIML recommendations the value is $r=0.5$, as it is in the current R-134 version. The aim is to consider the maximum permissible error of a brand new and adjusted instrument (intrinsic error) for the initial verification, and to double it for in-service verification because of the additional error due to the ageing and possible drift of an instrument after a couple of years of use.

However, this principle assumes that the measurand - quantity measured by the instrument, here the wheel or axle loads, and then the gross vehicle weight as the sum of all the axle loads, while the vehicle is in motion -, is equal to the reference value - here the vehicle mass or the static axle load of a stationary vehicle on a full flat apron -. That is not the case for a WIM instrument because of the dynamics of the vehicles and the pavement roughness. The instantaneous axle loads continuously vary along the road and almost never meet the static reference axle loads (Figure 1). These variations easily reach 5% on

a good pavement and a fully loaded truck, and may reach 20 to 25% on a rough pavement and partially loaded trucks (Dolcemascolo and Jacob, 1998), (Jacob, 1995).

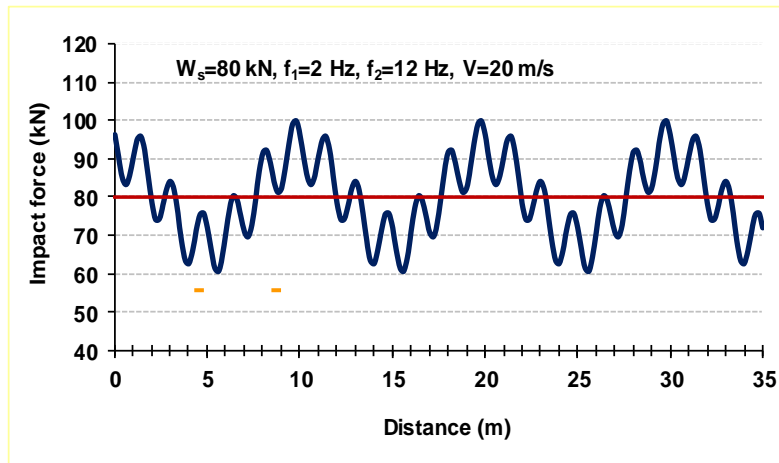


Figure 1: Dynamic variation of a 8 t vehicle weight at speed along a road

These variations apply both during a type-approval or initial verification, and during an in-service test. Therefore, the measurand differs from the reference value (weight or load) and the error of measurement E_t cumulates both terms as shown in Eq. 1:

$$E_t = (W_d - W_s) + E_i \quad (1) \quad \text{or with relative errors:} \quad e_t = (W_d - W_s)/W_s + e_i \quad (2)$$

where W_s is the reference value (static axle load or vehicle mass), W_d is the measurand, i.e. the dynamic axle load or gross vehicle weight as the sum of its axle loads), E_t is the total error observed during a test ($e_t = E_t/W_s$), and E_i is the error of the instrument ($e_i = E_i/W_s$). With static or quasi-static weighing instruments, $(W_d - W_s) = 0$ (or is negligible) and $E_t = E_i$, or $e_t = e_i$.

The maximum permissible error $MPE_t = \max((W_d - W_s)/W_s + e_i) \leq \max((W_d - W_s)/W_s) + MPE_i$ (3) where MPE_i is the maximum permissible error of the instrument. We can take the upper bound as the value of MPE_t because it may be reached. We consider the in-service MPEs. Eq. 3 may be written as: $MPE_t = p.MPE_t + (1-p).MPE_t$ (3')

where $p.MPE_t = \max((W_d - W_s)/W_s)$, p is the proportion of the MPE which cover the dynamics of the vehicle, or the difference between the measurand and the reference value, and $(1-p).MPE_t$ is the proportion of the MPE which represent the error of the in-service instrument.

Following the current metrological approach, for an initial verification, the MPE for the brand new and adjusted instrument is a half of the in-service MPE, i.e. $(1-p).MPE_t/2$. The total MPE for an initial verification is thus: $p.MPE_t + (1-p).MPE_t/2$ and the ratio r becomes:

$$r = (p + (1-p)/2) = (p+1)/2.$$

For $p=0$ (static or low-speed weighing), the measurand is equal to the reference value and $r=0.5$.

For $p=1$ (the error of the instrument being negligible with respect to the dynamics), $r=1$, the maximum value of r .

It is proposed, based on the studies on vehicle dynamics (Dolcemascolo and Jacob, 1998), (Jacob, 1995), and on the experience with WIM system used as the background of the COST323 (Jacob, 2000), (Jacob et al., 2000), to take $p=0.6$ i.e. to allocate 60% of the in-service MPE to the dynamics. It means that if the class 5 (OIML) is required, the maximum dynamic variations shall remain below 3%, and for the class 10, below 6%.

That leads to replace the former ratio 0.5 by 0.8 to account for the dynamics of the vehicles at speed and on a trafficked road.

However, the decision of the TC9SC2p11 is not yet taken.

2.3. Qualification of a potential test site for certification

Whilst the certification procedure does not specify any specific test site, Université Gustave Eiffel and the Cerema (Centre Est) have carried out trials with an instrumented LCV and 5-axle articulated combination, both in Transpolis, near Lyon and in Saint-Avold on the A4 motorway. The main advantage, compared to free flow sites, is the shortness of the loop to circulate with the reference vehicles, the quality of the pavement and above all its stability in time.

The site of Transpolis was developed to run road and street tests of solutions and equipments for new mobilities, incl. autonomous vehicles, both in urban or interurban area. The test site is located 30 km northeast of Lyon (France), on a former military camp of 80 ha (Figure 2). The WIM test zone is located on a 6-lane straight main boulevard of 1 km in length (Figure 3). The site is fully equipped with energy and telecommunication facilities, incl. 4G and Wifi. An axle scale is available in a garage located near the site entrance where the test vehicles are prepared.

The specifications of the site were finding a location where all categories of trucks could run at current speeds (up to 90 km/h), even fully loaded, and in safe conditions. The pavement is representative of a common/good motorway or highway pavement, with a good evenness in order to avoid too much dynamic effects, which may refrain a WIM system to meet the expected accuracy class during the type approval tests. However, the test site conditions are not much better than on open road where the WIM systems will operate after approval.

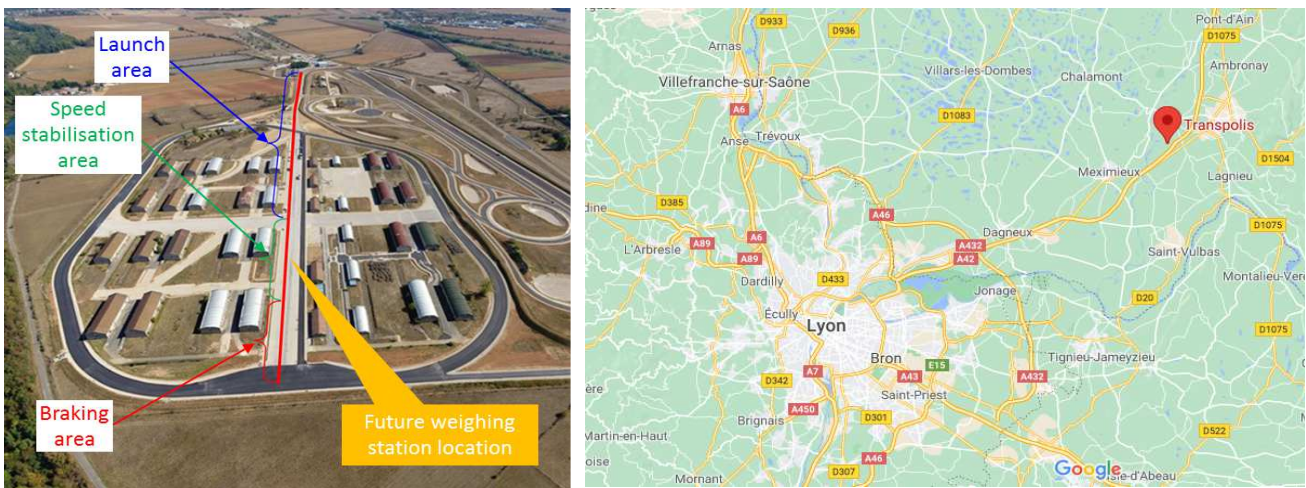


Figure 2: Transpolis closed test site

Two vehicles were instrumented, a 5-axle articulated truck and a light commercial vehicle, to perform measurements in Transpolis and on the site of Saint-Avold on the motorway A4. The aim of the test was to check that the axle load variations under the dynamics of the vehicles do not exceed the initial MPEs of the expected accuracy OIML classes. The trials aimed to compare:

(1) the variations of axle loads and gross vehicle weight of fully loaded instrumented vehicles, at speed in Transpolis, with the required tolerances;

(2) these variations of axle loads and gross vehicle weight with those of the same truck (T2S3) operated on the motorway A4, in Saint-Avold.



Figure 3: Trial in Transpolis on the main boulevard in the “urban area”

Accelerometers and inertial measurement units were mounted by the Cerema Centre-Est, on the tractor, the semi-trailer bodies and axles of the articulated truck T2S3, and on the body and axles of the LCV, to measure the vertical accelerations of suspended and unsprung masses. Measurements were carried out in April 2019 and July 2020 in Transpolis, and in July 2019 in Saint-Avold. Impact forces can be derived from the masses and accelerations (Betaille and Jacob, 2022).

The dynamic amplification factors observed in Transpolis were slightly less than in Saint-Avold and compatible with the requirements of the target accuracy classes. They even do not exceed the half-tolerance (MPE) of the target classes. These trials qualified the site of Transpolis to carry out type-approval tests of WIM systems for direct enforcement. The safety and facilities on this site are fully satisfactory: the test runs can be done in 2-3 min on a loop of app. 2 km, which may save a lot of time and fuel compared to a motorway site. Each category of vehicle may reach its maximum allowed speed even fully loaded. With 6 traffic lanes it is possible to install and test several WIM systems without any interference. The pavement conditions are representative of those of most of the highways and motorways in Europe, with a good evenness (class 1 WIM site according to the COST323). Moreover, as it is a closed site, it is possible to operate overloaded vehicles to check the systems in most of the operational range of weights.

3. WIM SYSTEMS PERFORMANCES

Three manufacturers of WIM systems took part in the tests carried out during the periods 2015-2018 and 2021 respectively: Sterela and Kapsch, joined in 2021 by Électronique Contrôle Mesure (ECM). All these manufacturers provided WIM systems using the Kistler Lineas G piezo-quartz sensors.

Figure 4 shows the test site of Saint-Avold on the concessionary motorway A4 operated by SANEF, where Kapsch and Sterela systems are installed. Figures 5a and 5b show the layout of these systems on the A4. Figure 6 shows the ECM system in Loisy on the motorway A31, a public motorway also in eastern France.



Figure 4: Test site of Saint-Avoid (A4)

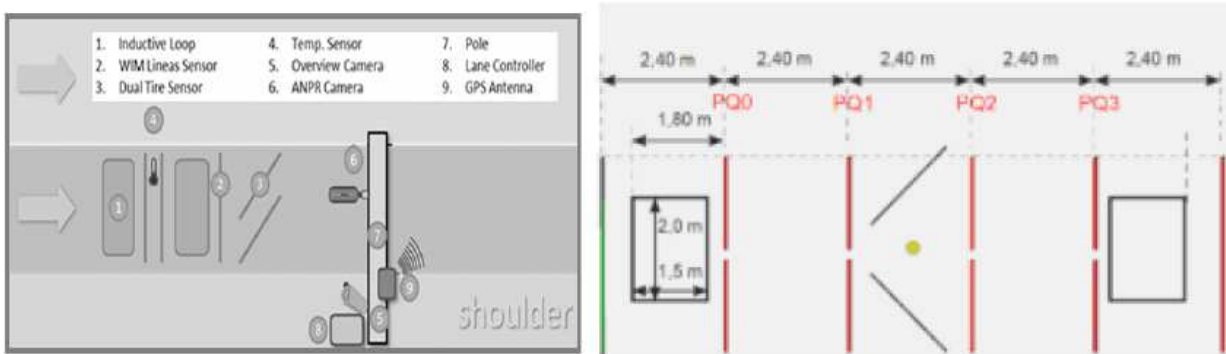


Figure 5: Layout of Kapsch (a) and Sterela (b) systems (A4 motorway in Saint-Avoid)

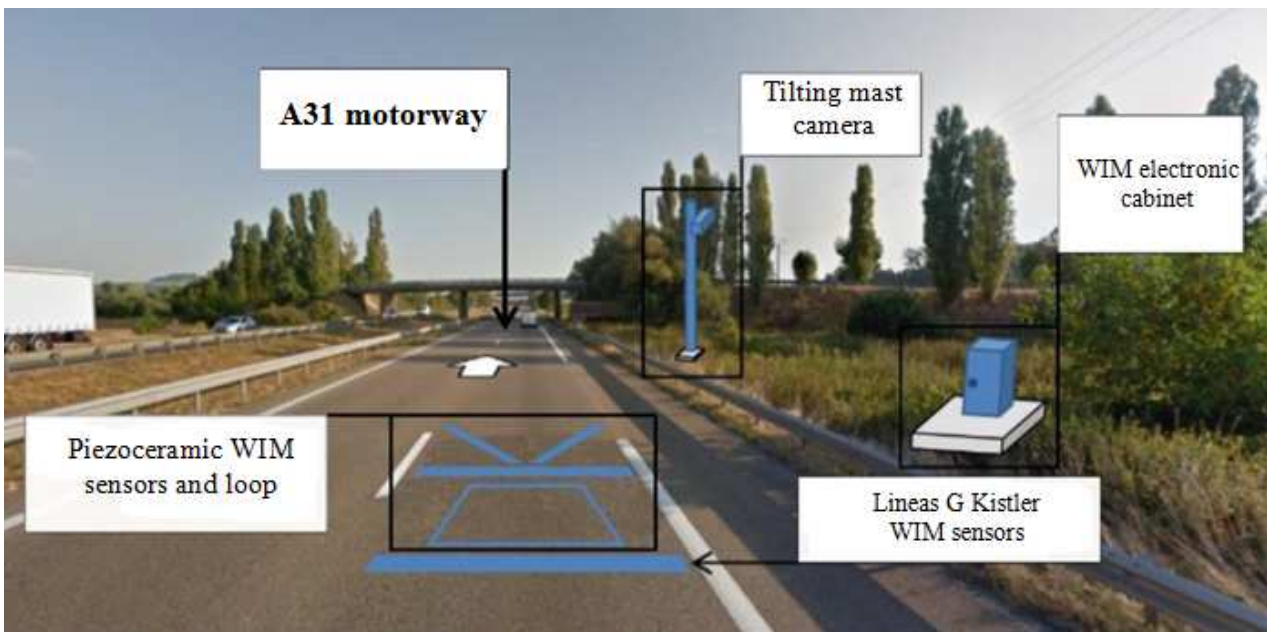


Figure 6: ECM WIM system located on A31 motorway (Loisy)

3.1. Summary of the final results of the 2015-2018 trials

In 2015-2019, extensive tests have been carried out in Saint-Avoid (A4). Static weighs collected on approved scales, installed on a parking lot right after the toll gate of Saint-Avoid, are used as references to assess the accuracy of the WIM systems by Kapsch and Sterela.

During this period, the Cerema has gathered measurements, respectively on 36 and 19 days for Sterela and Kapsch, depending on the availability of the systems. According to the COST32" specifications, the environmental conditions (III) "Full environmental repeatability" and test conditions (R4) "Full reproducibility" are met for these tests.

Several recalibrations occurred during this test period (Bétaille and Jacob, 20222). Tables 2 and 3 give the final results over the whole period for each system. Results are given for trucks (HGVs) and light commercial vehicles (LCVs). The global performances of both systems are reported with respect to the OIM R-134 recommendation (legal metrology, in-service MPEs) and to the COST323 specifications (statistical approach). Only the validated measurements by each system were reported, i.e. 83% and 99.5% resp. for Sterela and Kapsch. However, Sterela provided more results because the system was operational over 36 days instead of 19 days for Kapsch.

Table 2: Sterela results (2015-18)

Vehicles	Measures	36 Days (83% validated measurements)	
		OIML	COST323
1253 HGVs	Gross weight	10 for 100% 5 for 96.5%	A(5)
	Single axles	F for 99.8%	A(5)
	Axle group	F for 99.8%	A(5)
332 LCVs	Gross weight	10 for 97%	B(10)

Table 3: Kapsch results (2015-18)

Vehicles	Measures	19 Days (99.5% validated measurements)	
		OIML	COST323
561 HGVs	Gross weight	10 for 100% 5 for 96.4%	A(5)
	Single axles	F for 99.8%	A(5)
	Axle group	F for 100%	A(5)
186 LCVs	Gross weight	10 for 99.4%	B(10)

Even if the R-134 requires 100% of the measurements within the tolerances (maximum permissible error), in some case the results are provided with 95% or more than 99% of the results in the targeted class. It is expected that some improvement on the sorting algorithms will allow the manufacturers to meet these classes for 100% of the validated measurements. All the systems met the accuracy class A(5) for HGVs and B(10) for LCVs. For HGVs, both systems almost meet the OIML class 5 (gross weight) with more than 96% of the measurements within the tolerances.

3.2. September 2021 test results at three motorway sites

Three tests were organised for each of the 3 manufacturers: Sterela, Kapsch and ECM, on 3 motorways in Eastern France (A4 Saint-Avoid, A35 Selestat and A31 Loisy). Each test was carried out on 2 days (Sept. 13-14, Sept. 15-16, and Sept. 17-20). Three reference vehicles were used: one 5-axle articulated, one 2-axle rigid lorry and one 2-axle LCV, all fully loaded (Table 4). The same vehicles and drivers were used all over these tests. On each site, the vehicles made 12 runs at the maximum allowed speed and centred in the traffic lane on the first day, and 6 runs shifted to the right (by 0.5 m) and 6 runs shifted to the left (0.5 m) at a reduced speed on the second day (Table 4). The reference vehicles were weighed in static on a weighbridge (GVM) and on static axle scales.

In addition, fully loaded or overloaded vehicles from the traffic flow were measured by the WIM systems, and then stopped on a static weighing area, where the axles were weighed in static and the GVM calculated. The populations of these vehicles are summarized in Table 5 for the site of Saint-Avoid and the system Sterela.

Table 4: Test vehicles and runs on the 3 sites (September 2021)

Vehicles	GVM	Speeds (days 1 / 2)	Lateral location	Number of runs
5-axle articulated HGV	43,600 kg	90 km/h / 70 km/h	centred / ± 0.5 m	12 / 6+6
2-axle rigid HGV	19,200 kg	90 km/h / 70 km/h	centred / ± 0.5 m	12 / 6+6
2-axle LCV	3,580 kg	130 km/h / 110 km/h	centred / ± 0.5 m	12 / 6+6

Table 5: Vehicle from the traffic flow in Saint-Avoid (Sterela, September 2021)

Vehicles	Speeds (days 1 / 2)	Mass range	Single axis loads
4, 5 and 6-axle articulated HGV	77-100 km/h	38,000 – 47,000 kg	6,600 – 14,300 kg
2-axle LCV	84-130 km/h	2,900 – 6,100 kg	1,300 – 2,500 kg

The results of the reference vehicles and those from the traffic flow, with respect to the relative errors of GVM, single axle loads (but for the LCV) and groups of axles, were analysed according to the COST323 and the OIML R-134. For the COST323, the environmental conditions are (I) "Environmental repeatability", and the test conditions are "Full repeatability" (R1) for each reference vehicle day by day (one single speed and one single load per vehicle). For the vehicles from the traffic, the test conditions become "Full reproducibility" (R4) and the results are analysed over both days at once. The results are presented in Table 6 for Sterela in Saint-Avoid. The results of the other manufacturers are still being analyzed.

Results of the 5-axle articulated reference vehicle are very close on both days, in classes 5 (OIML R-134) and A(5) (COST323). The maximum errors (ME) of GVM are even below 2.8%. For single axles and groups of axles loads, the system is almost in class A(5) (COST323). These results comply with the previous results (Table 2). Axle loads are even more accurately weighed, in classes OIML E for single axles and D for groups of axles.

Table 6: Results of the Sterela system in Staint-Avoid (September 2021)

Vehicles	Entity	Sterela (day 1)		Sterela (day 2)				
		OIML (ME)	COST323	OIML (ME)	COST323			
Reference 5-axle articulated (HGV)	Gross vehicle mass	5 (2.46)	A(5)	5 (2.80)	A(5)			
	Single axles	E (6.31)	A(5)	E (6.49)	B+(7)			
	Groups of axles	D (3.64)	A(5)	D (3.46)	A(5)			
Reference 2-axle rigid (HGV)	Gross vehicle mass	10 (7.60)	B(10)	10 (6.17)	B+(7)			
	Single axles	G (9.62)	B(10)	G (9.93)	B(10)			
Reference LCV	Gross vehicle mass	5 (2.22)	A(5)	5 (3.27)	A(5)			
		Sterela (days 1 + 2)						
		OIML		COST323 (class and statistics of errors)				
		Class	ME	Class	Number	Mean	Std. Dev.	
HGVs (traffic flow)	Gross vehicle mass	10	5.26	A(5)	30	1.25	2.06	
	Single axles	F	9.32	B+(7)	60	0.72	4.14	
	Groups of axles	F	10.78	A(5)	31	1.14	2.93	
LCVs (traffic flow)	Gross vehicle mass	10	8.44	B+(7)	27	1.30	3.07	

The 2-axle rigid reference lorry is mainly weighed in COST323 class B(10), in OIML class 10 for GVM, and OIML class G for the single axles, for which the MPE is divided by 2 (OIML, 2006). For this vehicle, the WIM system was not well adjusted, with mean bias between 5 and 7%. However, this remains compatible with the previous results, because in the test 2015-19, only a few rigid vehicles were weighed, while the large majority was 5-axle articulated vehicles.

The reference LCV was surprisingly very accurately weighed with a GVM in class COST323 A(5) and OIML 5. The MPEs were even not greater than 3.27% and the mean bias below 1.3%.

The sample of HGVs from the traffic flow, mainly comprised fully loaded or slightly overloaded 5-axle articulated vehicles, with single axles loaded between 6,600 and 14,300 kg (maximum permitted axle load in France: 13,000 kg). These vehicles were weighed in class OIML 10, but very close to 5 with a ME of 5.26%, and in COST323 class A(5) for GVM and groups of axles. The single axles are in class COST323 B+(7). Single axles and groups of axles are both in OIML class F. These results again fully comply with those of 2015-19 for the same traffic.

LCVs are weighed in classes OIML 10 and COST323 B+(7), slightly better than in 2015-19.

3.3. Pre-certification tests

The tolerances and classification rules applied, were those of periodic (in-service) verification, both with the OIML R-134 and the COST323. It means that the full tolerance of MPE was applied. If submitting the system to an initial verification with the same data of the 5-axle articulated vehicle, and a MPE reduced at 80% of the full MPE, the accuracy class 5 (GVM) and E (axle loads) would be accepted. This factor 0.8 is proposed to the OIML TC9/SC2/p11 for the on-going revision of the R134, but not approved yet. However, it is also proposed to the LNE in France. The ME on GVM (2.80%) remains below $0.8 \times 5 =$

4%, and on axles and groups of axles (6.49%) very close to $0.8 \times 8 = 6.4\%$. However, including the 2-axle rigid lorry, which is mandatory according to the R134, the accuracy would fail in class 10 (GVM), both for in-service and initial verification, with a ME (7.60%) below $0.8 \times 10 = 8\%$. Axles would also remain in class G for an initial verification, with a ME (9.93%) below $0.8 \times 16 = 12.8\%$.

However, all these results prove that, if applying the current factor 0.5 to the in-service MPE for an initial verification, the system would lose one accuracy class in all cases. This would be quite embarrassing for the end users, using WIM for direct enforcement of overloads, because it would lead to increasing the tolerance given to the carriers by 1.5 (class 10 to 15), or 2 (class 5 to 10). Instead of reducing the most common overloads (mostly below 10%), it would allow the HGVs travelling 9.99% above the GVM legal limit...

The results of both periods (2015-19 and September 2021) show that the Sterela WIM system almost complies with the requirements of the OIML class 5 for GVM of fully and overloaded 5-axle articulated vehicles. The ME 5.26% slightly exceeds the MPE (5%), but only for one vehicle among 30. The initial verification, if performed with a single 5-axle articulated vehicle, would also accept this class 5, which is the requirement of the French Ministry of Transport. For axles and groups of axles (tridem), the class F is achieved in the traffic flow, while the class E could be met during an initial verification. This latter class is wished for direct enforcement of four and more axle vehicles.

The WIM system meets the accuracy class 10 for the GVM of 2-axle rigid HGVs and LCVs, and class F for the axles of 2-axle rigid HGVs, for in-service and initial verifications. That also complies with the requirements for direct enforcement in France.

The measurements made with the two other WIM systems, provided by Kapsch and ECM, are still under investigations, and they seem to be not too far from those of Sterela, at least for one system.

4. CONCLUSIONS

A certification procedure for type approval, initial and in-service verifications, was developed, based on the OIML recommendation R-134, with a few proposed and justified derogations. This procedure will be submitted for approval to the National Legal Metrology. Then, the manufacturers, which plan to submit offers in call for tenders for direct enforcement by WIM, will have to be certified in France according to this procedure. A test site (Transpolis, near Lyon) was qualified to carry out the type approval tests, if decided on a closed test site. It was checked, with two instrumented vehicles (a 5-axle articulated and a LCV) that the dynamic variations of impact forces and their impact on the measured GVM, remain within the MPEs of the targeted accuracy classes, with a reduction factor (compared to the in-service MPE) of 0.8, proposed in the certification procedure.

The objective of the measurements gathered in Saint-Avold from 2015 to 2019 was to prove the feasibility of using marketed WIM systems for direct enforcement. More precisely, the requirements were:

- checking that the OIML class 5/E or 5/F was achievable for 4 and 5-axle fully loaded or overloaded vehicles, and
- the class 10/F or 10/G for fully loaded or overloaded 2 (or 3)-axle vehicles and LCVs.

The rate of vehicles weighed in the required tolerances was very close to 100%. However, the systems showed some drift over time, which indicates that it is necessary, for direct

enforcement, to implement a self (drift) control algorithm or mechanism, and consecutive regular recalibrations (adjustments). Otherwise, an interlock should stop delivering the data in case of any doubt.

Moreover, the WIM systems to be used for direct enforcement are not supposed to weigh all the vehicle of a given category in the accepted accuracy class, but to self-sort the data, eliminating any doubtful measurements on criteria based on measured quantities, e.g. some speed variations, lateral wandering or too high differences between successive sensors. The aim is not fining any legally loaded vehicle and keeping the tolerance low enough, in order not increasing the mean overloads, which defines the required accuracy classes above. However, if a significant proportion of the vehicles from the traffic flow is not weighed in the accepted tolerances, but eliminated by the system, it is not an issue. With static or low speed non-automatic weighing, the number of checked vehicles is extremely low (app. 50,000 per year in France). Only one WIM system on a busy motorway can check 1 million HGVs per year. With a rate of 5 to 10% of overloaded HGVs, and a rate of 50% of validated measurements, one WIM system could lead fining 25,000 to 50,000 HGVs per year!

The test carried out in 2021 on three motorways aimed checking that the latest WIM systems meet the tolerances of initial and in-service verifications in the required classes. At least one system complies with these requirements, almost meeting the accuracy class 5/F (or E for initial verification) for fully or overloaded 5-axle HGVs, and the class 10/F or 10/G for 2-axle rigid lorries, and 10 for LCVs. Axles of LCVs are not to be enforced (too light).

These results are promising and encourage the National Legal Metrology and the Ministry of Transport to continue preparing the future certification of WIM systems and use for direct enforcement.

ACKNOWLEDGEMENTS

This work was made possible by the cooperation of the Cerema East and Centre-East of France, in particular the Metrology and Traffic Engineering team led by Eric Klein in Metz. This team organised the WIM measurements with the manufacturers on the test sites, in Saint-Avold (A4, 2015-19) and the two others (A31 and A35) in 2021. The team of Nicolas Grignard and Mohamed Bouteldja in Lyon instrumented the two vehicles used in Transpolis and Saint-Avold to assess the variations of axle loads along the pavement and to qualify the test site for certification, collected and analysed the data.

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