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Assessment of High-Speed Weigh-In-Motion Systems by Road Testing for direct Enforcement

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Abstract

The ongoing National research project on direct enforcement by WIM, supported by the French Ministry of Transports (DGITM) and carried out by IFSTTAR and Cerema, aims to demonstrate the feasibility of using adapted and certified existing WIM systems for direct overload enforcement. This project involves the participation of three volunteer WIM vendors. Trials have been carried out in lab and on the large pavement testing facility of IFSTTAR in Nantes, followed by a on road long period test. Sorting algorithms will be developed to identify the vehicles weighed within the required legal and metrological tolerances. The road test intends to assess the accuracy and performances of the proposed WIM systems and to demonstrate the feasibility of certifying and using them for direct enforcement. This paper reports the organization and results of this test conducted on a concessionary motorway in eastern France. Very promising results are presented which pave the way to the implementation of high speed WIM for direct enforcement.

More than 20 days of measurements were carried out from October 2015 until autumn 2017. Rented test trucks as well as the trucks from the traffic flow are used for this test. The rented test trucks are weighed carefully on static scales and then make several repeated runs on the WIM systems at various speeds and lateral locations in the traffic lane. Some trucks of the traffic flow are selected by the police, stopped for static weighing during check periods, and the data are used to assess the accuracy of the WIM systems.

Three WIM manufacturers provided full systems (sensors and electronics): Fareco (France), Kapsch TC (Austria) and Sterela (France). Fareco installed piezo-ceramic strip sensors, while Kapsch and Sterela installed piezo-quartz strip sensors. In addition, IFSTTAR-Cerema also installed additional piezo-quartz sensors. All together, 15 piezo-electric WIM sensor lines are installed on the test site. 11 lines are made with piezo-quartz sensors provided by Kistler, which may be used as a multiple sensor array or several sub-arrays. The test plan and the accuracy assessment methodology are based on the European specifications of WIM COST323. The data analysis is also carried out according to the OIML R134-1 recommendation, using the maximum permissible errors (mpe). An important task is to identify the measures which fall within the tolerances accepted for direct enforcement, i.e. ±5% for the gross vehicle weight, and above all for the fully loaded and overloaded trucks. Other measurements out of the tolerances may be eliminated based on criteria found by the systems.

More than 70 static weightings are carried out every day of testing, which are used to assess the WIM data provided by the 3 vendor's systems. The first five measurement days in autumn 2015 were used to calibrate the systems. Then 15 days of regular measurements were carried out in 2016 and 2017. More than 1000 weights were measured during this period, showing promising results. The mean relative errors on gross weight are under ±3% for the two best systems (Kapsch and Sterela).

Keywords: Weigh-In-Motion, Research project, Overloads, Direct enforcement, Road tests.

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1. Direct enforcement by weigh-in-motion (WIM) project presentation

The objective of the project is to study the feasibility of the automatic overload control (AOC) by WIM and to prepare its certification. IFSTTAR and Cerema, are in charge of the technical work packages of the project. The legal aspects are under the responsibility of the DGITM.

1.1. Contents and organization of the project

This project includes a central work package on the certification feasibility (WP1), three research and development works packages (WP2 to WP4) and a transversal work package on experimental studies (WP EX) containing experiments on road, as shown in Figure 1.

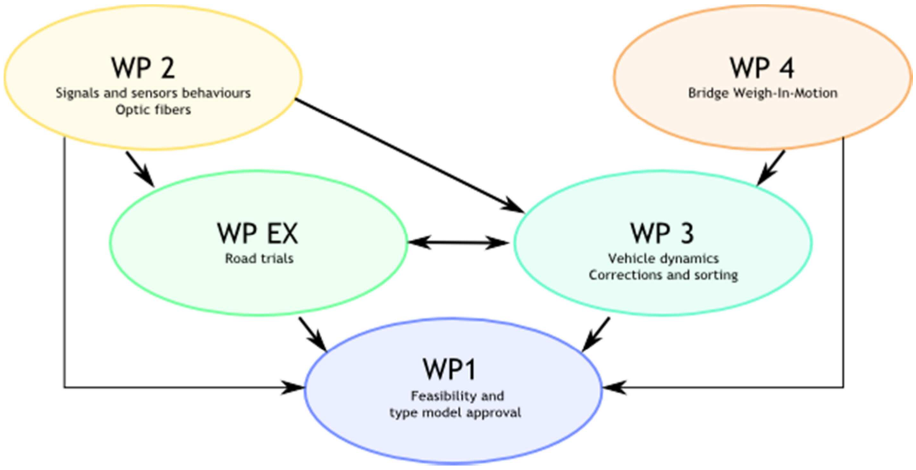

Fig. 1 – Automated Overload Control (AOC) project organization by WPs

The WP1 aims at deploying procedures for type approval and certification of systems for future AOC, in connection with legal metrology and LNE (National Metrology Laboratory). It will build on the French experience of speeding, spacing and traffic light crossing automated controls.

The WP2 has two subsets:

- the WP2.1 deals with sensor/pavement interactions and aims at analyzing the performance of various marketed sensors and characterizing their response in laboratory and on road controlled conditions, depending on the measurement conditions (external factors influencing load measurements),
- the WP2.2 aims at developing a new optical fibre sensor and WIM system, more efficient and less expensive than the most accurate current systems.

The WP3 addresses multiple sensor (MS-)WIM solutions for the AOC, including the design of optimal arrays, methods and information processing tools to correct or sort vehicles weighed within the AOC tolerances. MS-WIM aims at increasing the proportion of vehicles within these tolerances.

The WP4 aims at making a bridge (B-)WIM system operational. Such a B-WIM, including working on concrete frames bridges and orthotropic steel bridges, should meet the AOC requirements. Its adaptation to other types of structures (e.g. girder bridges) is also expected.

The WP EX contains road trials, including choice and instrumentation of test sites, realization of test plans, data collection and first analysis, in partnership with the checking bodies (police, DREALs/Services transport), system suppliers and road operators (SANEF motorway company).

2. Main objectives of road trials

Road trials aim at validating, with known test vehicles, traffic vehicles and in controlled current traffic conditions, the metrological and functional ability of the proposed WIM systems to be used for direct enforcement. The two main steps are :

- to demonstrate the technical and metrological performances of the measuring instrument. The measures gathered and filtered by the WIM systems should meet the tolerances of the OIML class 5, which correspond to the tolerances of the accuracy class A(5) of the European specifications of WIM by COST323, but for 100% of the measurements instead of 90 to 95% for a non-legal application,
- to demonstrate the equipment functionality by constructing one or more prototypes of WIM system integrating all required functions for direct enforcement.

3. Tests site description

The trial site is located on the motorway A4, with 2x2 carriageways, near the toll-gate of Saint-Avold (figure 4) from Metz towards Strasbourg, between the cities of Boulay-Moselle and Saint-Avold (point (B) on the figure 2). This motorway is currently trafficked by HGVs and is equipped with a high speed WIM (HS-WIM) equipment for screening presumed overloaded vehicles upstream of a control area fitted with an type approved static weighing system (figures 3). Given the position of the exchangers, a test truck can run the loop within about 35 minutes that is at least 8 loops a day (between the both points (A) and (C) on figure 2).

Fig. 2 – Overview of the road-test site

Fig. 3 – Static weighing system and park

Fig. 4 – Saint-Avold toll-gate

STERELA, FARECO and KAPSCH are the current industrial partners, each of them having installed a WIM system with piezo-electric (ceramic or quartz technology) sensors. In addition, IFSTTAR and Cerema installed a few more piezo-quartz sensors. All together, 14 WIM sensors are installed on the site, and may be used to investigate the performances of multiple sensor systems (MS-WIM). Some additional context sensors have been also installed to measure other influencing factors. Overall, an array of 46 sensors is installed on the test site. These sensors can be distinguished on the figure 5 :

- 14 weighing sensors (12 quartz in red color, and 2 ceramic in blue color),
- 10 inductive loops (in black color),
- 6 position sensors (in bias),
- 7 temperature sensors at various depths (in yellow color) ,
- 6 geophones (in green color) and 3 accelerometers (in red color).

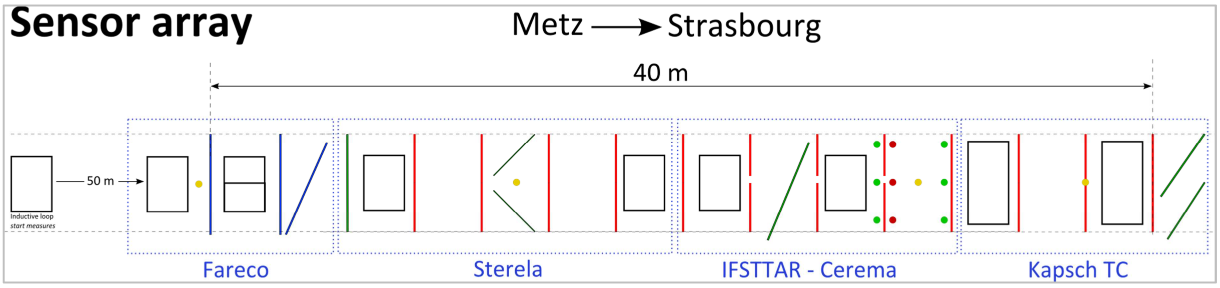

Fig. 5 – Sensor array

3.1. Road and traffics characteristics

Despite the asphalt road was redone in July 2014, the site characteristics place it in upper limit of the class III COST323. The road has a straight line of 130 m upstream of the HS-WIM and 190 m downstream. The road has a longitudinal slope <2% and a cross slope <2.5% (usual cant). The road has a low rutting, between 2 and 3 mm. Deflections are also low, of the order of 20 to 50 1/100 mm. UNI of this road shows notes APL between 8 and 10 for a road portion of 1000 m centered on the HS-WIM. The daily traffic of all vehicles is 9632 vehicles in both directions, with 2093 vehicles over 3.5 tonnes, or nearly 22%. Overload rate is 1.3%, including 0.24% of more than 10%. This site was the only one which include a HS-WIM system, a static weight system and acceptable road characteristics for this experimentation.

4. Companies partnership and systems deployed

A call for participation have been launched inviting companies involved in WIM, including ISWIM members, to participate to the project, including laboratory tests, accelerated pavement testing facility test and on road trials. STERELA (France), FARECO (France) and KAPSCH (Austria) joined the project as early as mid-2014 and proposed sensors (piezo-quartz by STERELA and KAPSCH and piezo-ceramic by FARECO) to three types of trials.

Companies marketing mature enough products and technologies to be assessed, and improved if needed, to meet the requirements of the AOC are eligible as project partners. In this case they provide the hardware, software and knowledge required for studies and research related to the tests. Each company installs, calibrates and maintains its devices for the duration of the trial, complying with the specifications of the road site operator and the project managers. It provides to IFSTTAR and Cerema all measurements produced by its device (raw and elaborated) during all measures periods and shall communicate all information useful for the implementation of these hardware and software. IFSTTAR and Cerema will keep confidential all information property of the partners and will not communicate to third party the raw data gathered by each system. Static or low-speed weighing reference will be provided to partners for all vehicles weighed by their system.

IFSTTAR and Cerema will give a feedback to each partner with regard to their own system. They could support improving their systems for the purpose AOC. The partners undertake to carry out the changes and updates, proposed by or jointly defined with IFSTTAR and Cerema provided that they are compatible with the system and the means available.

4.1. STERELA system presentation

The WIM system installed in the trial site by STERELA is a multi-sensor grid to evaluate many types of configuration in order to find the best one according to the cost/accuracy ratio. The system is composed of : 2 electromagnetic loops, 8 piezo-quartz sensors forming 4 lanes for weighing, 2 piezo-polymer sensors in V-shape to determine the lateral position of the vehicle in the lane and also for the twin wheels detection, and a camera for reading the license plate of vehicles (ANPR).

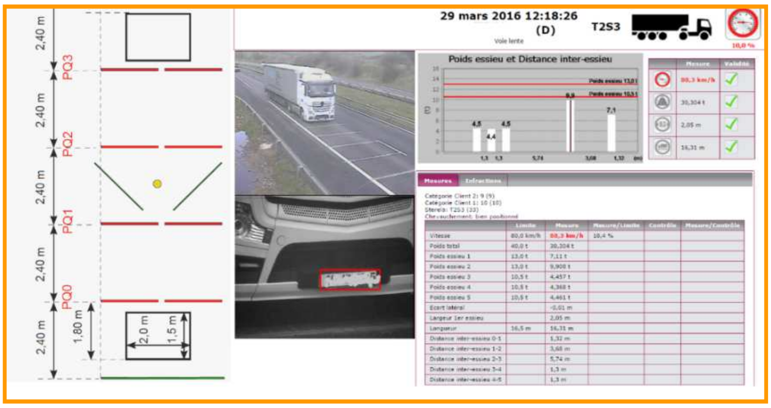

Fig. 6 – STERELA “Global WIM” system

The system can provide in real time the data of weight from only 2 piezo-quartz sensors. At the same time, it records the output signals of all sensors, which are post-processed using a multi-sensor processing algorithm.

4.2. FARECO system presentation

The diagram below shows the principle of road lane instrumentation and each sensor.

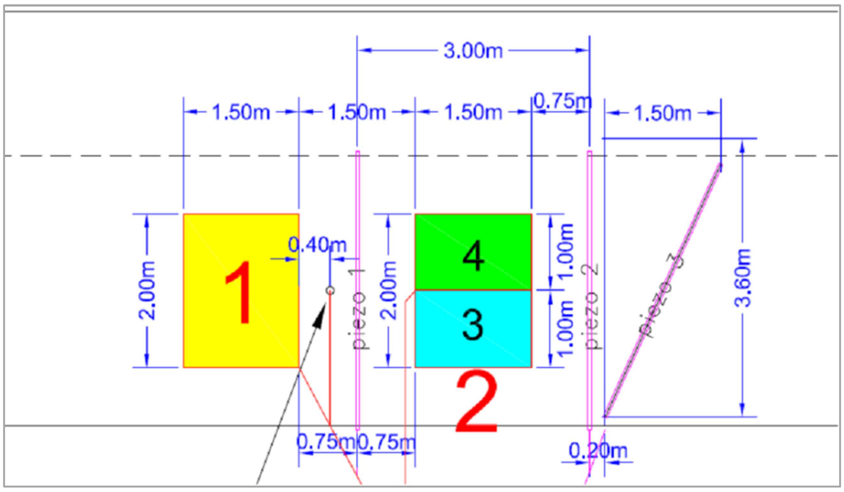

Fig. 7 – FARECO “SCC 400 WIM system”

Piezo 1,2 and 3 are Vitro ceramic Vibracoax®. The piezo 3 gives effective information on the lateral positioning of vehicles in the traffic lane. 1,2,3 and 4 are loops. A temperature sensor in the pavement. SCC400 road side unit is designed by FARECO. Algorithms developped are mainly designed to compensate for inaccuracies related to :

- Piezo sensors give an inhomogeneous signal along its lenght (3,2 m),
- Different piezo sensors don’t give same electrical response. Need to calibrate sensors,
- Pavement isn’t homogeneous and causes vertical acceleration of the vehicles,
- Twin axles cause, even for a same weight, a different electrical response of the sensors,
- Speed of the vehicles and pavement temperature have an influence of measurements.

4.3. KAPSCH system presentation

The WIM installation in France consists of High Speed Weigh-in-Motion components, which are installed along the road, in defined positions, to monitor vehicle parameters like speed, length, lateral position, gross weight, axle weight, axle group weight, vehicle class. The system is composed by several components some of them are mandatory but others could be added, to provide additional data and functionality. The WIM Controller component will receive signals from components present in the road. The data is translated into useful data, like vehicle parameters – date and time of detection, lane, driving direction, head, gap, length, speed, number of axles, class, distance between axles, wheel weights, axle weights and gross weight of each vehicle.

So the WIM pilot configuration in France consists of the following layout :

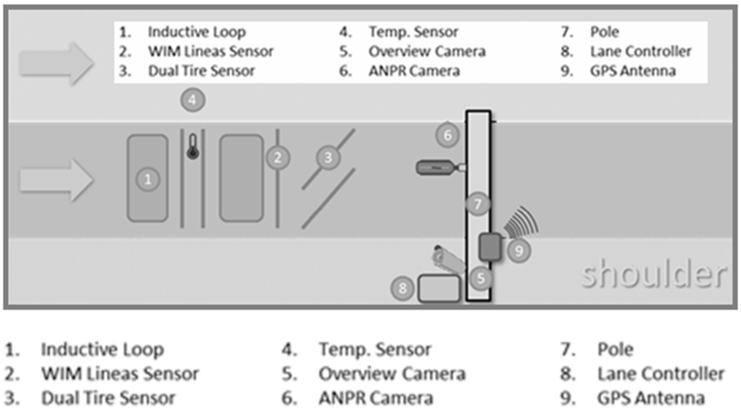

Fig. 8 – KAPSCH WIM system

The WIM controller is also able to read other signals not related with vehicles, like GPS time and temperatures interior and exterior, for example sensors placed in the pavement. All this data will be collected, analyzed and stored internally.

The KAPSCH Weigh-In-Motion System provides a unique validity check functionality. Due to driving behaviour or defects on vehicles passages are marked as non-valid measurements. The Validity Check System enables Direct Enforcement by showing 0 Validity flags, this means that the measurement is 100% valid and ready for Direct Enforcement.

5. Experimentation outlines

5.1. Main objectives

The test data will be used to validate sorting and filtering criteria and algorithms, allowing HS-WIM systems to provide a subsample weighed within the 5% tolerance required for gross weigh, and within the 8% tolerance for single axle direct enforcement. More than 20 periods of measures, each of a day, are carried out between October 2015 and June 2017 on HS-WIM site and on the static weighing control area. Cerema organizes and manages these periods of collect measurements from all systems; the preselected trucks are retrieved from the traffic by the police forces at the toll-gate for weighing on a certified static scale by the officers of the regional DOT (Lorraine). Data are processed by Cerema and IFSTTAR, and the measurement accuracy of each WIM systems is assessed.

5.2. Installation, settings and calibration

Each company take in charge the installation, configuration, calibration and maintenance of its own equipments for the duration of the tests, respecting an installation diagram validated by IFSTTAR and Cerema. It supports related logistics, with the exception of traffic guidance equipment required to be borne by Sanef. The Cerema provides test trucks needed for calibrating all systems. Calibration and verification phase take place during four days after the various systems installations.

5.3. *Tests plan*

The test plans and accuracy or reliability assessment are based on the European Specifications of WIM (COST323) and the OIML R134 International recommendation. Measurements are carried out in repeatability and limited reproducibility condition using rented test vehicles of different silhouettes and loads, and in full reproducibility conditions with vehicles from the traffic flow. The raw signals of all sensors are gathered and stored for further in-depth analysis and comparison with the IFSTTAR fatigue carousel dataset. More than 100 static weighing during each day are gathered to be compared with the dynamics weighing provided by WIM systems. Additional measures are collected such as the lateral position of the trucks, the pavement strains, vibrations, and temperature, licence plate number, etc. The first three days of measurements in 2015 were devoted to calibrate and tune the various systems in order to start the experimentation at the 2016 spring. Up to seven known test trucks (C2, C3 and T2S3) were rented and have made eight passages each. Test trucks will be equipped with air suspension for driving axles and groups of axles. Several test plans were implemented as shown in table (1), by varying the following criterias :

- Speed (90 km/h and 0,8 x 90 km/h = ~70 km/h)
- Lateral position in the lane (well-centred and ±50 cm off-centred)
- Load (median load and full load)

5.4. Data processing chain

Several steps, shown on figure 9, were necessary to make generic treatments and data analysis with the aim of saving time. In a first phase, the Cerema produced a single data model for storing heterogeneous data coming from the three industrial partners. The second step was to produce data integration scripts in the PostgreSQL database for each partner. These scripts have been produced using the ETL tool (extract and load transfer) "Talend Open Studio". A third step was to develop a website that allows local or remote users without computer skills to access the data. Finally, during a final stage, report templates were produced using the BOT tool (business object tools) "Birt" of the Eclipse Foundation. These reports allow to have all measures of the industrial partners in a unique format that can be exported to pdf or Mircrosoft Excel formats.

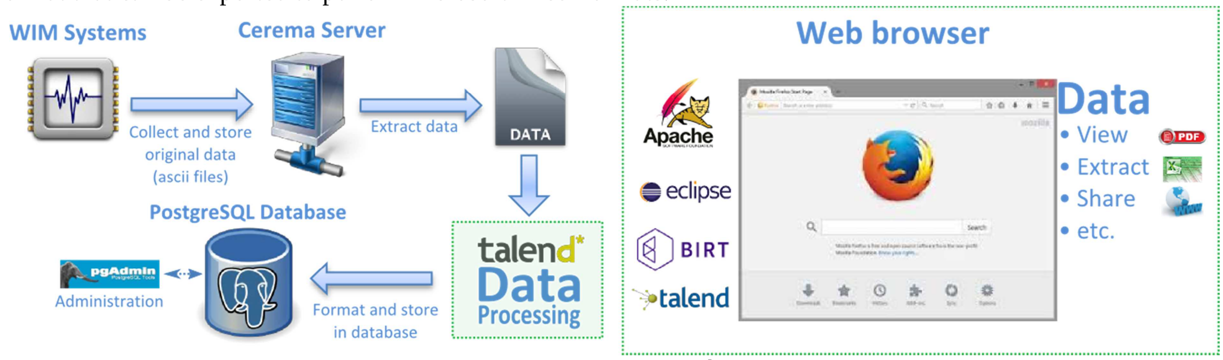

Fig. 9 – Data processing chain

6. Last results

6.1. *Accuracy and performance assessment*

Two types of evaluation will be carried out on the data collected :

- conventional assessment of the accuracy class COST323 according to the principles of these specifications (statistical approach),
- assessment for the AOC.

The AOC assessment involves checking that the system, which integrates correction algorithms and sort criteria, produced two kind of vehicles subsamples, all vehicles being weighed within tolerances OIML Class 5 or COST323 A(5). The first one subsample comprises all sorted and weighed vehicles (weighed within tolerances), the second one is limited to those of these vehicles having at least one overload (on single axle, axle of a group, group of axles or gross weight (GW)). All results presented in this article for STERELA and KAPSCH only within the assessment under COST323, AOC assessment being conducted from April, 2016.

In addition, outliers and doubtful measures were removed from each measures sample, i.e. :

- lateral offset in the lane less than ± 40cm,
- speed in the range 80 to 100 km/h,
- eliminating outliers "without position" or when {gross weight ≠ sum of axles weights}.

6.2. STERELA last results

These results were produced from a grid of four lines of two quartz half-sensors post-processed from a computer model in deferred time.
From May 18th 2017 and for the two last dates of measurement, new weighing coefficients have been programmed in the STERELA WIM system in order to correct the continuous bias drift observed after around one year after the initial setup. Moreover, for these two days, no measure was rejected by the sort algorithm.

As shown in figure (10), all results are now within the COST323 class A(5).

Conditions (1)	**Test plan R4**	**Envt II**				
SYSTEM Entity	**Number**	**Mean (%)**	**Std deviation (%)**	**Class**	**δ (%)**	**Accepted class**
Gross weight	50	0,14	1,88	A(5)	5	**A(5)**
Group of axles	43	1,28	3,42	A(5)	7	
Single axle	97	-1,18	3,55	A(5)	8	
Axle of group	118	1,36	4,38	A(5)	10	

Fig. 10 – COST323 results for STERELA system for one of the two last measurement days

6.3. FARECO results

Until June 2017, all the weighing measures were produced from two line ceramic sensors processed by the electronic WIM system. The performances still remain far away from the required accuracy for the OIML R134 certification class 5 but, in July, a weighing additional ceramic sensor was installed and one other replaced by a better quality one, so that it is hopeful that the next results will be much better for following measurements campaigns.

6.4. KAPSCH last results

The KAPSCH weigh-in-motion system was produced these results from a grid of three lines of two quartz half-sensors processed from a computer model in real-time. The system does not include any sort algorithm thus all of the measures are kept for the precision calculations.

As shown in figure (10), and just like for STERELA WIM system, all results are included in the COST323 class A(5).

Conditions (1)	**Test plan R4**	**Envt II**				
SYSTEM Entity	**Number**	**Mean** (%)	**Std deviation** (%)	**Class**	**δ** (%)	**Accepted class**
Gross weight	50	1,48	1,93	A(5)	5	**A(5)**
Group of axles	43	2,66	2,55	A(5)	7	
Single axle	97	0,74	3,01	A(5)	8	
Axle of group	118	2,72	4,01	A(5)	10	

Fig. 11 – COST323 results for KAPSCH system for one of the two last measurement days

7. Summary and conclusions

The AOC by WIM is a very challenging objective and requires a series of significant steps forwards and progresses, both in WIM technology and in its implementation, operation and certification. This project mainly addresses technological and scientific issues, but also, as a central issue, the metrological aspects of certification and type approval. Road tests allow in this way to validate progress and to capitalize behavior knowledges of the evaluated systems. The measures collected on road during the calibration phase and in real conditions, show very promising and accurate results, for two kinds of systems and sensors and confirm the proper installation of the various systems evaluated.

Next step is to continue the campaigns of measures from October 2017 using context measurements related to the dynamics of the vehicle, to the road characteristics and by using the correction and filtering measures methods products in the WP3. The principle of MSWIM will also be invested with the aim to average weighing errors but also to improve the sort criterion and filter outliers or measurements out of COST323 or OIML tolerance. More results will be presented in this way during the oral session in synthesis of all measures campaigns. The project team is very confident about demonstrating the feasibility of achieving the requirements of an AOC in France in a short term.

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