

## **IMPLEMENTATION OF WEIGH-IN-MOTION SYSTEMS FOR DIRECT ENFORCEMENT OF OVERLOADING**



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### **Abstract**

This paper describes the implementation of high speed Weigh-In-Motion (WIM) systems for the direct automatic enforcement of overloading. In this application the WIM measurements are directly used for enforcement purposes without any secondary verification measurement by static or low speed scales. This application does not only require the most advanced WIM systems, it also needs an organizational structure which will guarantee the minimum quality (accuracy and reliability) of each individual WIM measurement. These performance requirements should be guaranteed not only at initial system approval, but also during operation. This structure consists of three elements: legal acceptance, system certification and data quality control. This paper describes how the newly developed NMI WIM standard provides a basis for a successful implementation of WIM for direct enforcement and what is involved in the other two elements that are required when taken into use.

**Keywords:** Weigh-In-Motion, WIM, Implementation, Standard, Direct Weight Enforcement.

## **1. Introduction**

The damage caused by the loading of a heavy vehicle on the road infrastructure is one of the aspects of a vehicle's environmental footprint, (Mayer, 2011). Road pavements are especially impacted by high axle loads while road bridges are more affected by high gross vehicle weights (Cebon, 1999), (Znidaric, 2012). Weigh-In-Motion (WIM) systems are uniquely capable of measuring the actual axle loads and gross vehicle weight of a moving vehicle (Jacob, 2002). So far these systems are mainly used to provide statistical input for the assessment of the damage to the road infrastructure and to assist in the enforcement of the legal loading limits for heavy road vehicles.

### **1.1 Weight Enforcement**

In the traditional way of checking on overloading by the police or by traffic inspectorates the vehicles are selected from the traffic flow based on visual characteristics and guided over a fixed or mobile road side static weigh system. The number of trucks that can be controlled using these methods is only a fraction of the total number of trucks on the roads and requires a lot of staff. The number of trucks is simply far too big to create an acceptable level of control, using this traditional method. At the same time, transport companies that obey the rules are confronted with unnecessary delays and costs.

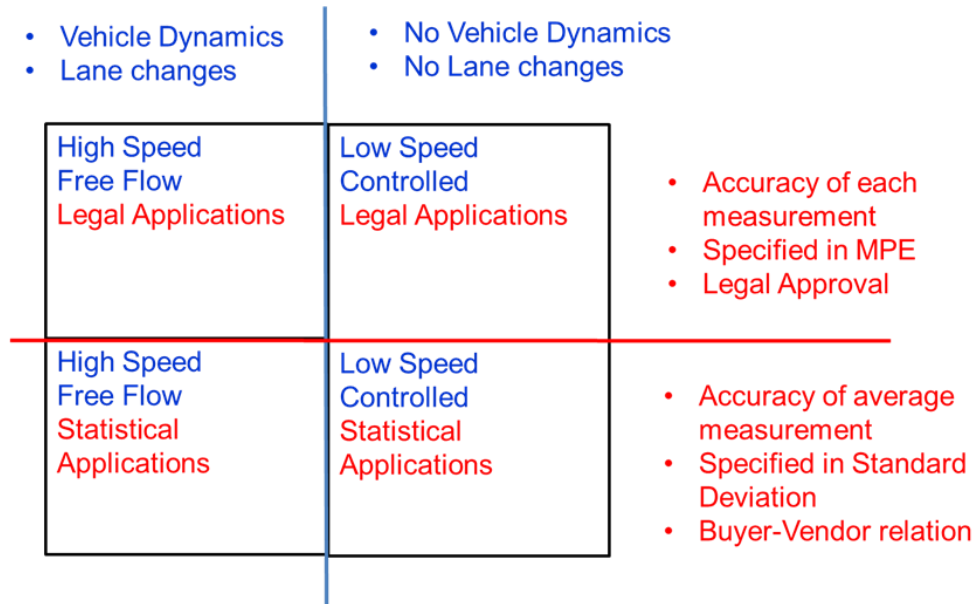
Weigh-in-motion offers the potential to the enforcement/inspection agencies to enlarge the number of checks on trucks drastically. At the same time it enables free flow for non-overloaded vehicles, (REMOVE, 2006). The WIM-system is based on the principle that sensors are installed in or under the road pavement, combined with roadside technology that automatically identifies the vehicle. Such systems have been used globally for many years as a screening tool for pre-selection of overloaded vehicles resulting in a higher efficiency of the enforcement controls. Fully automatic direct enforcement using WIM systems where the weight measurement is used directly as legal evidence is considered to be the most efficient way of enforcement. At the same time it requires the most advanced WIM technology and a very careful implementation. (Doupal, 2016).

### **1.2 Standardization on WIM**

For several years there have been three international standards on WIM: COST-323 European WIM Specification (COST-323, 1999), ASTM-E1318: the American Specification for Highway Weigh-In-Motion Systems (ASTM, 2009) and OIML R-134 recommendation for Automatic Instruments for weighing road vehicles in motion (OIML, 2006). All three specifications have been used extensively over the past years to determine the performance of WIM systems globally. All three documents have their specific advantages, disadvantages and applications. However, none of the three specifications apply to the use of WIM systems for direct enforcement under regular highway conditions. For years there has been a need from the WIM-industry for a full international standard for Weigh-In-Motion systems. This standard would cover all four areas of Weigh-In-Motion measurements, see also figure 1:

- At Low Speeds (generally up to 30km/h) in a controlled weighing environment (e.g. at a toll plaza), where the vehicle dynamics may be neglected;
- At High Speeds (generally more than 30km/h) under free flow traffic conditions (e.g. installed in a multi lane highway), where the vehicle dynamics may have a major impact;

- Statistical applications (like pre-selection, pavement and traffic loading) where the average measurement error is relevant but accuracy of each individual measurement is less important and generally specified in standard deviation;
- Legal applications (like direct weight enforcement and tolling by weight), where the accuracy of each individual measurement is crucial, generally specified in Maximum Permissible Error (MPE) and formal certification is required for legal acceptance.



**Figure 1 – Four areas of WIM**

NMi Certin, the Dutch authority for certification of enforcement measuring instruments has taken the initiative to bring together a select group of experts on standardization together with a number of international WIM experts to develop a new WIM standard. The experience of the members of this group covered the key-expertise required to develop a practical standard that in structure and content has a quality that is suitable for international use. The experience of the group of selected WIM experts also covered the interests from both vendors and users/buyers, different WIM technologies and systems, different applications and the different environmental conditions from various countries and continents.

### 1.3 NMi WIM Standard

The new NMi WIM standard (NMI, 2016) contains system specifications, test procedures and recommendations on site selection, calibration and example test plans. The standard may be used by any buyer and vendor of WIM systems and any National Metrology Institute or Bureau for Weights & Measures in any country as a basis for national legislation.

The standard applies to fixed and portable WIM systems installed on, in or under the road infrastructure including both roads and bridges, independent from which type of measuring technology is used. It applies to High Speed WIM-systems, i.e. systems installed directly in a normal road and operated under free-flow traffic conditions. It may also be used for Low Speed WIM systems since they operate in an environment where the measurement conditions

are controlled and vehicle dynamics more restricted. The standard covers two different groups of applications:

- Statistical (e.g. traffic monitoring, pavement loading, pre-selection) applications where the accuracy of the average measurement is important and the accuracy is specified in standard deviation. The use of the 2 sigma interval (containing roughly 95% of all measurements) as the accuracy level is internationally recognized for the interpretation and definition of measurement accuracy for WIM systems for Statistics applications;
- Legal (e.g. tolling by weight, direct enforcement) applications where the accuracy of each individual measurement is important and the accuracy is specified in Maximum Permissible Error (MPE). The use of the MPE interval as the accuracy level is the most commonly applied in international Legal Metrology, hence also for WIM systems that are used for Legal applications.

The document specifies the performance requirements for WIM-systems.

- It covers the requirements for accuracy and reliability of the weighing measurements and measurements related to the vehicle classification by the system;
- It covers the requirements for operational conditions that may affect the accuracy and reliability of these measurements;
- It does not cover requirements for the durability of the system over time or for operational conditions that may only affect the durability.

The standard does not apply to individual parts of WIM-systems only, e.g. WIM-sensors or to WIM systems that require e.g. a human operator to perform the measurements. It does not give accuracy specifications for other quantities that may be measured or recorded by a WIM system that are related to the vehicles passing the system, e.g. time, speed, height, pictures.

#### **1.4 Accuracy Classes**

The classification code used for the used weighing accuracy classes is based on a combination of a letter for the Application Group (**S** for Statistics and **L** for Legal) and a number for the Accuracy Level. For example:

- Accuracy class S(10) means a WIM system for Statistical applications where the accuracy - defined as the  $2\sigma$  interval - of the Gross Vehicle Weight measurement - during operation is between -10% and +10%;
- Accuracy class L(5) means a WIM system for Legal applications where the accuracy - defined as the Maximum Permissible Error interval - of the Gross Vehicle Weight measurement during operation is between -5% and +5%;

<b>Class</b>	<b>L(3)</b>	<b>L(5)</b>	<b>L(7)</b>	<b>L(10)</b>
Gross Vehicle Weight	3	5	7	10
Axle Group Load	5	8	11	15
Axle Loads	7	10	15	20

**Table 1– Accuracy levels per Class**

Within an accuracy class, there is a fixed relationship between the requirements for measurement of the GVW, the Axle Group Loads and the Axle Loads. A free relationship between the weight measurements would have allowed for more flexibility however this would greatly reduce the standardization of the accuracy classes and the possibility of comparing the performance of different systems. The ranges for the accuracy classes S(5) to S(20) and L(3) to L(10) are based on current applications and currently available WIM systems. One extra high accuracy class for both applications has been added as these may be feasible in the future.

## 2. Acceptance Tests

The second part of the NMi WIM Standard specifies the minimum testing procedures in order to determine the actual performance of a – type of – WIM-system. The results of the specified test procedures will provide a reference that may be used for (inter-)national comparison of the performance of WIM-systems. Users and Vendors are free to use more extensive test procedures for its own specific purpose. The main objective for the test procedures described in the document is that they are intended to be practical. This means that there is always a compromise between the confidence level of the outcome of the test required by the user and the budget and operational constraints set by the vendor or local conditions at the WIM system.

The standard distinguish three levels of tests in order to optimize the combination of tests that need to be carried out and at the same time provide a guarantee on the performance of a WIM system. The selected approach is based on the principle of “one time testing” that provides maximum confidence for the buyer/user on the performance of the WIM system yet results in minimum costs for the vendor for the test procedures. The three test levels are generally used for measuring instruments for legal purposes. The three test levels are, see figure 2:

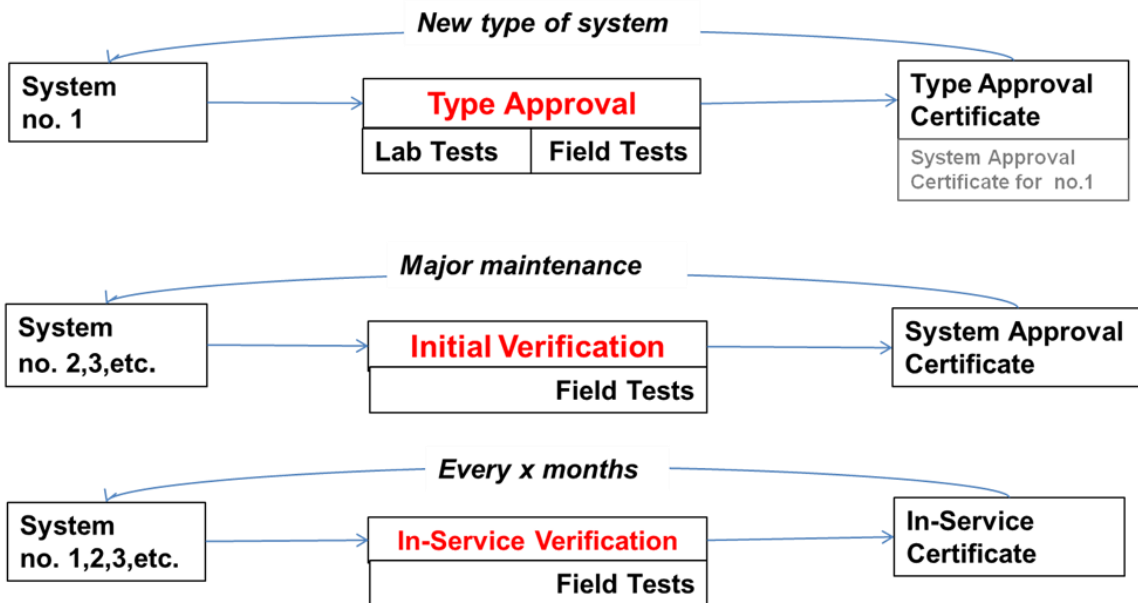


Figure 2, Test Procedures for Legal Applications

## **2.1 Type Approval Test**

This is the first level and most extensive performance test of a new (or modified) type of measurement instruments where the performance of the system is tested under the full operating ranges. This type of test is only required for WIM systems that will be used for Legal applications. It consists of both laboratory test and field tests and performed by NMi Certin or a National Metrology Institute (NMI). The test can be performed at any location around the world in mutual agreement between the manufacturer and NMi Certin or the NMI. The results of this test will be a certification stating the performance of all systems of the same type. Since the test are performed on side this implies that this also result in an initial verification certificate for the system under test, system number “1”. The certificate for type approval will serve as an international reference base for all following initial verification tests, performed on systems of the same type. Simulated functional tests are performed under controlled laboratory conditions to assess the resistance of the complete system to external environmental influences. These tests include: operating temperature range, relative humidity, immunity to RF electromagnetic fields, AC/DC mains variation and hard- and software security.

## **2.2 Initial Verification**

This is the second level and more limited performance test, made after the first installation or important repair/modification. The test is done in order to verify the performance of the measurement instrument under the specific local (traffic and environmental) conditions at the site where this system is installed. It consists of field tests only with a lower number of test vehicles and passes over the system than with the Type Approval Tests. The results of this test will be a certificate or document stating the performance of this specific system (system number 2, 3, 4, etc.). It will serve as a reference base for the In-Service Verification Tests of this specific system at this location. This test is required for all WIM systems, both for legal and statistical applications, however the content of the test procedures differs between the two applications, especially the number of vehicle runs. In case of Initial Verification for a WIM system for a Legal application the ‘System Approval Certificate’ has to be issued by NMi Certin or a NMI. For a Statistical application, the certificate may be issued by any competent body, as long as it has been agreed by both buyer and vendor but has no legal consequences.

## **2.3 In-service Verification**

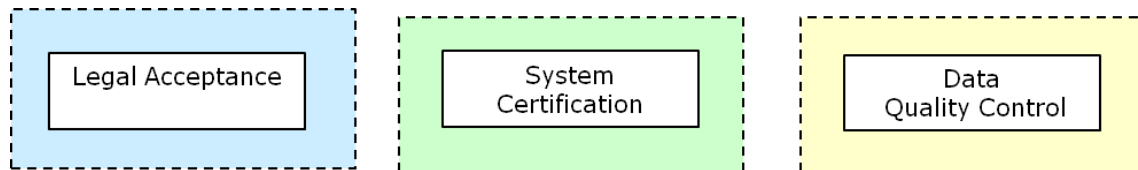
This is the third level and most limited performance test in order to verify if a system is still operating within specifications. This is a relatively limited test, executed when a system has been operational for a period of time, typically once a year. It consists of field tests only, with a lower number of test vehicles and passes over the system. The results of this test will be a certificate or document stating that this specific system still meets the required specifications. This test is required for all WIM systems both for legal and statistical applications, however also here the content of the test procedures (number of vehicles runs) differ between applications. In the case of an Initial Verification for a WIM system for a Legal application, the ‘In-Service Certificate’ has to be issued by the NMi Certin or a NMI. In the case of a system for a Statistical application, the certificate may be issued by any competent body, as long as it has been agreed by both buyer and vendor but has no legal consequences.

### **3. Procedure for Implementation**

The implementation of WIM systems for direct weight enforcement requires a careful procedure. The key issue is to create a structure which will assure the minimum quality (accuracy and reliability) of each individual WIM measurement that is used for enforcement. In this structure the independent certification of the WIM systems is important, however there are other steps to consider.

#### **3.1 Elements of the Implementation**

The implementation of WIM systems for direct enforcement consists of the following three basic elements; Legal Acceptance, System Certification and Data Quality Control.



**Figure 3 – Elements in implementation**

1. The System Certification involves the testing and approval based on an (inter-)national standard. International system certificates will be issued by an independent institute qualified for legal metrology like NMI Certin and accepted by the national metrology authority in the country where the system will be installed. The certification may be based on the OIML R-134 or the NMI WIM Standard. This phase is typically initiated by the manufacturer of such WIM systems or by the end user.
2. The Legal Acceptance involves the adaptation of national legislation in order that - and under what conditions - the WIM measurements may be used as legal evidence for overloading and will be accepted by a national court. This phase is generally initiated by an end user (an enforcement agency or road maintenance department) or sometimes by national metrology authority.
3. Data Quality Control involves the maintenance, calibration and data quality checks to assure the systems continues to operate within its specifications. This phase is generally developed by the manufacturer and independent experts, in cooperation with the end user under a quality system approved by the national metrology authority in the country where the system is installed.

#### **3.2 System Certification**

For WIM systems for Legal application all three levels of test apply as described in the previous paragraph, see figure 2. When a vendor has developed a new type of WIM system for legal application he will contact the NMI and apply for a type approval test. Together they will decide on the practical conditions (when, where and how) of the test, both for the laboratory and the field part of the test. A complete system (system no. 1) shall be installed at the selected test location for the field test. After the system, under test, has passed all requirements the certification body will issue a Type Approval Certificate. Any National Metrology Institute (NMI) or Bureau for Weight and Measures may use this Type Approval Certificate as basis for national legal acceptance.

In case of adaptations to the type of system, the manufacturer must contact the NMI, or the National Authority, to assess whether these changes can be made under the existing certificate or that a new type approval test is required. The Type Approval Certificate is always valid for a complete accuracy class (hence Gross Vehicle Weight, Axle Group Loads and Axle Loads). Together with the Type Approval Certificate and without additional tests, a System Approval Certificate will be issued for the initial system (no.1) at the test location.

For all following systems (no. 2, 3, etc.) of the same type but installed at different locations, only the more limited Initial Verification is required. This test will assess the impact of the local road pavement, traffic and environmental conditions on the performance of the system. The test will consist of field tests only. A System Approval Certificate may be valid for selected items of an accuracy class only (e.g. only gross vehicle weights), to be decided by the customer and will be clearly noted on the certificate.

After a certain period of time determined by the customer/user/manufacturer or demanded by the national authority, an In-Service Verification Test has to be done in order to assess if the system is still performing within its specifications. Wear and tear of the system and surrounding road (pavement/bridge) and changes in the traffic or environmental conditions may have an effect on the measurement accuracy and reliability. The test will consist of field tests only. An In-service Certificate may be valid for selected items of an accuracy class only, to be decided by the customer and clearly noted on the certificate.

The certification of a WIM system is crucial in the implementation for direct enforcement however by itself this is not enough. It ‘only’ certifies the measurement capabilities (accuracy) of the system based on a standardized test. It does not give any indication on whether the system’s measurements may legally be used directly for enforcement. At the same time it does not guarantee that the system continues to measure correctly during operation. For this it two additional elements need to be implemented as well.

### **3.3 Legal Acceptance;**

This element in the implementation structure will provide answers to questions like: what are the national regulations for the system approval, what are the requirements for these systems, how and how often should these verified and by whom? The objective of this element is to ensure through regulations that the WIM measurements may be used as direct legal evidence for the enforcement of overloading. The exact content of these regulations and the way they are included in legislation depends on the national legal system, e.g. in the Czech Republic (Fucik, 2016). In any case it is recommended to have the full set of regulations and operation procedures officially verified and accepted by the national court before start of the direct enforcement operation.

### **3.4 Data Quality Control**

What are the regulations and procedures for the correct operation, maintenance and calibration of the WIM-systems. Due to the nature of WIM-systems and the ‘hostile’ environment they have to operate, damages, wear and tear are part of normal operation of a WIM system. This means that the performance of all WIM systems will reduce over time, normally slowly because of wear and tear but sometimes quickly in case of damages to – parts



of – the system. The formal system verification tests ‘only’ verify and guarantee the performance of a system at the moment of the test. The question remains what is the performance of the system in between verification tests? Is it the blue line or the green line shown in figure 4? Additional data quality checks are required to verify and assure the quality of the measurements in between.

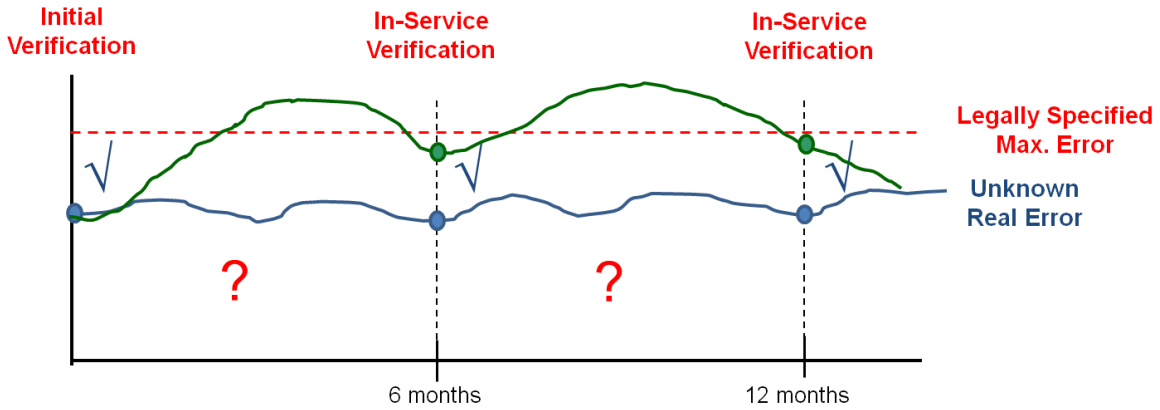


Figure 4 – Need for Data Quality Control

For direct enforcement it is essential that the performance of the WIM system is assured by the manufacture/vendor or user during the entire operational period. For this reason a quality control system must be in place that constantly verifies the quality of the measurements using a combination of quality checks. In general these checks monitor the stability of the certain criteria of the measurements. Examples of Data Quality Control systems can be found all over the world, e.g. in (Guerson, 2016) from Brazil, (de Wet, 2012) from South Africa, (Lees, 2016) from the EU and (Nichols, 2004) from the USA.

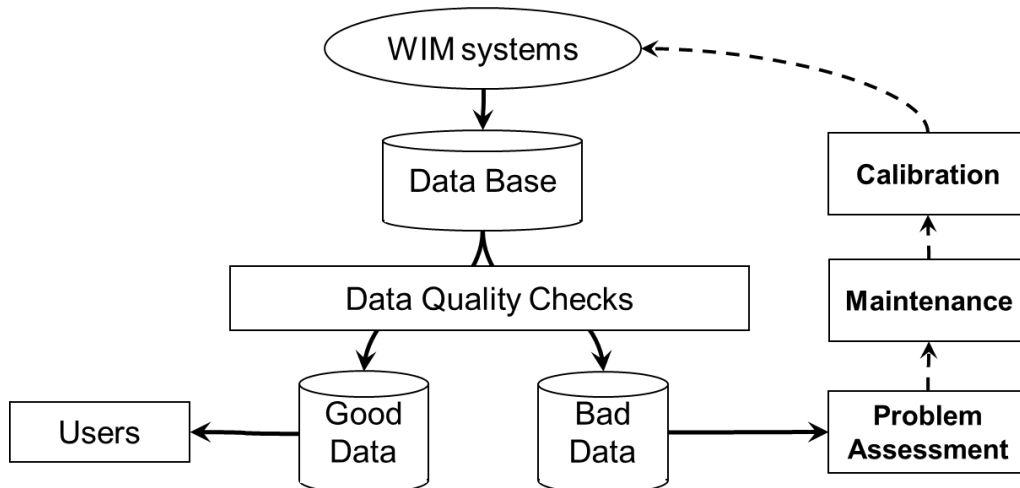


Figure 5 – Data Quality Management system

For example the first axle of loaded tractor semi-trailer combinations generally have a very similar value, when monitoring these first axle loads under normal conditions they lie within a narrow bandwidth around an average value. When these values start to move outside certain

boundaries this is an indication that the measurement performance of the system is no longer stable. In such cases the measurement from this system should no longer be used for direct enforcement until the reason for the changes has been detected and the system is fixed. In this way the output of the Data Quality Checks is also used as input for the maintenance and calibration of the systems, see figure 5.

The operation of the WIM system should be part of a quality system that has been approved by the national authority. The exact implementation of the Data Quality Checks depends on the type of WIM system and the local operational conditions (traffic, road infra and environment), These checks are generally developed by the manufacturer and independent experts in cooperation with the end user and the national metrology authority. It is recommended to have the Data Quality Management (DQM) system running for a couple of months to a year before the start of the direct enforcement operation to ensure proper functioning. During this time the DQM can be calibrated and fine tuned and it will show whether the performance of the WIM system is accurate and stable to be used for direct enforcement.

## **4. Conclusions and References**

### **4.1 Conclusions**

- Fully automatic direct weight enforcement using Weigh-In-Motion systems where the WIM measurement is used directly as basis for legal action in case of overloading is considered the most efficient way of enforcement;
- A new NMi Standard for WIM systems has been developed. This standard covers a combination of: Statistical and Legal Applications, High Speed and Low Speed systems, performance requirements, test procedures and recommendations;
- The implementation of WIM for direct enforcement requires the most advanced WIM technology and a very careful introduction procedure consisting of three elements: Legal Acceptance, System Certification and Data Quality Control;
- As base for the system certification the existing OIML R-134 or newly developed NMi WIM Standard may be used;
- The second element in a successful implementation is a set of legal regulations and procedures officially verified and accepted by a national court;
- The third element is an approved data quality control system must be in place that constantly verifies the quality of the measurements using a combination of quality checks.

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