<u>R</u>equirements for <u>E</u>nforce<u>M</u>ent of <u>O</u>verloaded <u>V</u>ehicles in <u>E</u>urope

Work Package 2

"Technical Issues"

Version: 0.7
Date: Jan 2006

Table of Contents

Document versions

Version	Date	Main changes	Comments by:
0.1	Oct. 2004	First general set up of the document	R. Henny
0.2	Jan. 2005		Members of Work package 2
0.3	Apr. 2005	Reduction of parts on Terminology and Applications which are now in separate documents. Including the chapters on the foundation for the acceptance test, the specifications for external influences, calibration and the selection of the location	Members of Work package 2
0.4	June 2005	Incorporation of comments by members of WP-2	Members of Work package 2
0.5	Sept. 2005	Conclusions and recommendations added. Consistency check with other WP's.	
0.6	Nov 2005	Terms of applications added	F.J. van Loo
0.7	Jan 2006	Foreword changed and Introduction to WIM added	F.J. van Loo

Foreword

As the work within the REMOVE project progressed and especially based on the results of the Questionnaire it became clear that some of the original objectives were set too ambitious. The main reason was that Weigh-in-Motion is a completely new technology to most of the enforcement world. Only a very few countries are currently using (High Speed) Weigh-in-Motion technology for enforcement applications. And even these countries only have a few years of operational experience in the use of WIM for enforcement. For the most advanced applications (direct enforcement and intelligence) the first test has recently started and consequently no operational experience exist. As a result the national regulations and procedures are scarce if they exist at all. On an international (EU) level there is nothing available at all, this means that the specifications and the test procedures had to be designed from scratch. The advantage is that no existing national regulations or procedures had to be changed.

In addition the 'Legal Metrology' basis of the REMOVE consortium is too limited to prepare a full set of specifications by itself. (The consortium was also never intended for that). For this reason the focus of the work of work package 2 shifted from the original idea of the preparation of a full set of specifications to the preparation of a technical framework for the acceptance and deployment of WIM-systems for enforcement of overloading.

The Questionnaire also showed that a large variety of terms and definitions existed for the different applications of WIM for enforcement. The terms were often overlapping or contradiction and in all cases very confusing even among the partners of the REMOVE project. That is why as a first step towards harmonisation a standard set of terms was devised for the different applications see chapter 3 of this report.

1 Introduction

1.1 Content

This document contains the 3rd draft of the report of Work package 2 “Technical issues” of the REMOVE–project. REMOVE stands for “Requirements for EnforceMent of Overloaded Vehicles in Europe”. The objective of the project is to provide a frame work within which both new and existing Weigh-in-motion systems can be operated at a strategic and tactical level across the European Community. The overall goal of the REMOVE project is the reduction of overloading by road truck transport and all its negative consequences. Enforcement of overloading consists of all activities to reduce overloading by heavy vehicles (more than 3.5 tonnes). So not only detecting violations and issuing citations but also e.g. communication with the drivers and transport companies

The project consists of five Work Packages: 1) Legal Issues, 2) Technical Issues, 3) Operational Issues, 4) Cost/Benefit Analysis and 5) Management. Work package 2 focuses on the technical issues involved in the introduction and the operational use of WIM-systems for enforcement. The work package was divided into three activities; inventory, specifications and test procedure.

1. Inventory of WIM technology. An inventory was made of existing technology and used (legal) technical specification for (high speed) WIM systems. This inventory was included in the general REMOVE Questionnaire [ref. Questionnaire] which covered the inventory for all work packages. This way people only had to answer one set of questions instead of four separate sets of questions from all work packages probably containing many of the same questions.
2. Specifications. The preparation of functional and certain technical specifications for WIM-systems to be used for enforcement. The specifications incorporated what is operationally and legally required (input from Work Package 3 and 1) and what is technically possible. Consideration will be given to the preparation development of a common data format for the exchange of information on overloaded vehicles between EU-member states;
3. Test Procedure. The establishment of a test protocol, defining and describing the procedures legal acceptance of WIM-systems to be used for direct automatic enforcement. This protocol should be both practical and well founded. Practical means that it should be possible to perform the test within operational boundaries, e.g. the number of trucks required for the test. Well founded means that the test procedure should be scientifically well founded to avoid question on the outcome. The test protocol involves the following:

- A description of the road to acceptance legal approval of WIM-systems. This will have a close link with the ‘required legal framework and standards’ part of work package 1.
- A test-procedure, a description of which tests should be done and how they should be performed. This includes not only the initial (type-) approval test but also the periodic performance tests.

1.2 Objective

The objective of this document is to facilitate the use of Weigh-in-Motion systems in the enforcement of overloading in EU-member states.

1.3 Scope

The document consists of following parts; the 1st chapter consists of this introduction. The 2nd chapter describes the road to acceptance of WIM-systems for enforcement. In chapter 3 the applications, the user requirements and the technical specifications are described for WIM-systems to be used as a measurement tool in enforcement. Chapter 4 describes the test procedures necessary to be able to accept the measurements from a WIM system in the prosecution of violators of the loading laws. Chapter 5 deals with the external influences which are involved in the registration of overloaded vehicles. In chapter 6 recommendations are given for the selection of a good location for a WIM-system both from a technical and operational point of view.

2 The road to acceptance.

2.1 Introduction to Weighing in Motion

The force of the axles of a truck on the road surface (the axle loads) changes because of irregularities in the road surface, steering movements and the suspension of trucks. The size of this dynamic force varies round a static value that can be measured when the truck is not moving. The total axle load of a moving vehicle can be described, in a simplified form, as a combination of a constant static axle load and two (semi-) periodic signals. The first is the dynamic force as a result of the 'body-bounce', the rocking/rolling motion of the whole vehicle. For heavily loaded trucks the frequency of the body-bounce lies between 1 and 3Hz. The second is the dynamic force as a result of the 'axle-hop', the hopping motion of the individual axles. The frequency of the 'axle-hop' lies generally between 8 and 13Hz. For a level section of a 'normal' highway the amplitude of the body-bounce component can amount up to 20% of the static axle load. In the case of heavily loaded trucks with modern, pneumatic suspension systems, the effect of the axle-hop is negligible in relation to that of the body-bounce.

Weigh-In-Motion is the technique to 'measure' the static axle loads of moving trucks. A WIM system consists of one or more force sensors that are installed in the road surface. The sensors measure the forces that each individual axle applies at the moment it passes over that sensor. From the measured forces the system calculates the static axle loads and the gross weight of the vehicle. A High-Speed WIM-system is capable of measuring axle loads of fast moving vehicles (high-way speeds). By placing a number of WIM-sensors after each other and by combining the individual measurements a Multi-Sensor (MS) WIM-system is created. In this way the accuracy and reliability of the measurement are improved.

2.2 What does a WIM-system measure?

If a heavy good vehicle is considered, its static gross weight (i.e. its mass m multiplied by the intensity of the gravity g), expressed in kN, is denoted Ws = m.g. If the vehicle is stopped on a perfectly flat and horizontal surface, the force applied by a wheel (through the tire) on the ground is called "static wheel load". For an axle, the sum of all the static wheel loads (for all the wheels belonging to this axle) is called the "static axle load". For the axle of rank i the static axle load is denoted Ws_i. Therefore, if the vehicle has K axles, we have:

$$Ws = \sum_{i=1}^{K} Ws_i \qquad (1)$$

Now, while the vehicle is travelling at speed on a road, the road surface unevenness induces dynamic motions of the suspended and non suspended masses of the vehicle, which result in accelerations to be added to the gravity. At any time t, the impact force F_t of a wheel is the instantaneous force applied by a wheel on the pavement through the tire. This force varies with the time t and thus along the pavement. At the time t, the dynamic axle load or axle impact force is the sum of the wheel impact forces of all the wheels which belong to this axle. The dynamic gross weight, denoted Wd, is expressed as:

$$Wd = \sum_{i=1}^{K} Wd_i \qquad (2)$$

Any WIM system measures either the wheel impact forces or directly the axle loads Wd_i. The gross weight measured by the WIM system is estimated by Eq. 2. Because Wd_i and Wd estimate the static axle and vehicle loads, the accuracy of the WIM system is expressed with respect to the relative errors, either of axle or vehicle loads, i.e.:

$$\varepsilon_i = \frac{Wd_i - Ws_i}{Ws_i} \quad (3a) \qquad \varepsilon = \frac{Wd - Ws}{Ws} \quad (3b)$$

where ε_i is the relative error on the axle i load and e is the relative error on the gross weight.

Figure 2.1, Example of vehicle driving over WIM-system

Not only are the quality of the WIM-sensors but also the geometric design, pavement condition of the roadway and the overall site location influencing the performance of a WIM system. These factors influence the dynamic behaviour of the vehicle and thus the accuracy of the estimate of the static weight estimate provided by the WIM system. Therefore the accuracy of a WIM system depends on its installation and environment (road) conditions, and not only on its intrinsic performances. Moreover, the vehicle characteristics, such as suspension type and performances, axle number and spacing, the Eigen frequencies and damping factors, but also the payload, the gravity centre height, etc. influence the dynamic loads, and thus the accuracy of each individual WIM measurement. However for most applications (e.g. Statistics & Planning) the average accuracy of all measurements is more important than that of each individual measurement (only for Direct Enforcement).

2.3 Introduction to WIM-technology

The following paragraph gives a short overview of the different kinds of WIM-systems. This intended as an introduction to WIM-technology for people involved in traffic enforcement. It is not comprehensive in depth analysis of all different technologies used in Weigh-in-Motion.
In general a WIM-system can be divided in the following parts:
1. External structure, this is the physical framework of a WIM-sensor how it is put in (or under) the road surface. Its purpose is to transfer the axle loads of the passing vehicles to the actual sensor without damaging the sensing material;
2. Sensor or Transducer, this heart of each WIM-system it transduces the axle load into an electrical signal. Examples of transducers are: Piezo-electric materials, Piezo-Quartz, Strain Gauges, Fibre Optics. The exact working principles of the different sensing principles can be found in the product information from the various WIM-sensor manufacturers.
The combination of parts 1 and 2 results in three different types of WIM-sensors:
- Line sensors, because the width of the tyre is larger than the width of this type of sensor only a part of the total axle load works on the sensor at each time. In order to measure the total axle load the signals measured during the passing of an axle over the sensor should be

integrated (combined);

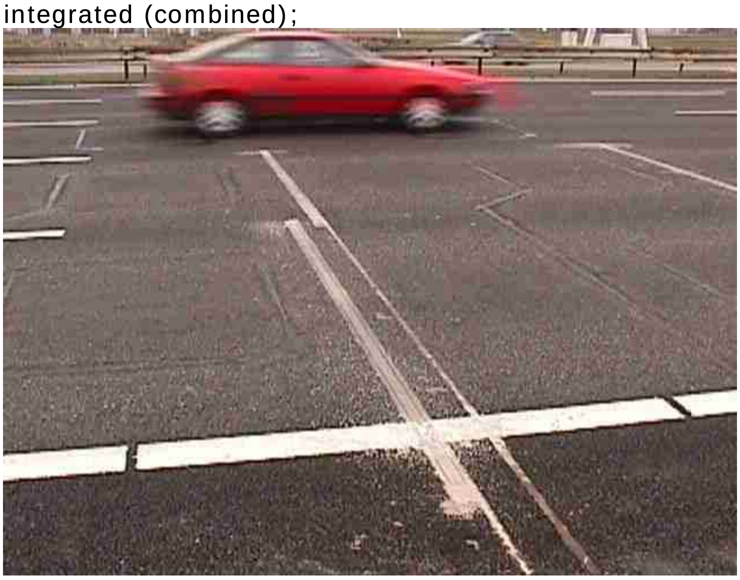


Figure 2.2, Example of strip sensor

- Plate sensors, since the width of the sensor are larger than the tyre in this case the total axle load is working at the sensor (at least at one moment). Depending on the sensing material this allows also for static axle load measurements;

Figure 2.3, Example of plate sensor

- Bridge sensors, in this case sensor are attached under a bridge or culvert. This way the bridge becomes more or less the weighing instrument. Typically this type of WIM-system measures the impact of multiple axles on the bridge at the same time. In order to distinguish the individual axle loads special signal processing software is required.

Figure 2.4, Example of bridge sensor.

3. Signal processor, this part transforms the measured electrical signal into the digital value representing the axle load;
4. Data Storage, this part combines the measured axle load with other quantities that were measured (e.g. time, speed, vehicle category) and stores it for later analysis;
5. Communication, often WIM-systems do not operate as stand alone units but as a part of a larger network of measuring system.
6. Camera, depending on the application a (digital) camera may be added to the WIM-system. This allows for the recording of images of the vehicle which axles were measured.

2.4 Cross-border enforcement.

The main goal of the REMOVE project is the harmonisation of the enforcement of overloading and the initiation of cross-border enforcement. The aim of cross-border enforcement is to ensure that the enforcement of road traffic laws and the penalties for violating them are applied equally to everyone using the roads regardless of were they live, work or are recognised to have citizenship.

As operational model for the cross-border enforcement the REMOVE project has adopted the COPEN-24 principle, [COPEN-24, 2004]. In simple terms this principle states that in order to invoke the enforcement of penalty for a violation across Member States' borders, all legal processes (including appeals) have to be concluded in the Member State where the violation took place (the Issuing State). If, once these processes are complete, the penalty incurred cannot be enacted on the vehicle owner/driver responsible, the power to enforce the penalty can be delegated to the Member State where the vehicle owner/driver is resident (the Executing State). In the VERA2 project [ref. VERA2 final report] an operational model has been presented (eNFORCE) on how the cross-border enforcement can be organised in daily practice. The REMOVE project adopts the eNFORCE model for the harmonisation of the operational process for cross-border enforcement of overloading.

When looking at the measurement-technology related aspect of cross-border enforcement the key issue is confidence that the record of the violation is a true reflection of what actually took place. This confidence is built on the following points:

- Standard data set. The record produced by an enforcement system should contain all relevant data describing that violation necessary for enforcement. This issue can be covered by a standard data set which describes all quantities or items that are required for enforcement of overloading;

- Type approval. All equipment used to enforce road traffic laws should be type approved by recognised/notified bodies. For this the REMOVE project proposes to use the Measuring Instruments Directive (MID) as a common starting point for setting national type approval requirements. Also as many existing European and international standards should be used (e.g. COST 323, ASTM E-1318, OIML R-134);
- System-approval. The performance of a Weigh-in-Motion system strongly depends on the local conditions of those systems and its surroundings. That is why a WIM-system besides the overall type approval also needs system approval for each individual system.
- Periodic approval. WIM-systems have to operate in hostile conditions which make them sensitive to wear and tear. That is why all WIM-equipment used to enforcement should be subject to regular inspection, re-calibration and re-certification by recognised bodies.

The enforcement application a WIM-system will be used for determines which of the points are required.

2.5 Measuring Instruments Directive.

The Measuring Instrument Directive is a EU-directive [ref. MID 2004] regularising the construction and certification procedures of several measuring instruments in order to improve free trade of these devices across Europe. The MID is set of uniform European specifications and a European framework for type and product approval. The actual approval of measuring instruments will be done by Notified bodies according to national legislation. The MID will be adopted in each Member States' national legislation within the coming year.

The MID comprises of several parts, following a main body it consists of a number of annexes. The main body contains the general articles on the legal background and the role for all parties involved (e.g. manufacturers, notified bodies and national governments). The annexes contain the actual requirements for the various measuring instruments. Annex I describes the essential requirements valid for all measuring instruments. Annexes A to H1 describe a range of conformity assessment procedures. Annexes MI-001 to MI-010 describe the specific requirements for the different measuring instruments. Also the applicable conformity assessment procedures are listed for each instrument. Because of the structure of the MID it is - in principle - quite easy to add new instruments. In principle, because it took more than 10 years to finalise the MID, so new additions may also require a long time to be formally included and implemented.

At the current time, the MID does not include specifications and certification procedures for weight (axle loads and vehicle mass) enforcement systems. The REMOVE project follows the approach, equal to the one adopted by the VERA 2 project [ref VERA 2 Deliverable D5-1], to use the framework of the MID as much as possible without becoming a formal part of the MID. The advantage of this approach is that all countries will have a very similar legal framework which is an excellent basis for a harmonised implementation of requirements for weight enforcement systems. This way all general articles of MID can be used unchanged and the 'only' thing that has to be done is to prepare a new and specific virtual annex. Virtual means that the annex will not become a formal part of the MID (the MID was never intended for enforcement systems) however will use the same structure, procedures and general articles. 'Only' does not mean that the preparation of this virtual annex should be taken lightly.

The REMOVE has prepared a first draft version of this 'virtual' annex on weight enforcement systems; this is the direct automatic enforcement application. The preparation of a more comprehensive version of this annex lies outside the scope of the REMOVE project. This would require the cooperation with European (or world wide) organisations for legal metrology like OIML, WELMEC and CEN.

The OIML has a Technical Committee (nr. 9 on Instruments for measuring mass and density) with a Sub-Committee 2 on Automatic Weighing Instruments. This Sub-Committee is working on a recommendation R134-1 on Automatic Instruments for weighing road vehicles in motion. Unfortunately this is only intended for WIM-systems in a controlled environment and not for operation in roads or highways. In its current form this recommendation is not suitable for enforcement purposes because the reliability of the test procedure is far insufficient. Since the OIML is a world wide organisation it might not be the most logical organisation to start the preparation of a European norm.
The other possibility is to start a Working Group within the CEN. This group could consists of the partners of WP-2 of the REMOVE project, the (still) active members of the COST 323 management group and some of the operational partners of the REMOVE project. The advantage of a CEN Working group is that it is directly linked with the EU-commission. In an other European project (Eureka/Footprint) there might be already an initiative for such a working group.

3 Applications

3.1 Introduction

This chapter provides a definition and short description of the possible applications of Weigh-in-Motion (dynamic vehicle weighing) systems for goods vehicles. Some applications are currently in operation in EU Member States others are possibilities for the future. The purpose is to provide clarity of meaning for terms within the project documentation so that common terms are accepted and utilized throughout the life of the Project Remove documentation and feature in the final report.

The enforcement of overloaded Goods Vehicles in Europe is carried out by various agencies and organisations e.g. Police Agencies, Transport Inspectorates or Customs. The way that the enforcement is executed in daily practice also differs considerably, depending on the member state situation, regulations and procedures.

When looking at the use of weighing systems for the enforcement of overloaded vehicles there are a number of different possible applications. The different uses that the weigh systems will be put to will result in different requirements and specifications for each system, the data that is measured and the manner that it is recorded, displayed and ultimately processed.

3.2 Human Selection.

Traditionally Large Goods Vehicles were selected for weighing by an enforcement officer using their own judgement. This method of enforcement is sometimes termed “Traditional Enforcement” or “Manual Selection”, within the Remove project the term “Human Selection” is used.
Human Selection is a means of carrying out overload enforcement without the use of (high speed) Weigh-in-Motion (WiM) technology. Here the officer uses his/her field experience to select overloaded vehicles based on external characteristics. The selection can take place either from a vehicle driving in normal traffic or stationary from the side of the road. The selected vehicle is then escorted to a location for static (or in some countries Low Speed) weighing which is currently the only legally accepted method for enforcement.
The disadvantage of this method is that not all selected vehicles are overloaded this could be due to a number of factors which include the skills of the officer selecting the vehicles and/or the characteristics displayed.
The Human Selection procedure for weighing large goods vehicles is not seen as efficient either in terms of the efficacy of the enforcement or the time wasted by vehicles which have been incorrectly selected. One of the consequences of this inefficiency is that (groups) of overloaded vehicles may never be selected at all and therefore never be checked. In addition the time taken to process each potential offender is increased as the vehicle has to be escorted from the road network to a designated weigh station.

3.3 Statistics and Planning.

In this case the data measured by a WiM system or a network of WiM-systems is stored in a central data base. The measured data contains no identification of individual vehicles. The measured data may include the axle loads, vehicle weight, vehicle category, speed, location, time.
The data gathered is used to generate statistical overviews on the loading situation on a specific road or a road network. The overviews may include the total amount of overloaded vehicles (in absolute numbers or percentages), the severity of overloading (in absolute values or percentages), the type of the overloading (overloading of individual

axles or vehicle weight), the distribution per time of day, per day of the week, the distribution over the different vehicle categories or different axles or a combination of all previous items. Such overviews are traditionally used by road administrations authorities for road design and road maintenance.
Enforcement agencies can use this overview in the planning of enforcement activities, when and where are control units deployed so that the peeks in the overloading are targeted. This way the (scarce) enforcement recourses are used most efficiently and the controls, either manual or pre-selection, are more effective. The statistics are also an important tool in the evaluation of the effects of enforcement activities.

3.4 Pre-selection,

In this case a WiM-system is used to select potential offending vehicles. The WiM-system will only give an indication that a vehicle is probably overloaded. Within the Remove project this application of WiM for enforcement is termed “Pre-selection”. The measurement that would be legally valid for enforcement is carried out by a second system. This second system could either be a static weighing system or a Low Speed WiM-system depending on member state regulations. The WiM-system weighs all passing vehicles, when it detects an overloaded vehicle, an image of the vehicle is taken and the target vehicle is guided to the ‘Static weighing area’. The measurements taken by the WIM-system are ‘only’ an indication that the truck involved is probably overloaded. The measurements and the pictures can not directly be used as evidence in legal procedures.

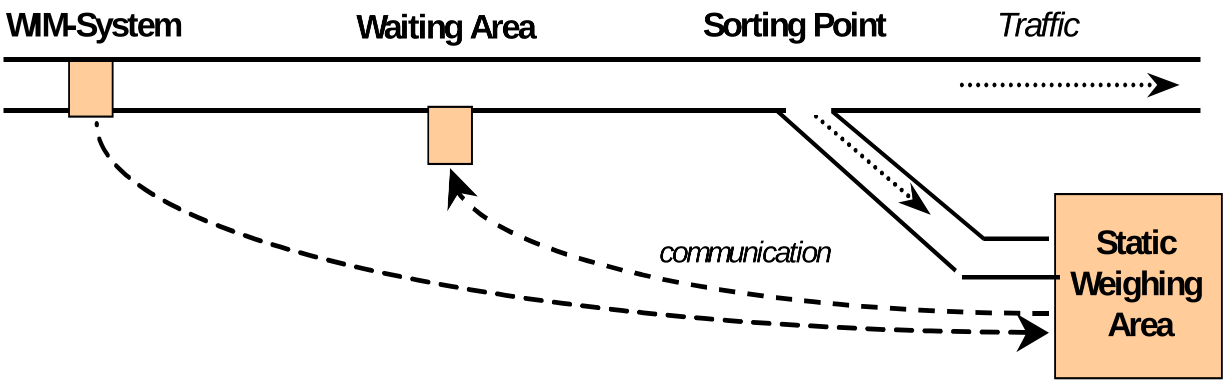
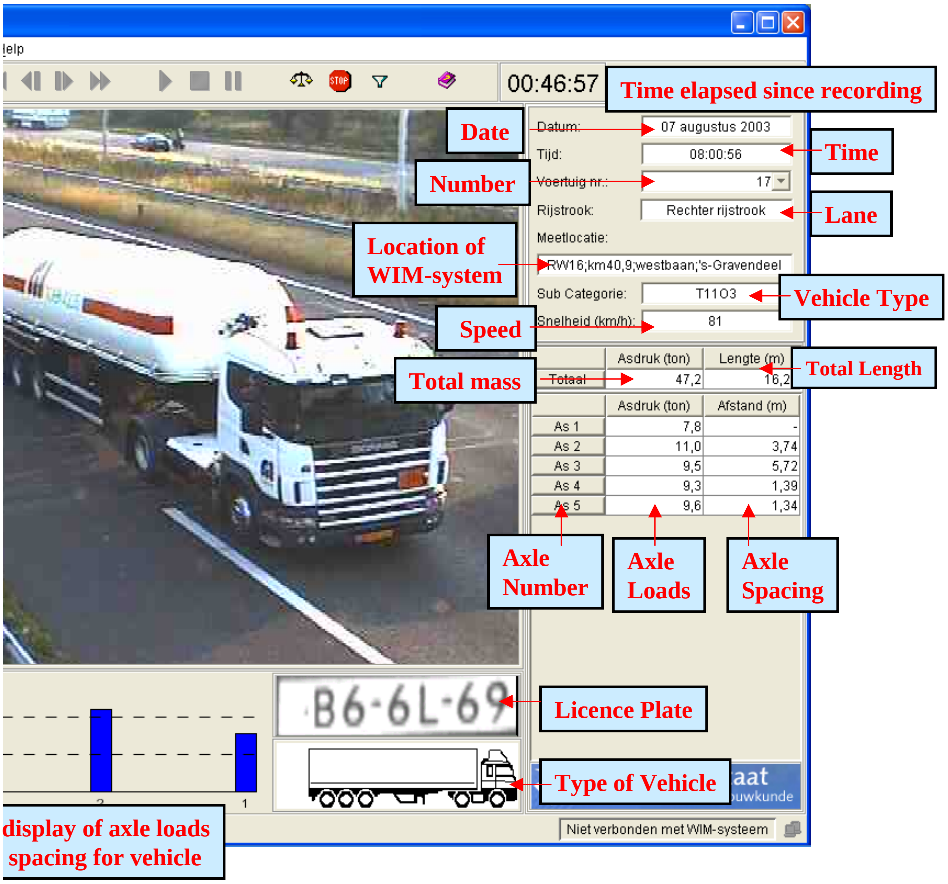


Figure 3.1, Pre-selection using manual escort

There are two possibilities for the selection and escort of the target vehicle from the traffic to the static weighing area; Human Escort and Automatic Escort:

Human Escort, in this case the WIM-system takes one or more digital pictures of the overloaded vehicle. One picture focussed on the licence plate and one overall picture of the front/side of the vehicle. The pictures are then sent to an enforcement officer, who is generally located at the static weighing location, (see figure 1). This officer passes a description of the offender to a second enforcement officer who is positioned by the roadside.

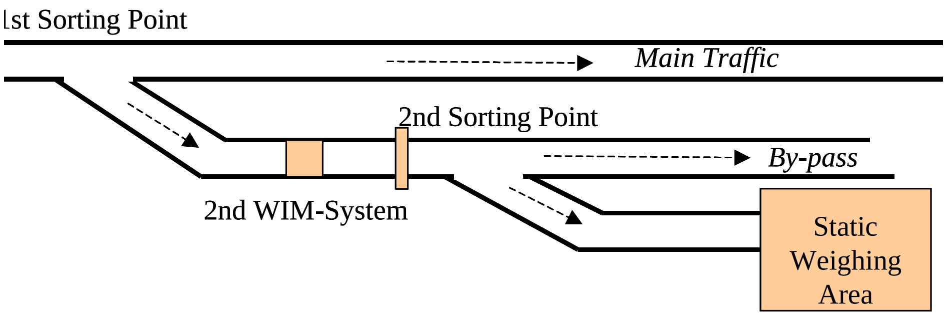


The description of the target vehicle can be given in words over the radio or telephone or by sending the picture to a PC/laptop/display at the road side. The second officer is located either in a car or on a cycle motorcycle at the 'Waiting Area' or standing at the 'Sorting Point'.
In the first option, when the target vehicle passes the police officer, he will stop the target vehicle, and direct and/or escort it to the static weighing location for the legally accepted after-weighing.
In the second option the officer will be standing next to the road just before the sorting point. When the target vehicle approaches he will instruct the vehicle to take the next exit to the static weighing area again for the legally accepted after-weighing. This second option is only possible under certain traffic condition (low speed and low volume) to ensure the safety of the police officer.

Automatic Escort, in this case the target vehicles are guided by means of automatic traffic signs. In instances of low volume and low speed traffic the target vehicle can be guided directly to the static weighing area. There will be no confusion as to whom the traffic sign is intended for.

In the case of high volume traffic a second WiM-system can be used, located on a special lane at the sorting point. This second system will measure at lower speeds and with greater accuracy. When still overloaded the vehicle will be guided to the static weighing area again by means of automatic traffic signs when not overloaded the vehicle may return directly to the main road without further delay.

Figure 3.2, Pre-selection using automatic escort with second WIM-system



The advantage of the pre-selection method compared to human selection is that almost (95%>) of vehicles selected are overloaded and no groups/types of overloaded vehicles are omitted.
The disadvantage of this application is that it is still labour-intensive due to the fact that the static (or Low Speed) after-weighing remains necessary.
To be able check all strategic locations on the TERN 24 hours per day, 7 days a week this method remains costly. In the case of automatic escort the method becomes less labour intensive however it requires a large geographic area to accommodate all systems which may not be available in all member states.

3.5 Problem Solving

The aim of Problem Solving is not to achieve compliance through the enforcement of the regulations or by the imposition of penalties, but to resolve the problems that underlie offences. An increase in compliance is achieved by removing one or more of the obstacles to compliance with the regulations. The solutions are often wide ranging and can be regarded as innovative. In general they are not regarded as an easy and immediate solution to a problem, but if approached correctly by trained officers they can provide long term resolutions to deep rooted issues in relation to offender behaviour. Especially in the case of overloading of individual axles it is often possible to avoid overloading by changes in: the way the vehicles are loaded, the logistic chain or adaptations to the vehicles. Within the Remove project the term of “Problem Solving” is used instead of a term like “Pro-active Enforcement” or “Company Profiling”. The terms “Company Profiling” and “Direct Feedback” are used within the application of Problem Solving.

Direct Feedback, in this case the WiM-system is used to warn passing trucks when they are overloaded. The system set up consists of a WiM-system, a traffic sign (variable message sign) and locations were the target vehicle can remove some of the load to reduce the weight of the vehicle.
When the WiM-system detects a vehicle that is overloaded a warning message will appear on the traffic sign. The message may consists of a simple text (“You are overloaded”), a more detailed text describing the kind of overloading (“Your second axle is overloaded”) or a combination of a text with a licence plate number. After the message has been shown the measurement data may either be destroyed or stored for Company Profiling depending on privacy regulations.

Company Profiling, in this case a network of WiM-systems stores all measured data, including the pictures of the vehicle, of all overloaded vehicles. Again the WiM-systems ‘only’ gives an indication that a vehicle is probably overloaded the data can still not be used as evidence for direct legal action. Using the licence plate information the identity and nationality of the overloaded trucks is determined. The information is stored in a central national, or even international, data base. Regularly the data base will be used to identify “green” (no or few infringements), “yellow” (too many infringements but not extreme) and “red” (far too many and/or too serious infringements) transport companies. Based on this information red companies are selected and further action is taken. This action may consist of a warning letter, a company visit or inspection. The procedure may start with sending a letter warning a company that in the last period X number of (probable) overloading violations have been detected. The company is advised to check its loading regime and that the progress will be monitored. The primary goal of a first visits is to discuss the existence of an overloading problem of the company, the possible reasons behind it and possible solutions. In addition non-overloading related permits/regulations may be checked during such visit. Experience has shown that companies involved in overloading vehicles are more likely than not to breach other laws or regulations. The innovation of this approach could involve a multi-agency approach to resolve the issues which could include Vehicle Inspectorate Tax Officer, or Customs Officers.
In some cases it is advantageous to be able to use the data measured by the WIM-system as a basis for further legal action. In order to make this possible some kind of quality control or certification will be required. The level of this quality control or certification depends on local or national legislation. In any case this level will be less than the one required for the next application ‘direct enforcement’.

3.6 Direct Enforcement.

Direct Enforcement means that the (evidence for the) prosecution of an overloaded vehicle is directly based on the measurement by a weighing system. Sometimes this application is termed “Automatic Enforcement” or “Evidential Weighing”; however within the Remove project the term “Direct Enforcement” is used. Within the procedure of Direct Enforcement both “Automatic enforcement” and “Manual Enforcement” are possible.

For Automatic Enforcement the procedure from the measurement to prosecution can be completely automated and is similar to that of automatic speed enforcement. The procedure for automatic enforcement is shown in figure 3.3. The (in-)accuracy of the weigh-system is deducted from the measured value in order to make sure that the offender always has reached at least the corrected value. This corrected value is used to determine the violation and for the possible further prosecution. The enforcement margin means that only violations larger than that margin e.g. (5%>) are actually prosecuted. In this way, the enforcement is focussed on the more severe cases of overloading and cases of small accidental overloading do not immediately result in a prosecution. The use and the variance of the enforcement margins are an operational consideration, and a decision for the enforcement agency.
A disadvantage of automatic enforcement is that severe cases of overloading are not stopped and dealt with immediately. To overcome this problem the direct manual enforcement procedure can be used.

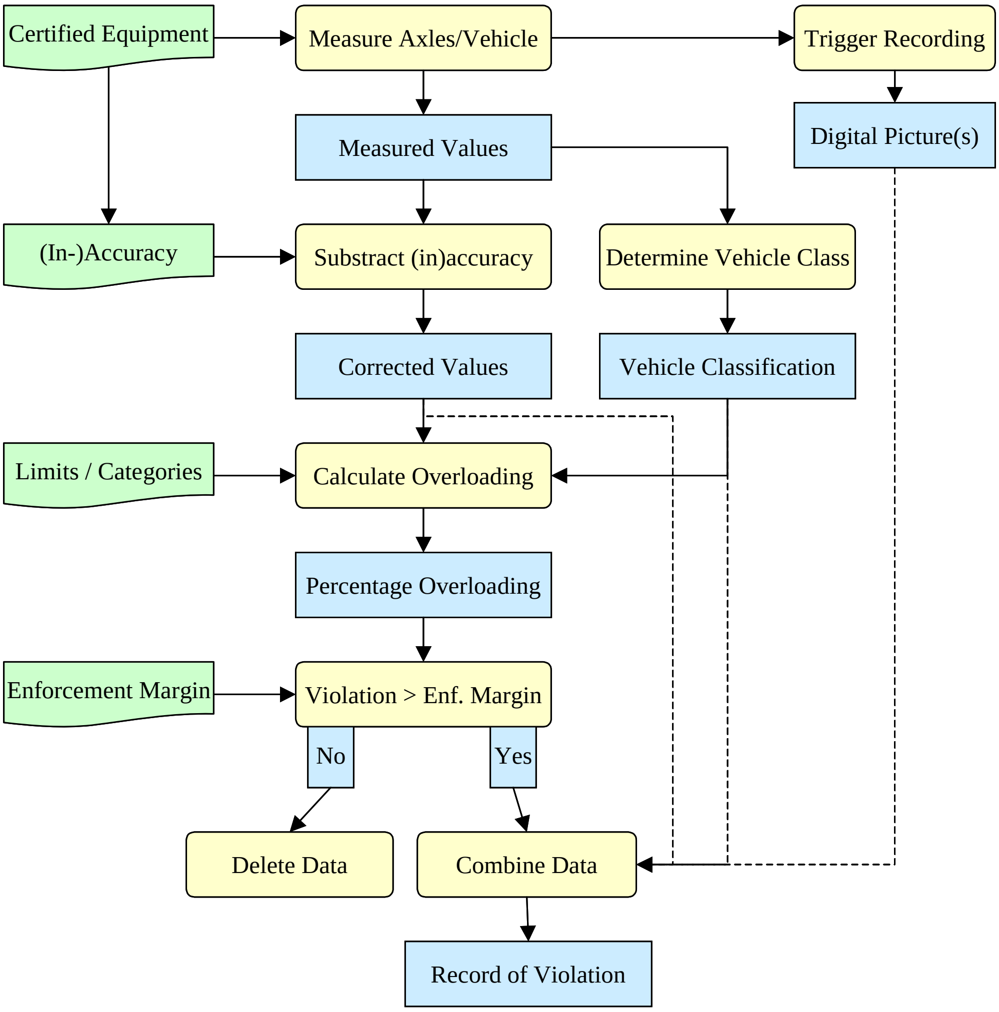


Figure 3.3, Procedure for automatic enforcement.

For Manual enforcement the procedure differs from direct enforcement as it incorporates either the 'Human Selection' or 'Pre-Selection' procedures previously described. Manual enforcement will always require some element of 'human interaction'.
In both selection procedures the vehicle selected either visually by the experienced human operator, or by automatic pre-selection may then measured again using a legally accepted, certified weighing system, (low-speed Dynamic WIM, or Static weigh system).
The results are noted by a human operator, and if an overload is detected the information regarding that vehicle, and offence are conveyed to other human operator/s (police or other enforcement officer) who will manually stop the vehicle, and then deal directly with the driver in relation to the overload offences detected. A manual prosecution process is activated, relevant to the particular country's laws, rules, regulations and tolerances.

This may also include activation of a further prosecution, or other levels of procedure again, which are country specific, involving other responsible entities such as the haulage company, agent, shipper or consignor. Communication may also be needed with other prosecuting bodies from the country where the vehicle is registered.
Unfortunately all the disadvantages as previously mentioned in the description of Human Selection and Pre-selection apply in these circumstances.
The advantage in using direct manual of enforcement as other offences; additional to overloading may also be detected, by the direct human interaction. E.g.:- driver hour's discrepancies / mechanical faults, which when detected, and dealt with, potentially lead to higher levels of road safety. However compared to direct automatic enforcement the manual enforcement looses most advantages because of the automation.

3.7 Intelligence + Wider Applications

Intelligence is a collection of applications using the power of modern ICT to combine all possible forms of collaborative data and aggregate the information into intelligence for policing or enforcement application. These may not be aimed exclusively at the problem of overloading. Here the data recorded by a network of WiM-systems distributed over the TERN is stored in a number of data bases. This way the behaviour of specific vehicles can be monitored as they move over the TERN. Possible applications are the monitoring of transport of dangerous or illegal goods or issues of national security.

An advantage of this way of working is that is optimises the intelligent use of measurement data without the necessity to have the most high-end (and most expensive) WiM-technology. Possible examples for these applications are: Average speed enforcement, Driving and resting times, transport of dangerous goods, noting instances when identified vehicles enter and leave the TERN and the weight recorded at these events.

<u>Speed enforcement.</u>
Since a WiM-system also records the speed and an image of each passing vehicle it can also be used for speed enforcement. In this case the WiM-system will have to be certified for this application according to existing specifications for measurement equipment for speed enforcement.

<u>Driving and Resting Times</u>
When combining the registrations of the same vehicle recorded at different times at different locations a calculation can be made of the time it took the vehicle to get from point A to point B. In combination with the maximum speed and the minimum distance between point A and B it can be detected whether the driver has been speeding or has respected the driving and resting regulations or not.

<u>Dangerous or illegal goods</u>
Similar to the automatic reading of licence plate numbers also the UN Hazardous Material identification plates used for the identification of dangerous materials can be detected and verified. In this way the transportation of dangerous goods can be monitored, and the combination of overloading and/or dangerous goods can be detected or the restrictions or operating licences on driving with dangerous goods in member states can be verified.

<u>National Security</u>
Since WIM-systems are capable of recording information, not only from overloaded trucks, but from every passing vehicle this offers possibilities in the field of National Security.

3.8 Summary of terms

The following table gives a short summary of the descriptions of the applications terms used throughout the various reports of the PEMOVE project. These summaries serve as a reminder of what is meant by which application term.

	Vehicles were selected for weighing by an enforcement officer ıt. Human Selection is a means of carrying out overload use of (high speed) WIM technology. Here the officer uses his/her overloaded vehicles based on external characteristics. The scorted to a location for static (or in some countries Low Speed) ly the only legally accepted method for enforcement.
	sured by a WiM system or a network of WiM-systems is stored in data gathered is used to generate statistical overviews on the cific road or a road network. Such overviews are traditionally ons authorities for road design and road maintenance. ı use this overview in the planning of enforcement activities, rol units deployed. The statistics are also an important tool in the of enforcement activities.
	ıll passing vehicles, when it detects an overloaded vehicle, an ken and the target vehicle is guided to the 'Static weighing area'. by the WIM-system are 'only' an indication that the truck oaded. The measurements and the pictures can not directly be procedures. There are two possibilities for the selection and hicle from the traffic to the static weighing area; Human Escort
	ıg is not to achieve compliance through the enforcement of imposition of penalties, but to resolve the problems that ıre two sub applications: "Direct Feedback" and "Company ase the WiM-system is used to warn passing trucks directly l. The basic system set up consists of a WiM-system, a case the WiM-system stores all measured data, including , of all overloaded vehicles in a data base. Based on this e selected that qualify for further action. This action may a warning letter, a visit of the company for an inspection or
	for the prosecution of an overloaded vehicle is directly nt by a weighing system. Within the procedure of Direct atic enforcement" and "Manual Enforcement" are possible. rcement the procedure from the measurement to etely automated and is similar to that of automatic speed ıt will always require some element of 'human interaction'.
	of applications using the power of modern ICT to combine all ative data and aggregate the information into intelligence for pplication. These may not be aimed exclusively at the problem of a recorded by a network of WiM-systems distributed over the er of data bases. This way the behaviour of specific vehicles can ve over the TERN. the monitoring of transport of dangerous or illegal goods or nt, driving and resting times and issues of national security

3.9 (Dis)-Advantages per application

The following tables give an overview of the advantages and disadvantages of the various applications of Weigh-in-Motion for the enforcement of overloading.

	ossible. Suitable for n or seasonal overloading r other offences. I-system required.	y effectiveness. personnel required. es actually controlled, less than 1%. 60% of controlled vehicles are cles are also stopped hence loose ories of trucks or companies are ternal characteristics of vehicle
	heap WIM-systems can be nforcement resources. ffectiveness possible.	tion or Pre-selection. erloaded vehicles possible. nual or pre-selection required.
	overloaded vehicles more than 95%. aded vehicles are stopped. n be used for other	stem + camera required around WIM-system(s) f WIM-site by overloaded trucks
	I at compliance instead of n be used for other rea around WIM-system. ement personnel required. ansport companies	stem + camera and data base onfronted with many initial ‘non-
	hed with high effectiveness. an 99% ement personnel required e controlled, operational network with (very) high n be used for other	n high-tech and expensive WIM- ted certification procedures. cks ‘only’ get a citation. around WIM-system(s) f WIM-site by overloaded trucks
nual	cks are directly dealt with.	es of automatic enforcement.

4 Specifications

Weigh-in-Motion systems measure the dynamic axle forces of moving vehicles and estimate the corresponding static axle loads and axle group loads and the gross vehicle mass of the static vehicle. Furthermore other traffic data like the speed, lane of operation, date and time of passage, number and spacing of axles and the classification of each vehicle may be recorded. This chapter describes the first draft of a virtual annex to the MID with specifications for WIM-systems used in enforcement of overloading.

4.1 Existing specifications.

At this moment there are three existing international sets of specifications in the field of Weighing in Motion of road vehicles: COST 323, ASTM E-1318 and OIML R-134.

- The COST 323, the European WIM Specification [COST 323, 2002] was one of the products of the European COST 323-action 'Weigh-in-Motion of road vehicles' that ran from 1997 until 2001;
- The [ASTM E-1318, 2004] 'Standard Specification for Highway Weigh-In-Motion Systems with User Requirements and Test Methods' from the American Society for Testing Materials defines and specifies four different types of WIM-systems. The type IV systems are intended for low-speed weighing for enforcement purposes.
- The OIML R-134 [OIML, 2004] from the International Organisation for Legal Metrology is a recommendation for 'Automatic Instruments for weighing road vehicles in motion'. This recommendation is intended for use in enforcement however only for low speed weighing and weighing in restricted weighing areas (not in main roads).

The main difference between the COST323 or ASTM E1318 and the OIML R-134 requirements for accuracy assessment comes from the fact that the OIML is a Legal Metrology Organisation. As a result maximum permissible errors (mpe) are considered for the accuracy classes definition. In the COST323 and ASTM E1318 specifications the acceptance criteria are based on the estimation of the interval of confidence of the real static load for a given or specified level of confidence. However both COST 323 and ASTM E-1318 were basically intended to facilitate the relation between a buyer and a vendor in the process of testing and accepting (or rejecting) a new WIM-system. Both were not intended - and are not directly suitable - for high speed weighing for direct enforcement of overloading.

The OIML R-134 is applicable for enforcement purposes however it is limited to Low Speed Weigh-in-Motion in restricted areas. Low Speed WIM means a maximum speed of 15 to 20 km/h which reduces the dynamic effects in the vehicle. This is why a new set of specifications was necessary.

4.2 Starting Points.

The starting points for the new specifications are:

- Direct enforcement. The specifications are intended for WIM-systems that in the future will be used for the direct enforcement of overloading. Key element is that the measurements for the WIM-system will be directly used for enforcement;
- High speed weighing. This document is intended for HS-WIM (High Speed) systems, i.e. systems installed on one or more traffic lanes of a road and operated under normal traffic conditions. However, it may also be applied to LS-WIM (Low Speed) systems, i.e. systems installed in a specific weighing area, where the speed is limited and the travelling conditions of the vehicles are controlled;
- WIM-systems. This document is intended for complete WIM-systems not individual WIM-sensors or measurement techniques;

- Minimum specifications. The specifications are the minimum level necessary for the harmonisation of the international enforcement and data exchange. Each Member State may use lower specifications for national use only. When following the COPEN-24 principle for direct enforcement there is no direct need for this because a citation will be issued based on national regulations and specifications;
- Minimum specifications are essential in case of international data exchange and/or the storage of data from different WIM-systems from different countries in one central international data base. Experience in the USA during the Long Term Pavement Performance programme (LTPP) showed that without minimum specifications and data quality control the combination and interpretation of data becomes impossible;
- Functional specifications. The specifications are set up as functional or performance specifications. This means that 'only' the output and the performance of the system will be specified and no requirements for the internal processes of the WIM-systems will be given;
- Technology independent. The requirements and test are designed to be independent of the technology, measuring principle and manufacturer. This is to make sure that the specifications will not hinder any future developments in the WIM-technology.
- No specifications for location. There will be no specifications on the location were the WIM-system will be installed because this might be a limitation for future technology. However in chapter 6 a set of recommendations is given instead because experience shows that the choice of a location has an important influence on the performance of the currently available WIM-systems.
- Fixed and portable. The specifications are intended for both fixed and portable WIM-systems. However in the current situation portable WIM-systems are unlikely to qualify for direct enforcement;
- Finally the overall conditions for the preparation of these specifications were that they should be operationally usable, technically feasible and legally acceptable.

4.3 Set up of specifications

The set-up of the specifications is in line with the general organisation of the REMOVE project, were the end-user (the enforcement agencies) is leading. This means that the specifications are determined by the applications (see REMOVE Application Terms Utilised in Vehicle Weighing version 1.0) and the user requirements (see REMOVE WP1 User Requirements and Use Cases, Final version). When looking at the different applications of Weigh-in-Motion as described before the specifications can be organised in three groups:

- Enforcement without using WIM, so no specifications necessary;
- WIM for direct enforcement applications, a citation is directly based on the measurement by the WIM-system;
- WIM for other enforcement applications, the measurement by the WIM-system serves 'only' as an indication of a possible overloading.

The fundamental differences between the specifications for direct enforcement and the other applications are:

Acceptance test. For direct enforcement the acceptance test serves as the basis for the certification by a notified body. The outcome of the test determines whether the system may be used for enforcement. The certification guaranties the 'customer' (the driver/owner of an overloaded vehicle) that the WIM-system always performs within specification. For the other applications the acceptance test is an agreement between the manufacturer and the buyer (enforcement agency) on how to determine the performance of the WIM-system. In this case the 'customer' is not involved.

Certification. This has to do with the discussion what should a WIM-system measure; Axle loads or vehicle mass or both? Key of the discussion is the contradiction that on one hand axle loads and vehicle mass formally have with different (SI-) units (Newton and Kilogram) and on the other hand both axle loads and vehicle mass are measured in the same way and in daily practice the same unit (tonne) is used for both. For direct enforcement this means that for axle load measurements and for mass measurements separate certifications are necessary. For the other applications the certificate or rather the test result may cover both measurements.

Accuracy. The accuracy (δ) of a measuring system is the range around the measured value in which the actual value must lie. The accuracy is often expressed as a relative value in ± x%. The accuracy of existing enforcement systems is recorded in the NMI test certificate. For direct enforcement the accuracy is specified in a Maximum Permissible Error (mpe). In the enforcement practice, the mpe of the measuring system is deducted from the measured value. That way you are 'certain' the offender in question has in all events at least reached that corrected level. For other enforcement applications the accuracy is specified in the Average Error (μ)

Reliability. The reliability (α) of a measuring system is the chance that a measured value lies within the accuracy of the actual value. Conversely, in many cases the error probability of a measuring system is indicated. The error probability ($1-\alpha$) of a measuring system is the probability that a measured value lies further from the actual value than the accuracy. The reliability is often used by the end-user of the measurement system while error probability is generally used by the OIML and CEN.
For direct enforcement the error probability indicates the change that an unjust citation is issued. Obviously the error probability should be as low as possible and ideally 0%. However for stochastic measuring processes - like Weigh-in-Motion - this is statistically impossible. For direct enforcement the error probability is covered in the acceptance test and thus by the certification. For the other enforcement applications the reliability is specified in the Standard Deviation (σ).

4.4 User requirements

The specifications are based on the user requirements as formulated in Work package 1 of the REMOVE "User Requirements and Use Cases, Final version". A large part of the user requirements can be characterised as 'general' requirements for measurement equipment for traffic law enforcement. These systems generally have four functional blocks Measurements, Decision, Action and Settings, as shown in figure 3.1.

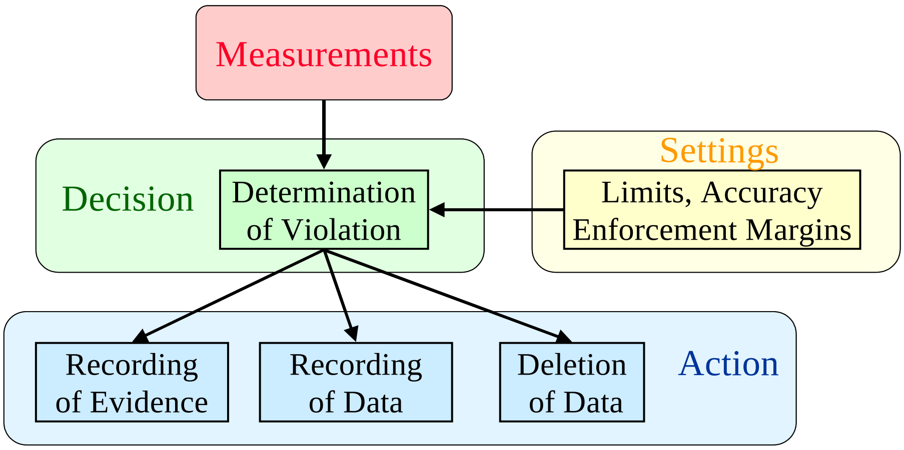


Figure 3.1, The general functional blocks

The measurements take a sample of what is happening in the out side world. Based on these measurements and some pre-set operational setting a decision is made weather or not is was a violation. Based on this decision and the application of the system a following action is initiated. As can be seen the measurements are only a relatively small part of the complete enforcement system. In case of a Weigh-in-Motion measurement this block can be divided in smaller blocks, figure 3.2.

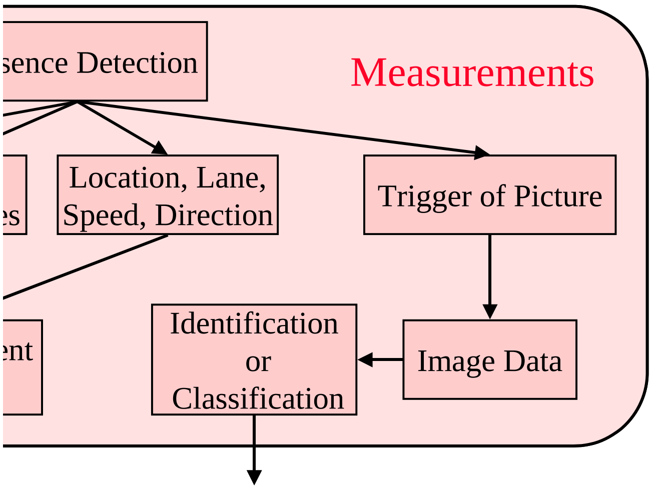


Figure 3.2, The measurement block

4.5 Specification

This specification classifies three types of WIM-systems according to their application. These specifications were determined in close cooperation with the partners of work package 3, Operational Issues.

4.5.1 Data recorded by WIM

A Weigh-in-Motion system is capable of recording the following quantities:

- Date of the recording, [day-month-year];
- Time of the recording, [hh:mm:ss];
- Location of the WIM-system including:
  - o Road number
  - o Kilometre, hectometre
  - o Direction
  - o (Nearest Town)
  - o Or a more detailed written description of the location
- Lane of passage;
- Vehicle record number;
- Number of axles on the vehicle (i);
- Axle loads of the individual axles 1 to i, [kg or tonne];
- Total vehicle weight [kg or tonne];
- Axle distances 1 to (i-1) [m];
- Length of the vehicle [m];
- Vehicle category, see appendix D;
- Speed [km/h]
- Pictures of the vehicle:

1. Overview picture of the entire vehicle that was measured;
2. Detailed picture of the licence plate (front and/or back of truck). This will not be necessary when Electronic Vehicle Identification (EVI) is generally operational in the EU.

Whether a WIM-system will actually record all these quantities depends on the application. For example: for the planning and statistics application does not require the recording of the pictures of the vehicle. The direct enforcement application may not require the determination of the vehicle category when a match with a vehicle registration data base is made based on the licence plate number.

4.5.2 Specifications per type of system

When looking at the applications three different types of WIM-systems can be distinguished, were each type has a separate set of specifications. The values mentioned in these specifications are intended to give an indication of what is currently technically possible. Also these values may serve as a starting point for the preparation of a formal EU-specification on WIM for enforcement.

Type I

Enforcement application: Statistics + Planning. Explanation; the Deviation (1σ) of x% means that on average 70% of all measurements are within ±x% of the actual value. The Deviation (3σ) of y% means that more than 99.5% of all measurements are within ±y% of the actual value.

* From an operational enforcement point view it is not necessary to have separate specifications for the measurement of axle group loads and for the axle distance. A question remains what will be the relation between the specifications for axle loads and vehicle mass, if any?

Type II

Enforcement applications: Pre-selection, Problem Solving and Intelligence.

	are*		

* Remark, Problem Solving and Intelligence also require the use of Automatic Number Plate Recognition (ANPR) software or other means of vehicle identification
** In this case for the accuracy of the measurements relative value is chosen. This could also be an absolute on, e.g. a deviation (3σ) of 50cm for vehicle length.

Type III
Enforcement applications: Direct enforcement

	0 tonnes	
	tonnes	
	re	

* Question: Should this be a ‘flat’ specification for the whole weighing range or divided into two parts like what is normal in legal metrology (OIML).
** These quantities need not to be measured when a link with a vehicle registration data base is available. Based on the identification of the vehicle all these quantities can be retrieved from the record of the vehicle in this data base.
*** This specification for the speed measurement is for non-enforcement purposes only. Otherwise the existing specifications for speed enforcement systems should be used.

4.6 Vehicle Classification

Base for the future enforcement is the possibility to recognise the trucks (to classify the vehicle class) which is a necessary parameter beside the weight data for weight enforcement.

The vehicle classification recommended here follows the method to categorise heavy vehicles devised by the Top Trial project [ref Top Trial]. The advantages of this classification method are that it is universal and flexible; all- even exotic- vehicle combinations can be classified and new vehicle types can easily be added. This method distinguishes seven main vehicle categories based on the signals from the WIM-sensors and the induction-loops.

ICLE CATEGORY		de
i-Trailer		

Table 3.1: main vehicle categories

Based on the distances between the individual axles, axle groups can be determined. If the main vehicle categories are combined with the number of axles per axle group, a vehicle subcategory can be distinguished. A subcategory is defined by a string of letters and numbers. The letter(s) denote the main category. The numbers denote the number of axles in each axle group on that (part of the) vehicle.

y	-Category	e Category	Axles	
		Semi Trailer		

Table 3.2: examples of subcategories.

To be able to analyse and exchange measurement results of different WIM-systems each vehicle subcategory can be described by means of a unique binary code. Starting point of this method is that it is possible to determine the number of axles on one vehicle, the distance between the axles and the separation between the parts of a vehicle (between Truck and Trailer, between Articulated Truck and Semi trailer, etc). Using the distance between axle's axle groups can be determined. In the figures below the procedure for the determination of the total binary vehicle code is described at two examples.

e	e	e group	e

Table C.3: binary codes for the different kinds of axle (groups)

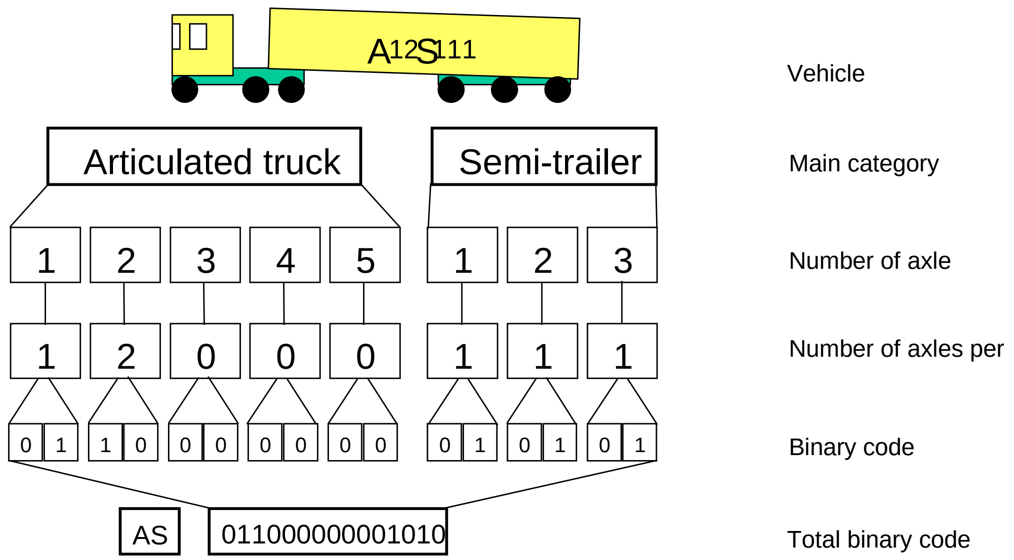


Figure 3.4. Determination of the total binary code for A12S111

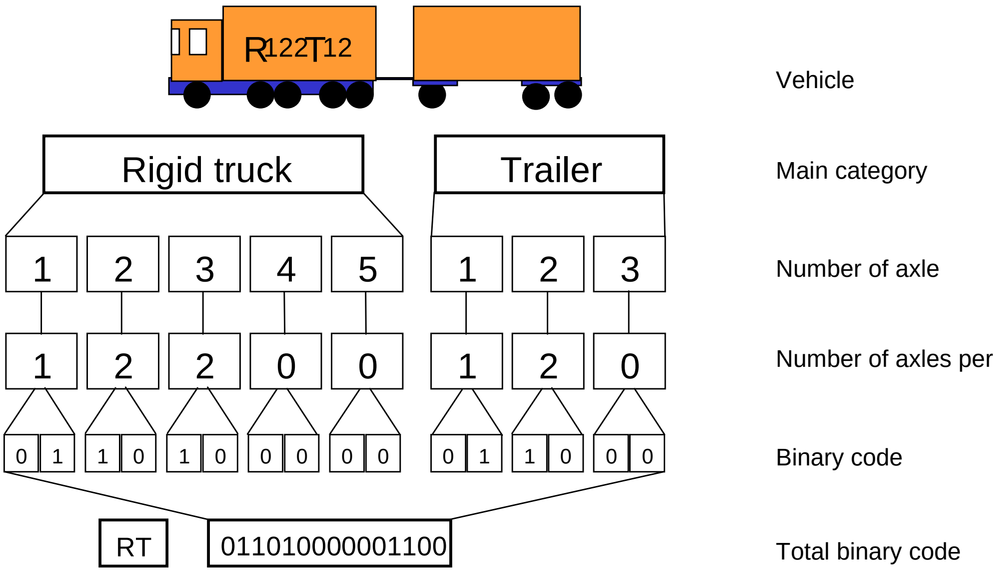


Figure 3.5, determination of the total binary code for R122T12

5 Test Procedure

This chapter describes a first draft for the test procedures necessary for the EU-acceptance of WIM-systems to be used for enforcement.

5.1 Introduction

Weigh-in-Motion is a relatively new technology in the field of traffic enforcement of overloading. In a number of EU-member states WIM-systems are currently already being used in for applications like; statistics, pre-selection and company profiling. However the ultimate application of WIM for enforcement, the direct enforcement of overloading, has not yet been used anywhere in the EU. Recent developments in France [Dolcemasculo, 1998] and the Netherlands [van Loo, 2001 and 2003] show the first large scale practical tests of Multiple-Sensor WIM-systems intended for direct enforcement. At the moment there are no national specifications for WIM-systems for direct enforcement, let alone harmonised EU-specifications. Neither are there any procedures for these acceptance tests. This document contains the first draft proposal for an acceptance test for WIM-systems for direct enforcement.

This is not the first time a test procedure for WIM-systems has been devised. However it is important to understand that because of the special nature of the enforcement applications the criteria for a good test procedure will differ from the existing procedures. Nevertheless this procedure will – as much as possible – be based on and using existing test procedures [COST 323, ASTM, OIML]. Since these specifications were never designed for direct enforcement, as a consequence not all parts of these procedures are suited for this new test procedure for enforcement applications.

5.2 Starting Points

The following starting points have been observed for the design of the acceptance test.

<u>1. Technology Independent</u>, the tests must not hinder any existing or future technology. This means for instance; no requirements for static weighing for WIM-sensors that only measure dynamic axle loads or fixed specifications for the surrounding (road) environment of the WIM-system which is important for current technology but may in the future be solved in software. During the acceptance test, the environmental conditions are recorded and a system can be accepted for these conditions or better. If, for instance, the rutting at the tested system was 4 mm, the system can be accepted for roads where the rutting is 4 mm or less.

<u>2. Static Reference</u>. In daily practice, the limits for the axle loads are interpreted as the maximum value for the static axle loads. If WIM systems are going to be used for enforcement axle load limits they will have to measure, or even better calculate, these static axle loads. In current practice, the measuring results of static axle load measurements are internationally generally accepted for enforcement. The equipment for static axle load measurements has been accepted as enforcement measuring instrument for quite some time now. For that reason, it seems logical to use the static axle load measurements as accepted reference value for the test procedure. However, for the acceptance test there will have to be strict requirements for the static weighing location (incline and slope) and the way in which the measurement must be carried out. The static reference measurement will consist of two parts:

- Measuring the total vehicle mass using a weighbridge. In the course of a test day, this measurement will be carried out several times to detect possible influence of rain, fuel consumption, etc.

- Measuring an accepted reference value for the individual axle loads of a test vehicle. This is done by repeating the static axle load measurement several times and using the average value as a reference value. The difference between the total vehicle mass and the total of these reference values must lie within the specified maximum permissible error margin. Vehicles with favourable properties will be selected for the test (configuration and suspension system). That way 'unnecessary' variation in the measured reference values will be avoided.

3. Quality assurance, to be able to be used for direct enforcement a WIM-system will have to be certified by a notified body. This certificate guarantees that the system will always be operating within specifications. In daily practice the only specification to be considered is the accuracy, since the accuracy will be subtracted from the measured value. This is to guarantee that the value used for the determination of the violation is always less than the actual value. In other words the only thing an enforcement officer needs to know is the accuracy of the WIM-system and the rest will be covered by the certificate. The accuracy of a WIM-system is closely related to the hard- and software that is used and the design and the implementation of the system.
The certificate will be issued by a notified body and is based on the results of one or more acceptance tests. The reliability basis for the certificate is the accreditations and the quality assurance programme of that notified body. The acceptance test and the necessary accreditations and quality assurance will be covered in an International standard. In the case of Weigh-in-Motion this could be the OIML or The CEN (or both).

The acceptance test will have to be based on solid experimental and scientific foundations. The content of actual acceptance test will depend on a number of things: required accuracy and reliability of the tested system and the available number of sample vehicles. The scientific base for a future acceptance test for WIM-systems for direct enforcement is described in Appendix A. The combination of all things mentioned above results in the necessary quality assurance required for direct enforcement applications.

5.3 Test Design

The purpose of an acceptance test is to be able to make a valid decision on weather a measurement system performs within specifications. The outcome of the test is the basis for the certificate that states that the system may be used for (direct) enforcement purposes. This is equal for all types of measurement systems that are used for enforcement, e.g. radar speed measurement and static axle load measurement.

The acceptance test for enforcement systems are generally based on many years - if not centuries - of practical experience. However compared to other enforcement systems the practical experience for High-Speed Weigh-in-Motion systems for direct enforcement applications is very limited. This has two consequences; first the gaining of practical experience should be part of the (first) acceptance tests. Second; based on the results of the first acceptance tests it might be possible to reduce the size of the later tests.

5.3.1 Staged Tests.

On testing HS-WIM systems, the practical limitation has to be dealt with of the maximum number of vehicles available for subsequent static weighing. In the current practice, on one inspection day the maximum of vehicles that can be weighed statically is about 30. For a specific testing day this number could possibly be doubled. A testing day requires assistance of an enforcement team, consisting of some 6 people. It is not possible to deploy an inspection team for assistance on testing for more than two weeks. All this leads to the conclusion that the practical maximum number of vehicles, also for a comprehensive test, will be around 500 to 600.

The complete acceptance test will consist of a number of tests in stages. The design of these tests is such that the results of one test are used as experience and reference for the following, smaller tests. That way a relatively small sample (i.e. a low number of statically weighed vehicles) still allows a highly reliable assessment of systems. The successive tests are shown in figure 4.1. Appendix B shows a first draft for the implementation of the various tests.

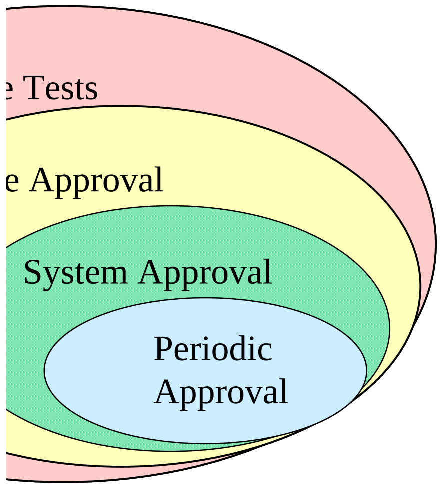


Figure 4.1, the successive tests

1. Performance Test. This is the most comprehensive test intended to obtain experience into the performance and stability of certain types of WIM systems (e.g. multi-sensor systems or bridge WIM). This test will be carried out by the manufacturer possibly in cooperation with a Government Agency and/or a National Metrological Organisation or an other type of Notified Body. This test will consist of at least four periodic tests in a year, in order to investigate the influence of temperature, the weather, wear and other long-term effects. The total number of vehicles from regular traffic for this test is about 1,200.

2. Type Approval test. This is a once-only test of a certain kind of measuring system in which the type-specific properties can be tested, which is the same for every unit. For WIM systems that includes the sensor type, the layout of the sensor array and the analysis software. The total number of vehicles from regular traffic for this test is about 300.

3. System Approval test. This test focuses on all system-specific and location-specific properties of one certain WIM system. The total number of vehicles from regular traffic for this test is about 40.

4. Periodic Approval. This verification test is intended to detect any change in the performance (drift) of the measuring system over time. Wear of the sensors and the surrounding road surface are decisive for the long-term performance of a WIM system. The periodic re-inspection could be carried out using a calibration vehicle. The frequency of this test can be determined on the basis of the results of the Type Approval Test.

5.3.2 Division of the measurement system

In order to allow the most comprehensive testing of the measuring system, the total measuring system has been divided into three parts. These parts can be tested both separately and in combination. The division is as follows.

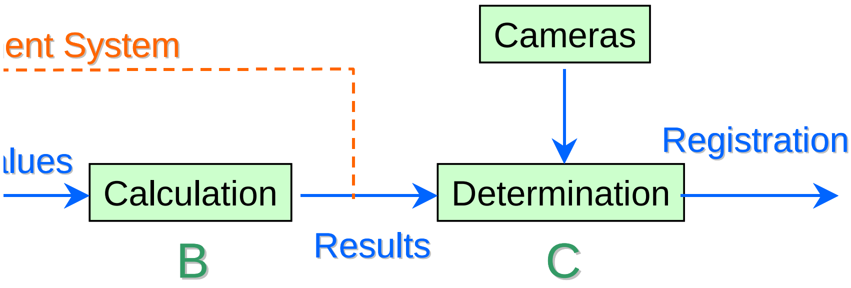


Figure 4.2. Division of the measuring system

A. Measuring. This part consists of sensors embedded in the road surface that convert the axle loads into electrical signals (measured values). The measured values consist of the axle loads measured* by the individual sensors, the time when the measurements were made, and information on what axles belong to what vehicle. * strictly speaking, the sensors measure wheel loads and the measuring system directly adds them up to axle loads;

B. Calculating. This part calculates the measuring results of the dynamic weighing from the measured values obtained from part A. The results per vehicle include: axle loads, total of axe loads, axle spacing, and speed and vehicle category.

C. Determination of the violation. This part compares the measuring results with the legal limits. In the event of a violation, the measuring results are combined with the images recorded by the cameras and stored in a registration system for further prosecution. Implementation of this part depends on national legislation and is not part of the measuring system.

5.3.3 Different Tests

As stated above, there is a practical limit to the number of vehicles that can be selected from traffic for subsequent static weighing. On the other hand, for the dependability of the test it is necessary to test as comprehensively as possible. For certain parts of the test, simulations can be used instead of field tests to solve this contradiction.

1. Simulation. The performance of parts B and C is first tested using simulations. In the test of part B the stability of the calculation software and the sensitivity to incorrect or disturbed measurements is investigated. The test of part C includes a check whether axles are combined correctly into one axle group and whether classification of the various vehicle categories is made correctly.

In the field test the performance of part A is tested in combination with part B. The practical test consists of two parts.

2. The repeatability of the dynamic measurement. Testing the repeatability is carried out by measuring two types of vehicles several times (e.g. 10 times). The dynamic measurement values must lie within a specified range around the average value. The types of vehicles used include: V11, a two-axle fixed vehicle with leaf spring system and a T11O3, a two-axle tractor with three-axle trailer, both equipped with air suspension. The test vehicles will make a number of test runs at different speeds (55, 70, 85 and 95 km/h) and at different axle loads (7.5, 10.0 and 12.5 tonnes).

3. The correctness of the dynamic weighing. The correctness is tested by taking a representative selection of vehicles from daily traffic. These vehicles are measured both dynamically and statically. Static weighing will be carried out three times, while the average

value will be taken as reference. The accuracy class for which the system can be accepted will be determined with the aid of e.g. the Tolerance Interval Method.

5.4 Calibration

The force sensors of a WIM system are installed in the road surface. In fact the combination of the road surface and the sensors forms the measuring system. A WIM system can only be calibrated accurately after the sensors have been installed in the road surface. In case of the measurement of heavy trucks traffic the environment may be described as hostile to say the least. This makes WIM-systems sensitive to wear and tear of the sensor itself and of the surrounding pavement. This means that a WIM-system once installed needs monitoring of its performance and periodic calibration. In any case a WIM-system should be recalibrated following any significant maintenance or relocation
Strictly speaking calibration is the determination of the difference (error) between the measured values and a reference value. The calibration is the basis for the verification, the process of checking if the performance of a measurement system lies within its specifications or not, and the adjustment of the system, by means of varying the offset and/or the gain in the software, in order to keep the performance within the specification. In daily practice the combination of calibration and adjustment is often also called calibration.
This paragraph describes the various ways to perform the justification and calibration.

5.4.1 Static Calibration
This is the most common method of calibration for WIM-systems. Static means that the measurements of the WIM-systems are compared to the static axle loads of a specific vehicle. The procedure is strait forward; first the axle loads of a specific vehicle are measured using static weighing scales/plates. Then the vehicle passes over the WIM-system a number of times, e.g. at different speeds. Finally the vehicle is weighed statically again to compensate for eventual changes in axle load because of fuel consumption or rain. Normally these three steps are repeated a number of times for different axle load of the vehicle and for different vehicle types. The number of runs with different speeds, different axle loads and different vehicle types depends on the intended application of the WIM-system and the available resources.

5.4.2 Dynamic Calibration
Dynamic calibration means that the axle load measured by a WIM sensor is compared with the 'actual' (dynamic) axle load at the moment an axle passes the WIM sensor. ‘Actual’ means the axle load measured at that same moment by a different reference measuring system. This reference measurement must be carried out from the passing vehicle. This means that at least one of the axles of a special vehicle must be equipped with sensors. These sensors register the force at the moment the axle in question passes a certain WIM sensor. A vehicle of which at least one axle is equipped with (force) sensors will be referred to as a (WIM) calibration vehicle.

Dynamic calibration is – so far- only used for the high speed calibration of the individual sensors of a Multiple Sensor WIM-system. High speed means that the operating range of the WIM system lies at considerably higher speeds (e.g. 50 – 100 km/h). As the name indicates a Multiple Sensor WIM-systems consist of a number (typically 4 to 16) WIM-sensors placed behind each other in the direction of the traffic. The basic idea of a MS-WIM-system is that by taking a number of samples from the dynamic behaviour of the passing vehicle the static axle loads can be estimated more accurately.

5.4.3 Automatic Calibration
Automatic calibration is processes were the WIM-system is calibrated based on the measurement of standard vehicles or standard axles. Standard vehicles are identical vehicle types with an identical load/mass, for instance the vehicles of one factory carrying a standard load. Standard axles are the axles of all vehicles that have a small variation in the load, for

instance the steering axle of trucks. The success of the automatic calibration procedure depends strongly on the distribution of the traffic at the site of the WIM-system. If it is possible to identify a group of vehicles/axles with a small variation in the mass/load then automatic calibration proves an effective procedure. For example for railway-WIM-systems the mass and axle loads of certain types of locomotives are used for calibration. The advantage of automatic calibration is that it is a continuous process where there is no need for periodic calibration or the risk that the systems perform outside specifications between calibrations.

6 External influences

6.1 Introduction

The components of the modular constructed system have to be building, that functioning of the complete system (measurement, calculation, analysis, documentation, recording etc.) is guaranteed in such a way that the components are resist against external influences. Existing EU-requirements of standardisation (e. g. 2004/22/EC for measuring instruments (MI) or EN 50081-2 for Electromagnetic Compatibility (EMC)) have been integrated into this chapter. If there are other EU-requirements for standardisation which are handling with the same components and the same influences they can be integrated into these chapters in the future.

To integrate the EU-directive 2004/22/EC for the complete measuring WIM-Systems, it would make sense, if there will be a new chapter for this kind of system into the MI-Directive (equivalent to the 2004/22/EC MI-006 chapters VI for Automatic Rail Weighbridges). At the present version of the 2004/22/EC it is only possible to take the items – which are reasonable for WIM-Systems – out of each chapter of Annex 1 (Essential Requirements) and Annex MI-006 (Automatic Weighing Instruments), although it is known that they do not apply for Traffic-WIM-Systems.

6.2 Measuring Instrument Components

Components which are necessary for functioning of a WIM-system are in detail:
- sensors for weight measurement
- sensors for speed measurement
- cameras for front- and rear-view on a vehicle (motor vehicle and trailer)
- cameras for registration of the license plate number (front/rear respectively motor vehicle license plate number / trailer license plate number)
- Lines (cables) / wireless transmission from the WIM-System to the network and its databases and to the location of control in the case of using pre-selection-mode.
- Components for selection of traffic (automatic traffic signs)

Mobile visual display units at the location of control in the case of using pre-selection-mode.

6.3 Climatic influences

Climatic influences are :
1. entering humidity into the system components,
2. humidity on the camera-objective,
3. Snow,
4. Hail,
5. Temperature,
6. Wind,
7. dust,
8. solar radiation (UV-Resistance),
9. situation of light (rain, hail, snow, fog, twilight, unfavourable solar radiation),
10. Corrosion because of salty water,

Other influences are :

11. Electromagnetic Compatibility (EMC),
12. Mechanic Load (because of wind of the passing vehicles or because of touch of chattering tarpaulins of the passing vehicles),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement.
15. Vibrations of passing vehicles

6.4 Components x Influences

Each component of the WIM-System has to assign to the a. m. external influences. At this juncture there is the possibility that several influences are not being effective to one component (e. g. dust to the component cable), up to the possibility that all external influences are being effective to one component (e. g. at the component camera). The links of components and external influences are:

Sensors of weight measurement
1. Entering humidity into the system components,
3. Snow,
4. Hail,
5. Temperature,
1. Electromagnetic Compatibility (EMC),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement.
15. Vibrations of passing vehicles.

Sensors for speed measurement:
1. Entering humidity into the system components,
3. Snow,
4. Hail,
5. Temperature,
11. Electromagnetic Compatibility (EMC),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement,
15. Vibrations of passing vehicles.

Cameras for front- and rear-view on a vehicle (motor vehicle and trailer)
1. Entering humidity into the system components,
2. Humidity on the camera-objective,
3. Snow,
4. Hail,
5. Temperature,
6. Wind,
7. Dust,
8. Solar radiation (UV-Resistance),
9. Situation of light (rain, hail, snow, fog, twilight, unfavourable solar radiation),
10. Corrosion because of salty water,
11. Electromagnetic Compatibility (EMC),
12. Mechanic Load (because of wind of the passing vehicles or because of touch of chattering tarpaulins of the passing vehicles),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement
15. Vibrations of passing vehicles.

Cameras for registration of the license plate number (front/rear respectively motor vehicle license plate number / trailer license plate number)
1. Entering humidity into the system components,
2. Humidity on the camera-objective,
3. Snow,
4. Hail,
5. Temperature,
6. Wind,
7. Dust,

8. Solar radiation (UV-Resistance),
9. Situation of light (rain, hail, snow, fog, twilight, unfavourable solar radiation),
10. Corrosion because of salty water,
11. Electromagnetic Compatibility (EMC),
12. Mechanic Load (because of wind of the passing vehicles or because of touch of chattering tarpaulins of the passing vehicles),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement,
15. Vibrations of passing vehicles.

Lines (cables) / wireless transmission from the WIM-System to the network and its databases and to the location of control in the case of using pre-selection-mode.
1. Entering humidity into the system components,
11. Electromagnetic Compatibility (EMC),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement.

Components for selection of traffic (automatic traffic signs)
1. Entering humidity into the system components,
3. Snow,
4. Hail,
5. Temperature,
6. Wind,
8. Solar radiation (UV-Resistance),
9. Situation of light (rain, hail, snow, fog, twilight, unfavourable solar radiation),
11. Electromagnetic Compatibility (EMC),
12. Mechanic Load (because of wind of the passing vehicles or because of touch of chattering tarpaulins of the passing vehicles),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement,
15. Vibrations of passing vehicles.

Mobile visual display units at the location of control in the case of using pre-selection-mode.
1. Entering humidity into the system components,
5. Temperature,
7. Dust,
9. Situation of light (rain, hail, snow, fog, twilight, unfavourable solar radiation),
11. Electromagnetic Compatibility (EMC),
13. Act of sabotage in the meaning of tampering of measured values,
14. Act of sabotage in the meaning of loss of measurement,
15. Vibrations of passing vehicles.

6.5 Test Requirements

Fixing of the test requirements:

1. Entering humidity into the system components:
Protection against infiltration of water in accordance to protection class IP 43.

2. Humidity on the camera-objective:
Protection against infiltration of water in accordance to protection class IP 43.

3. Snow:
Protection against infiltration of snowmelt in accordance to protection class IP 43.

4. Hail:
Penetration on the top of each component, which is mounted on the facility, with globes made of steel with a diameter of 5 mm and a contact speed of 100 km/h.

5. Temperature:
The Measuring Instruments have to fulfil at minimum the values of the 2004/22/EC annex 1 item “1.3.1 climatic environments”:
Upper temperature limit: + 70°C
Lower temperature limit: - 25°C.

The tests have to be done in accordance to OIML D11 Edition 1994 Annex B (Performance Tests) item B1 (static temperature).
Item B.1.1 Dry heat “Severity level 4” (70°C at an duration of 2 h)
Item B.1.2 Cold “Severity level 3” (-25°C at an duration of 2 h)
Item B.2 Damp heat (non condensing) “Severity level 2” (Temp. 40°C / Humidity 93 % rel. at an duration of 4 days)
Item B.3 Damp heat, cyclic (condensing) “Severity level 2” (max. temp. 55°C / 2 * 24 hours cycles with changing temperatures).

6. Wind:
The components which are placed near by the driving lines of a street have to be constructed and assembled in such a way, that they can withstand a wind-speed of 200 km/h. The evidence can be given by calculation or by test.

7. Dust:
Protection against infiltration of dust in accordance to protection class IP 43.

8. Solar Radiation (UV-Resistance):
In the style of ECE Regulation No. 22 Item 7.2.5 (Ultraviolet-radiation conditioning):
7.2.5.1. Ultraviolet irradiation by a 125-watt xenon-filled quartz lamp for 48 hours at a range of 25 cm.
Deviant to the a. m. test procedure the time for conditioning should be 240 hours.

9. Situation of light:
In environmental situations like rain, hail, snow, fog, twilight, unfavourable solar radiation. Should be fixed by a standard which is acting with operation of automatic cameras on public places.

10. Corrosion because of salty water:
In the style of ECE Regulation No. 22 Item 7.11.3.4:

“Place the complete mechanism in a closed cabinet so that the mechanism can be continuously wetted by a spray while still allowing free access of air to all parts of the mechanism.
Subject the mechanism to a spray of a solution consisting of 5 per cent (m/m) of reagent grade sodium chloride in distilled or deionised water for a period of 48 h at a temperature of 35 + 5 °C. Rinse the mechanism thoroughly in clean running water to remove salt deposits and allow it to dry for 24 h.”
Deviant to the a. m. test procedure the time for spraying should be 240 hours.

11. Electromagnetic Compatibility (EMC):
The Measuring Instruments have to fulfil the 2004/22/EC annex 1 item “1.3.3 Electromagnetic environments” class E2 (instruments used in locations with electromagnetic disturbances corresponding to those likely to be found in other industrial buildings) and item 1.3.4 “Other influence quantities” like voltage and frequency variation and power frequency magnetic fields.

The tests have to be performed in accordance to:

- Electromagnetic Compatibility (EMC); Based Standard emitted interference Part 2 Industrial Area (EN 50081-2 : 08.93)
- Electromagnetic Compatibility (EMC); Based Standard interference resistance Part 2 Industrial Area (EN 50081-2 : 08.93)

12. Mechanic Load (because of wind of the passing vehicles or because of touch of chattering tarpaulins of the passing vehicles):
In accordance to OIML D11 Edition 1994 Annex B (Performance Tests) item B.5 (mechanical shock)

13. Act of sabotage in the meaning of tampering of measured values:
Electromagnetic Compatibility (EMC); Based Standard interference resistance Part 2 Industrial Area (EN 50081-2 : 08.93)
In accordance to OIML D11 Annex B (Performance Tests) item B 6 (Power voltage variation).

14. Act of sabotage in the meaning of loss of measurement:
Electromagnetic Compatibility (EMC); Based Standard interference resistance Part 2 Industrial Area (EN 50081-2 : 08.93)
In accordance to OIML D11 Annex B (Performance Tests) item B 6 (Power voltage variation).

15. Vibrations of passing vehicles:
The Measuring Instruments have to fulfil the 2004/22/EC annex 1 item "1.3.2 Mechanical environments" class M2 (locations with significant or high levels of vibration and shock, e.g. transmitted from machines and passing vehicles in the vicinity or adjacent to heavy machines, conveyor belts, etc.).

The test have to be performed in accordance to OIML D11 Edition 1994 Annex B (Performance Tests) item B.4 (vibration), especially B.4.1 Random vibration with severity level 2.

7 Selection of location

7.1 Introduction

The geometric design, pavement condition of the roadway and the overall site location are influencing the performance of a WIM system. These factors influence the dynamic behaviour of the vehicle and thus the accuracy of the static weight estimate provided by the WIM system. Therefore the accuracy of a WIM system depends on its installation and environment (road) conditions, and not only on its intrinsic performances. Moreover, the vehicle characteristics, such as suspension type and performances, axle number and spacing, the Eigen frequencies and damping factors, but also the payload, the gravity centre height, etc. influence the dynamic loads, and thus the accuracy of the WIM measurements.

That is the reason why the European COST323 Specifications on WIM propose an accuracy assessment procedure of on-site WIM systems, taking into account the environmental and testing conditions, which qualify the WIM system in its real conditions of use. The North American standard ASTM E1318 intends to qualify a WIM system installed on an "ideal" and standardized test site, and is more oriented to a type approval standard. The same applies to the OIML recommendation on WIM, which only applies to LS-WIM systems.

7.2 Infrastructure Characteristics

In addition to accuracy, site characteristics can significantly affect the durability of WIM systems. Properties such as deflection and rutting clearly influence the long term integrity of the sensors in their surroundings. Deep ruts may lead to brittle sensor failure and to shocks increasing the dynamic vehicle motions and affecting the accuracy. Large deflections may lead to sensor failure by fatigue or brittle failure, but can also affect the repeatability of the measurements. Pavement cracking also generally results in sensor failure. Other site properties are specified for installation of a WIM system, such as road geometry and pavement layer thickness. Some environmental factors are also considered.

ASTM standard (ASTM, 2004) adds some specifications about the road profile: "For a distance of 46 metres before and after the sensor the roadway surface shall be maintained in a condition such that a 150 millimetre diameter circular plate 3 millimetres thick cannot be passed beneath a 6 metre long straightedge".

The COST 323 specifications (COST323, 1999) define three classes of WIM site based on rutting, deflection and evenness limits as presented in Table 1. Table 2 give indications about the accuracy class that is likely to be achievable on each site class. This is in accordance with the results of most of the tests carried out in various countries and under various pavement conditions, above all the European tests carried out in the frame of the COST323 action (Jacob et al., 2002).

of WIM sites			**ite Class**		
					)
3 m - beam)					
		n) $^{-2}$ mm)			

)		m) -2 mm)			
e)		m) -2 mm)			
		-2 mm)			
		m) -2 mm)			
l)		m) -2 mm)			

(1) *The APL is a car-towed device used to measure longitudinal profile in the short (SW), medium (MW) and long wavelengths (LW) respectively.*

The pavements should also meet the following criteria:

- No hard spots in the underlying courses or under the wearing course (toll slabs, service tunnels, etc.);
- thickness of bonded layers greater than 10 cm;
- Good mechanical bonding between courses, in particular of bituminous concrete on granular materials stabilised by hydraulic binders. The sensors must be installed in homogeneous layers, not in a joint;
- surfacing should be deterioration-free in the area of sensor installation;
- pavement should be homogeneous across each traffic lane, ruling out the presence of joints of coated materials in the length of a sensor;
- The lateral deflexion near the sensor should remain as constant as possible because the response of the sensor is deflection sensitive.
- In addition, it is necessary to know the age of the pavement to be sure that no overlay will occur for the next 3 years. It is well-know that the accuracy dramatically decreases when the sensor are recovered.

7.3 Site Location

The site needs to be located in an area with specific facilities including:

- Power and telephone network accessibility; the site should be easily linked to an AC power source and telephone network. Solar power and cellular phones can be used if power and telephone line are not available.
- It is recommended to have a road side cabinet to protect the WIM station against rainfall, snowfall, sunshine, vandalism.
- For maintenance and checking, a parking lot and safety barrier close to the system are necessary for safety reason.
- Proximity of a weighbridge or static weighing area; this facilities allows to check the WIM system's accuracy and to perform calibration. The distance between the WIM site and static weighing area must be between 3 and 10 km in order, if necessary, to have time to send the photo of the suspicious trucks to the police who are located on the static weighing area.
- It is also recommended to choose a WIM site so that the weighed trucks are not able to leave the road after passing the WIM station: It must not be possible to leave the road between the WIM site and the static weighing area.
- Adequate drainage; the site should not be located in an area subjected to flooding.

It is strongly recommended that road section between 200 m upstream and 50 m downstream of the system meets the following geometrical characteristics:

- longitudinal slope < 1% (class I site) or < 2% (other site classes), depending on the site class (table 2) and as far as possible constant;
- transverse slope < 0.5%;
- Radius of curvature > 1000 m (but a straight road would be preferred).

7.4 Traffic conditions.

Because WIM systems are expensive, it is necessary to install the sensors on road having a high density of truck in the traffic;

- The WIM systems should be installed away from any obvious acceleration or deceleration area (i.e. close to a traffic light, toll station, etc.), in order to weigh vehicles travelling at uniform speed. It is also likely to avoid the area where drivers make gear changes, such as slip-roads, etc. For this reason, it is also recommended to avoid stop and go traffic and slowly moving traffic;
- Areas with increasing or decreasing number of lanes should be avoided as this can lead vehicles to change lane; drivers must be informed before passing the instrumented lane that they must use the instrumented lane, this can be done using Variable Message Sign. When trucks are not passing on the measured lane, they can be considered as suspicious and thus a video camera should be used and the corresponding recognition plate sent to the police in order to pick up the suspicious truck from the traffic and to control it using for instance a low speed weigh in motion system.
- When trucks are passing the measured lane between the slow and fast lane, obviously, the measurement is not correct. So it is important to install an additional sensor (called also ‘on/off scale sensor’) in order to detect this incorrect measurement. However, this truck can be considered as suspicious and pick up from the traffic for enforcement control.
- Because the response of some sensors depends on the wheels lateral position on the sensor, it is recommended to avoid sites where the Lorries transverse location distribution is widely scattered, or to add a transverse location measuring system if applicable. This can be check on site with video camera or by a technician on site (observation of hundred trucks should be sufficient).
- When trucks are passing on a 2x2 lanes, because the right wheel of trucks have a tendency to pass on the hard shoulder, it is necessary that the right part (about 25 cm of the sensor) of the sensor to be installed on the hard shoulder. That means that the sensor length must be greater than 3.5 m. This is especially true for Piezo-ceramic bar sensor.
- When trucks are passing the WIM system in platoons, it is not easy, if needed, to pick up the suspicious truck by a policeman:
- After passing the WIM station, it is recommended to use a Variable Message Sign to inform the suspicious truck to leave the road and to go to the static weighing area ;
- If the driver doesn’t follow the instructions of the VMS, the vehicle must be stopped by the police, e.g. at a toll barrier. In this case, the static weighing area must be located behind the toll barrier. The distance between the toll barrier and the WIM system must be between 3 and 10 km.

8 Conclusions and recommendations

8.1 Conclusions

Conclusions:

- Weigh-in-Motion is a new technology to most of the enforcement world, offering a range of new applications for the enforcement of overloading;
- Instead of delivering a complete and internationally accepted set of technical specifications work package 2 concentrated on the set up of a structure of these specifications in line with the operational requirement that came out of WP-1 and 3;
- A standard data set for Weigh-in-Motion systems for the various enforcement applications, including an universal and flexible method for vehicle classification, has been devised. This data set is a corner stone for the future international exchange of WIM-data for enforcement;
- For the direct automatic enforcement, which is technically the ultimate application of WIM for enforcement, the structure of an acceptance test has been set up;
- A scientific bases has been given for the test procedure necessary for the acceptance of WIM-systems for direct (automatic) enforcement which is required for a legally accepted certification of the WIM-system;
- The acceptance and quality control of WIM-systems for the other enforcement applications is less strict and depend on national procedures;
- The external influences relevant for the proper functioning of a WIM-system for enforcement have been listed;
- The technical and operational criteria for the selection of a location suitable for a WIM-system for enforcement have been listed;

8.2 Recommendations

- Initiation of a workgroup/project in cooperation with the OIML/CEN on the technical standard (specifications and test procedure) for Weigh-in-Motion systems for direct (automatic) enforcement of overloading;
- Harmonisation of the specifications and quality control of Weigh-in-Motion systems for all applications except direct enforcement in the form of an EU-code of practice including international data exchange.

Appendix A, Acceptance Tests of WIM Systems

A.1. Summary of statistical terminology and definition

The measuring error (μ) is the difference between a measured value and the real value or the accepted reference:

$$\mu = W_d - W_s \tag{1}$$

Where W_d = the measured dynamic weight of a vehicle (or an axle, or a group of axles) and W_s = the corresponding real value or the accepted reference (static weight). The relative error (μ_r) is the measuring error divided by the value actually measured.

$$\mu_r = \frac{W_d - W_s}{W_s} \tag{2}$$

The accuracy (δ) of a measuring system is the range around the real value in which the actual measured value must lie. The measurement system is said to have accuracy δ if:

$$W_s - \delta \leq W_d \leq W_s + \delta \tag{3}$$

or straightforward:

$$-\delta \leq \mu \leq +\delta \tag{4}$$

The accuracy is often expressed as a relative value in ± δ %. The accuracy of existing enforcement systems is recorded in the test certificate from a notified body. In the enforcement practice, the accuracy of the measuring system is deducted from the measured value. That way you are 'certain' the offender in question has in all events at least reached that level.

The reliability (1-α) is the minimal probability of a chance that a measuring error μ lies within the accuracy interval $[-\delta, \delta]$:

$$(1-\alpha) \leq P(|\mu| \leq \delta) \tag{5}$$

where P(.) means the probability value and $|\mu| \leq \delta$ means $-\delta \leq \mu \leq +\delta$.

The error probability α of a measuring system is the probability that a measured value lies further from the actual value than the accuracy:

$$\alpha \geq P(|\mu| > \delta) \tag{6}$$

where P(.) means the probability value and $|\mu| > \delta$ means that the measuring error μ is $\mu > \delta$ or $\mu < -\delta$.

The reliability is often used by the end-user of the measurement system while error probability is generally used by the International Organisation for Legal Metrology (OIML).

The dependability (β) of an acceptance test is the probability that - on the basis of the sample - a correct judgement is given on the accuracy and reliability of the tested system:

$$P(\alpha \le P(-\delta < \mu < \delta)) \ge \beta \qquad (7)$$

The desired dependability determines the size of the sample, the higher the sample, the higher the dependability of the judgement.

A.2. Tests of normality

With respect to [Danielson, ….] the normal distribution should be expected for WIM systems because the using order statistics (distribution independent) for small sample sizes the result is fairly imprecise.

Tests for normality are important in WIM test procedures because in a lot of data analyses the data are required at least approximately normally distributed. Furthermore, the confidence limits assessment requires the assumption of normality. There are known a lot of method of tests of normality like:

- Pearson test (Chi-Square Goodness-of-Fit Test)
- Kolmogorov-Smirnov test
- Anderson-Darling and Cramer-von Mises test

All above mentioned tests for normality are based on the empirical distribution function (EDF) and are often referred to as EDF tests. The empirical distribution function is defined for a set of *n* independent observations $X_1, \dots, X_n$ with a common distribution function $F(x)$. Under the null hypothesis, $F(x)$ is the normal distribution. Denote the observations ordered from smallest to largest as $X_{(1)}, \dots, X_{(n)}$. The empirical distribution function, $F_n(x)$, is defined as

$$\begin{aligned} &F_0(x) = 0,\ x < X_{(1)} \\ &F_i(x) = i/n,\ X_{(i)} \le x < X_{(i+1)},\ i = 1, \dots, n-1 \\ &F_n(x) = 1,\ X_{(n)} \le x \end{aligned} \qquad (8)$$

Note that $F_n(x)$ is a step function that takes a step of height $1/n$ at each observation. This function estimates the distribution function $F(x)$. At any value x, $F_n(x)$ is the proportion of observations less than or equal to x, while $F(x)$ is the probability of an observation less than or equal to x. EDF statistics measure the discrepancy between $F_n(x)$ and $F(x)$. In next chapter the Pearson test (Chi-Square Goodness-of-Fit Test) will be introduced as a practical example of EDF tests.

A.2.1 Pearson test (Chi-Square Goodness-of-Fit Test)

The chi-square goodness-of-fit statistic χ_q^2 for a fitted parametric distribution is computed as follows:

$$\chi_q^2 = \sum_{i=1}^{L} \frac{(m_i - n \cdot p_i)^2}{n \cdot p_i} \qquad (9)$$

where L is number of histogram intervals, m_i is observed percentage in i^{th} histogram interval, n is the number of observations, p_i is probability of i^{th} histogram interval computed with help of theoretical distribution. The degrees of freedom for the chi-square test χ^2 is equal to *L*-*r*-1, where r is parameters number of theoretical distribution (in case of normal distribution r=2).

a) Example 1:

We have a set of 200 WIM measurements and the measured values are processed in Tab 1. The goal is to make test of normality and decide on 5% level whether the measured values could be modelled by normal distribution.

Table. A.1 Processed measured data

						2

Computed mean value is $\overline{x} = 4.3$ and the standard deviation is $\sigma = 9.71$, x_i^* is the middle of i-the interval and p_i is computed:

$$p_i = \Phi(z_{i+1}) - \Phi(z_i) \qquad (10)$$

where z_i is normalized left boundary of interval (x_i, x_{i+1})

$$z_i = \frac{x_i - \overline{x}}{\sigma} \qquad (11)$$

and $\Phi(z)$ is Laplace function that is available in statistical tables [2]:

$$\Phi(z) = \frac{2}{\sqrt{2\pi}} \int_0^z e^{-t^2/2} dt \qquad (12)$$

The chi-square goodness-of-fit statistic χ_q^2 could be given

$$\chi_q^2 = \sum_{i=1}^{9} \frac{(m_i - n \cdot p_i)^2}{n \cdot p_i} = 7.09 \tag{13}$$

with the degree of freedom equal to *6*. By using statistical table for chi-square distribution [Novovicova, 1999] the following result could be obtained:

$$\alpha_q = P\left(\chi^2 \geq \chi_q^2\right) = 0.313 \tag{14}$$

Based on statistical test we can decide that the measurement has normal distribution where decision is done on level 5%.

A.3. Estimation of mean value and standard deviation of WIM systems

The test of WIM system should cover in the first part:

- estimation of mean value based on measured data - the goal of the test is to decide whether the WIM system has bias error and the accuracy and reliability of the mean value tests (the statistical test with known standard deviation is written in chapter A.3.1 and with unknown standard deviation in chapter A.3.2),
- estimation of standard deviation based on measured data - the goal of the test is to decide which standard deviation WIM system has together with the accuracy and reliability of the standard deviation test (the statistical test is written in chapter A.3.3).

A.3.1 The estimation of mean value with known standard deviation

Assume that measuring value μ is normally distributed with the estimated mean value $\overline{\mu}$ from measured data:

$$\overline{\mu} = \tfrac{1}{n} \sum_{i=1}^{n} \mu_i \tag{15}$$

and the known variance ${\sigma_0}^2$. Then the following equation for mean value $\hat{\mu}$ could be written based on normalized normal distribution:

$$P\left(\overline{\mu} - z_{\alpha/2} \cdot \frac{\sigma_0}{\sqrt{n}} < \hat{\mu} < \overline{\mu} + z_{\alpha/2} \cdot \frac{\sigma_0}{\sqrt{n}} \right) = 1 - \alpha \tag{16}$$

where z_α is given

$$\int_{z_\alpha}^{\infty} \Phi(z) dz = \alpha \tag{17}$$

where $\Phi(z)$ is Laplace function (12).

Based on above given analyses we can decide that the mean value $\hat{\mu}$ will fall into interval $\overline{\mu} \pm z_{\alpha/2} \cdot \frac{\sigma_0}{\sqrt{n}}$ with the reliability (1-α).

Typical task in WIM evaluation process is to decide how many measurements is necessary to prove that the predefined mean value accuracy δ is achieved with the predefined reliability $(1-\alpha)$. The number of necessary measurement could be computed from (16)

$$n = \left(\frac{z_{\alpha/2} \cdot \sigma_0}{\delta} \right)^2 \qquad (18)$$

b) Example 2:

We have the normal distribution with standard deviation $\sigma_0 = 12.1$ and we estimated the mean value $\overline{\mu} = 36.38$ from sample set of n=50 measurements. The required reliability is $(1-\alpha) = 0.9$ [1]. What is the accuracy δ of the bias error of WIM system?

From statistical table [2] we can write:

$$z_{\alpha/2} = z_{0.05} = 1.645 \qquad (19)$$

and the accuracy according to (3) could be given

$$\delta = 1.645 \cdot \frac{12.1}{\sqrt{50}} = 2.815 \qquad (20)$$

then we can decide that the mean value $\hat{\mu}$ (bias error of WIM system) will fall into interval:

$$P(33.56 < \hat{\mu} < 39.19) = 0.9 \qquad (21)$$

with reliability of 90%.

c) Example 3:

We know that the standard deviation of observed data is equal to $\sigma_0 = 413$. How many measurements are necessary during WIM test of bias error to prove that the measured WIM system has the mean value accuracy $\delta = 15$ with the reliability 95%?

From equation (18) we can compute:

$$n = \left(\frac{z_{\alpha/2} \cdot \sigma_0}{\delta} \right)^2 = \left(\frac{1.96 \cdot 413}{15} \right)^2 = 2912{,}26 \approx 2913 \text{ samples} \qquad (22)$$

A.3.2 The estimation of mean value with unknown standard deviation

Assume that we have normally distributed set of n measurements with the estimated mean value $\overline{\mu}$ and estimated standard deviation value s from measured data:

$$\overline{\mu} = \tfrac{1}{n} \sum_{i=1}^{n} \mu_i$$
$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (\mu_i - \overline{\mu})} \qquad (23)$$

than the following equation for mean value $\hat{\mu}$ could be written based on t-distribution:

$$P\left(\overline{\mu} - t_{\alpha/2} \cdot \frac{s}{\sqrt{n}} < \hat{\mu} < \overline{\mu} + t_{\alpha/2} \cdot \frac{s}{\sqrt{n}} \right) = 1 - \alpha \qquad (24)$$

where $t_{\alpha/2}$ is value from Student t-distribution with *n*-1 degree of freedom. This value is available in statistical tables [Novovicova, 1999].

[1] It means 90% reliability

Based on above given analyses we can decide that the mean value $\hat{\mu}$ will fall into interval $\overline{\mu} \pm t_{\alpha/2} \cdot \frac{s}{\sqrt{n}}$ with the standard deviation reliability (1-α).

The number of necessary measurement for the proof of predefined standard deviation accuracy δ with the predefined reliability $(1-\alpha)$ could be computed from (24)

$$n = \left(\frac{t_{\alpha/2} \cdot s}{\delta} \right)^2 \tag{25}$$

but the value $t_{\alpha/2}$ is dependent on *n* (degree of freedom is *n*-1) so the number of necessary measurement *n* must be computed numerically.

d) Example 4:

We have measurements of mean value and standard deviation $\overline{\mu} = 450, s = 30$ obtained from n=30 samples. We need to find the accuracy δ of mean value with the reliability of 99%.
We can find that $\alpha = 0.01$ and than from statistical tables [Novovicova, 1999] $t_{0.005} = 2.756$ (the degree of freedom is 29). The accuracy δ of mean value with the reliability of 99% is based on the statistical test equal to 15.092.

A.3.3 The estimation of standard deviation

Assume that we have normally distributed set of n measurements with the estimated standard deviation value s from measured data:

$$\overline{\mu} = \tfrac{1}{n} \sum_{i=1}^{n} \mu_i$$
$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (\mu_i - \overline{\mu})} \tag{26}$$

than the following equation for standard deviation $\hat{\sigma}$ could be written based on χ^2-distribution:

$$P\left(\frac{n-1}{\chi^2_{\alpha/2}} \cdot s^2 < \hat{\sigma}^2 < \frac{n-1}{\chi^2_{(1-\alpha/2)}} \cdot s^2 \right) = 1 - \alpha \tag{27}$$

where $\chi^2_{\alpha/2}, \chi^2_{(1-\alpha/2)}$ are values from χ^2-distribution with n-1 degree of freedom. This value is available in statistical tables [Novovicova, 1999][2].

Based on above given analyses we can decide that the variance of measured data $\hat{\sigma}^2$ will fall into interval $\left(\frac{n-1}{\chi^2_{\alpha/2}} \cdot s^2, \frac{n-1}{\chi^2_{(1-\alpha/2)}} \cdot s^2 \right)$ with the reliability (1-α).

[2] In tables [Novovicova, 1999] the χ^2_α means the probability (α, ∞) but in other tables or approximation equation (38) it means interval $(0, \alpha)$. The transformation is simple.

e) Example 5:

We have measurements of n=12 values from which the standard deviation was computed $s = 0.047$. We need to find the interval of variance $\hat{\sigma}^2$ with reliability of 95%.
The degree of freedom is 11 and the values $\chi^2_{0.975} = 3.816, \chi^2_{0.025} = 21.920$ were fond from statistical tables. The variance $\hat{\sigma}^2$ will fall into interval (0.033,0.080) with reliability of 95%.

A.4. Equation for accuracy, reliability and dependability

A.4.1 Known mean value and standard deviation

We can start with the equation [Jilek, 1998]:

$$P\left\{P\left[\mu_0 - z_{(1-\alpha/2)} \cdot \sigma_0 \leq \mu \leq \mu_0 + z_{(1-\alpha/2)} \cdot \sigma_0\right] \geq (1-\alpha)\right\} = 1 \qquad (28)$$

where μ is measured value, μ_0, σ_0 are known mean value and standard deviation and $z_{(1-\alpha/2)}$ is percentile of normal distribution (e.g. for $\alpha = 0.05$ we can find in statistical table $z_{0.975} = 1.96$)
.

Based on the (28) we can decide that accuracy $\delta = z_{(1-\alpha/2)} \cdot \sigma_0$ is guarantied with reliability $(1-\alpha)$. Because the mean value and standard deviation are known the dependability $\beta = 1$.

A.4.2 Known standard deviation and unknown mean value

Now we expect that the mean value is estimated according to (15). Than we can write equation [Jilek, 1998]:

$$P\{P[\overline{\mu} - k \cdot \sigma_0 \leq \mu \leq \overline{\mu} + k \cdot \sigma_0] \geq (1-\alpha)\} = \beta \qquad (29)$$

where *k* is computed from following equation:

$$\Phi\left(\frac{z_{(1+\beta)/2}}{\sqrt{n}} + k\right) - \Phi\left(\frac{z_{(1+\beta)/2}}{\sqrt{n}} - k\right) = 1 - \alpha \qquad (30)$$

where function Φ was defined in (12). Based on equation (29) we can say that for predefined values of reliability $(1-\alpha)$ and dependability β and the number of measurements *n* the accuracy will be $\delta = k \cdot \sigma_0$.

A.4.3 Known mean value and unknown standard deviation

For known mean value and unknown standard deviation we can write the equation:

$$P\left\{P\left[\mu_0-\left(z_{(1-\alpha/2)}\cdot\left(\frac{n}{\chi^2_{(1-\beta)}(n)}\right)^{\frac{1}{2}}\right)\cdot s\le\mu\le\mu_0+\left(z_{(1-\alpha/2)}\cdot\left(\frac{n}{\chi^2_{(1-\beta)}(n)}\right)^{\frac{1}{2}}\right)\cdot s\right]\ge(1-\alpha)\right\}=\beta \qquad (31)$$

where s is estimated according to (26), $\chi^2_{(1-\beta)}(n)$ means chi-quadrate distribution with *n* degree of freedom.

Based on equation (31) we can say that for predefined values of reliability $(1-\alpha)$ and dependability β and the number of measurements *n* the accuracy will be:

$$\delta=\left(z_{(1-\alpha/2)}\cdot\left(\frac{n}{\chi^2_{(1-\beta)}(n)}\right)^{\frac{1}{2}}\right)\cdot s \qquad (32)$$

A.4.4 Unknown mean value and standard deviation

This variant is the most important one for practical WIM measurement but the solution is theoretically very difficult. But fortunately a lot of approximation forms exist based on which the practical simulation were done at CTU. The presented approximations were tested and are feasible for practical use.

We start by task description

$$P\{P[\overline{\mu}-k\cdot s\le\mu\le\overline{\mu}+k\cdot s]\ge(1-\alpha)\}=\beta \qquad (33)$$

where mean value $\overline{\mu}$ and standard deviation *s* are estimated from *n* samples according to (26).

Howe [Howe, 1969] defines the very simple approximation form for k:

$$k\approx\left(\frac{n+1}{n}\right)^{\frac{1}{2}}\cdot z_{(1-\alpha/2)}\cdot\left(\frac{n-1}{\chi^2_{(1-\beta)}(n-1)}\right)^{\frac{1}{2}} \qquad (34)$$

Bowker [Bowker, 1946] defines:

$$k\approx z_{(1-\alpha/2)}\cdot\left[1+\frac{z_\beta}{\sqrt{2n}}+\frac{5\cdot z_\beta^2+10}{12n}\right] \qquad (35)$$

Ghosh [Ghosh, 1980] defines next approximation form:

$$k\approx z_{(1-\alpha/2)}\cdot\left(\frac{n}{\chi^2_{(1-\beta)}(n-1)}\right)^{\frac{1}{2}} \qquad (36)$$

If take approximation forms for z_x for x>0.5 [Novovicova, 1999][3]:

[3] the approximation error is not greater than 0.003

$$z_x = u_x - \frac{2.30753 + 0.27061 \cdot u_x}{1 + 0.99229 \cdot u_x + 0.04481 \cdot u_x^2}$$
$$u_x = \left[\ln(1-x)^{-2}\right]^{\frac{1}{2}} \qquad (37)$$

and for $\chi_x^2(\gamma)$ [Jilek, 1988][4] (the number of degree of freedom is usually $\gamma = n - 1$):

$$\chi_x^{\prime 2}(\gamma) = \gamma + z_x \cdot \sqrt{2} \cdot \gamma^{\frac{1}{2}} + \frac{2}{3} \cdot \left(z_x^2 - 1\right) + \frac{1}{9\sqrt{2}}\left(z_x^3 - 7 \cdot z_x\right) \cdot \gamma^{-\frac{1}{2}} - \frac{1}{405}\left(6 \cdot z_x^4 + 14 \cdot z_x^2 - 32\right) \cdot \gamma^{-1} +$$
$$+ \frac{1}{4860\sqrt{2}} \cdot \left(9 \cdot z_x^5 + 256 \cdot z_x^3 - 433 \cdot z_x\right) \cdot \gamma^{-\frac{3}{2}} \qquad (38)$$

the analytical equation for estimation of accuracy δ based on estimated mean value and standard deviation based on n sample data with the predefined reliability $(1-\alpha)$ and dependability β can be computed.

The more simple approximation form but with not so good approximation error could be fond in [Jilek, 1988]:

$$\chi_x^{\prime 2}(\gamma) = \frac{1}{2} \cdot \left[z_x + (2 \cdot \gamma - 1)^{1/2}\right]^2 \qquad (39)$$

f) Example 6:

How does the accuracy δ of WIM system depend on the number of measurement during the acceptance test if the standard deviation was computed through (23) and predefined parameters of reliability and dependability are:

a) $\alpha = 0.3, \beta = 0.5$

b) $\alpha = 0.05, \beta = 0.99$

From (33) the accuracy δ of WIM system is given $\delta = k \cdot s$. For finding the parameter *k* the equations (34), (37) and (38) was used. The Fig 1 and Fig 2 show the dependence of parameter *k* on number of measurements for both cases (a,b).

[4] for $x \in \langle 0.01, 0.99 \rangle$ and $\gamma \geq 20$ the absolute error of approximation is not greater than 0.001

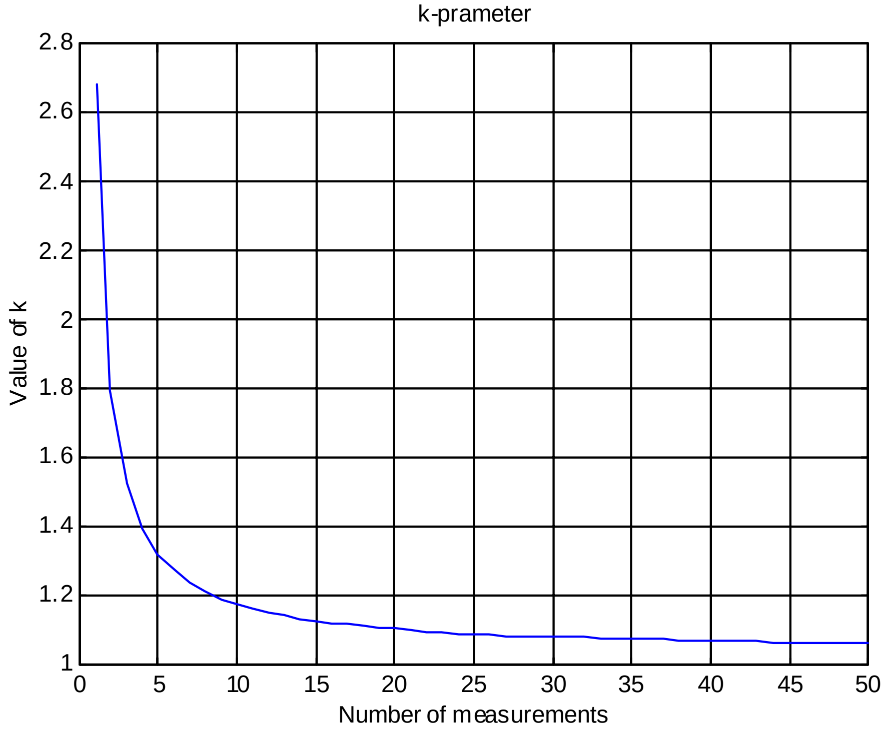


Fig. A.1 Dependence of parameter k on number of measurements $(\alpha = 0.3.\beta = 0.5)$

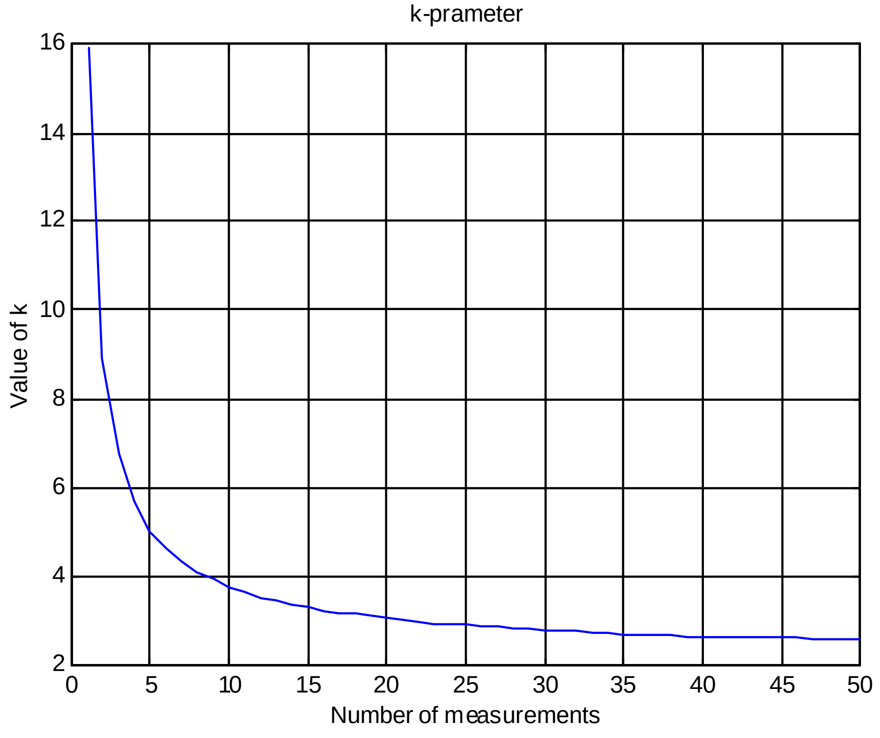


Fig. A.2 Dependence of parameter k on number of measurements $(\alpha = 0.05.\beta = 0.99)$

g) Example 7:

Could the results from example 6 be proved by simulation if number of measured values is n=30?

For both cases a) $\alpha = 0.3, \beta = 0.5$ b) $\alpha = 0.05, \beta = 0.99$ the values of *k* were found in Fig.A.1 and Fig.A.2 respectively a) k=1.0584, b) k=2.797.

In MATLAB the set of 1000 samples of normal distribution with zero mean and standard deviation equal to one was generated. From first 30 samples the mean value and standard deviation was estimated (26). Than the interval $(\overline{\mu} - k \cdot s, \overline{\mu} + k \cdot s)$ was selected in accordance to (33) and the probability of falling into interval was computed from whole set of 1000 samples (it is procedure to compute the reliability).

The procedure described above was repeated 5 000 times and the probability of exceeding the predefined reliability limit was computed (it is test of dependability).

The obtained results for dependability through simulation could be summarized:

a) $\beta = 0.447$

b) $\beta = 0.0136$

The test was repeated many times and the predefined parameters for reliability and dependability were achieved in all experiments.

Appendix B, Description of Acceptance Tests

This table has shown an example of the content of the staged acceptance tests. The numbers indicate the number of runs with those settings. The total number of runs gives an indication of what is necessary for the acceptance of WIM-systems for direct enforcement.

Test-vehicl			**Perf. Tests**	**Type Appr.**	**Syst Appr.**	**Per. Appr.**
V11			x	x	?	?
V12A11			x	x		
T12O4 (Instrumented vehicle)			x	x	x	x
T11O3			x	x	?	
Per type of test-vehicle						
Speed	Axle Load	Special				
70	7,5		20	5	0	0
	10		20	5	1	1
	12,5		20	5	1	1
	15		20	5	0	1
85	7,5		40	10	4	1
	10		40	10	5	1
	10	Only right wh	20	5	1	0
	10	Only left whe	20	5	1	0
	10	Braking	40	10	1	0
	12,5		40	10	5	1
	15		40	10	4	1
100	7,5		20	5	0	1
	10		20	5	1	1
	12,5		20	5	1	1
	15		20	5	0	0
Total			**400**	**100**	**25**	**10**
Type of veh		Perc. of Tot				
R11		10	120	30	4	0
R12		5	60	15	2	0
R22 or R1111		5	60	15	2	0
A11S1		5	60	15	2	0
A11S2		20	240	60	8	0
A11S3		40	480	120	16	0
RxxT11		5	60	15	2	0
RxxT12		5	60	15	2	0
Other		5	60	15	2	1
Total		**100**	**1200**	**300**	**40**	**1**

**** Dutch situation***

Appendix C, References

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