Methodology for WIM

Data Quality Management

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1 Introduction

1.1 Weigh-In-Motion

Weigh-In-Motion is the technique to measure the dynamic axle loads of moving trucks and from these to calculate the static axle loads when the vehicle is static. A WIM system consists of a number of sensors that are installed in − or under - the road pavement. The sensors measure the forces that each individual axle or wheel 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. Most WIM systems also measure information on the passage of the vehicle (date, time, road, lane, direction) and on the vehicle (number of axles, axle distances, type/class of vehicle, speed, temperature).

The force of the wheels of a truck on the road surface (the dynamic 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 periodic signals. The first is the dynamic force as a result of the 'body-bounce', the rocking/rolling motion of the whole vehicle. The second is the dynamic force as a result of the 'axle-hop', the hopping motion of the individual axles. In the case of heavily loaded trucks with modern, pneumatic suspension systems, the effect of the axle-hop is generally negligible in relation to that of the body-bounce.

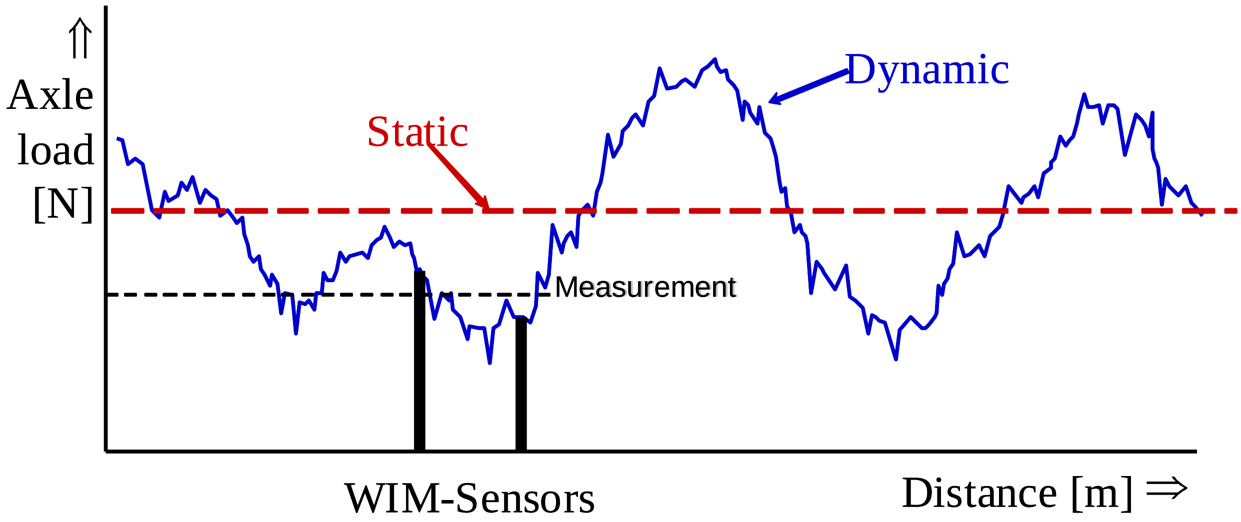

Figure 1: Measuring dynamic axle loads

The performance of a WIM system is not only influenced by the quality of the WIM-sensors but also the geometric design, pavement condition of the road pavement and the environmental conditions at the location of the site. 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. Also the vehicle characteristics, such as suspension type and performances, axle number and spacing, but also the payload, the gravity centre height, etc. influence the dynamic loads, and thus the accuracy of each individual WIM measurement. For most applications (e.g. statistics on traffic loading) the average accuracy of all measurements is more important than that of each individual measurement (only for direct enforcement).

The different applications of WIM systems can be divided into three groups; Statistics on traffic loading, weight enforcement and toll collection by weight. For the two network of WIM systems in Brazil PNCT and PIAF only the first two are relevant and will be described in further detail.

1.2 Statistics on traffic loading

A network of WIM systems will collect detailed and comprehensive information on the traffic flow and the actual traffic loading. This information can be used for several applications:

Input for transport policy; a strong economic development requires an adequate road infrastructure and an efficient transport system. Investments in new or extended roads are very expensive, long term and normally irriversible decisions. The road policy and plans begin with a comprehensive evaluation of the current traffic situation and a prediction of the developments for the future. Monitoring the actual traffic conditions over time using WIM will generate essential information for an economic road and transport policy.

Input for Design Codes, authorities responsible for the construction of roads and bridges need realistic information on the traffic flow and loading. The damage to the road pavement is related to the fourth-power of the passing axle loads, whereas the damage to the bridges is related to the total vehicle weight. The history of the actual traffic loads measured by a WIM system are an important input for design codes for new road pavements and bridges. (Equivalent Single Axle Loads).

Planning of road maintenance, only a WIM is capable of measuring the actual pavement loading. This information can be used to calculate the remaining operational life of the elements in the road infrastructure, both pavements and bridges. Experience has shown that well planned preventive maintenance will avoid further deteriation of the roads and more costly repairs later on. With the information from WIM systems the planning of maintenance activities and budgets can be optimised and therefore optimize public spending.

1.3 Weight enforcement

WIM data stored in central data base / Per transport company / Based on number plate / Analysis of records / Calculation of road damage / Number of evasions / Results in 'Top 100' Enforcement action / Warning letter / Company visit / Suspended penalty/ Monitor behaviour

Statistics and Planning, in this case the data measured by a network of WIM-systems is stored in a central data base. The measured data does not contain any identification of the individual vehicles. The measured data will include the axle loads, vehicle weight, vehicle category, speed, location, time. This data 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.

Enforcement agencies can use these overviews 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.

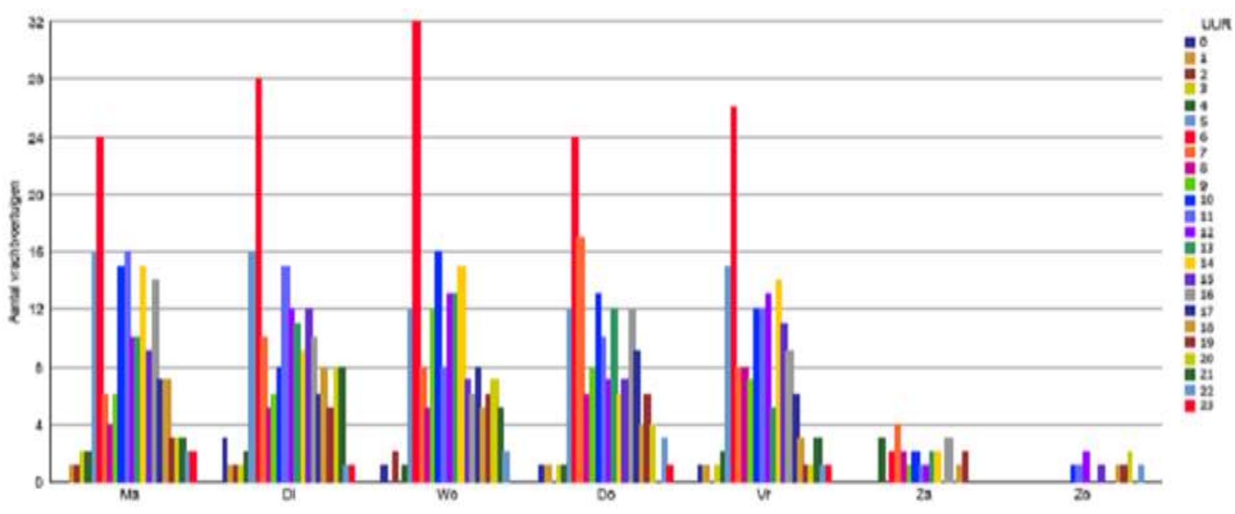

Figure 2: Overview of overloaded trucks in a week

Pre-selection, here a WIM-system is used to select potential overloaded vehicles. The WIM-system will only give an indication that a vehicle is probably overloaded, the measurement that is legally required for enforcement is carried out by a second system further down stream. This second system could either be a static weighing system or a Low Speed WIM-system depending on national regulations. The measurements and the pictures of the WIM system can not directly be used as evidence in legal procedures.

The advantages of using WIM for pre-selection is an increase of the hit-rate of stopping trucks that are actually overloaded to more than 95% while almost no correctly loaded vehicles are stopped. However the effect of the controls is limited to the area around WIM-system and it is sensitive to evasion of WIM-site by overloaded trucks

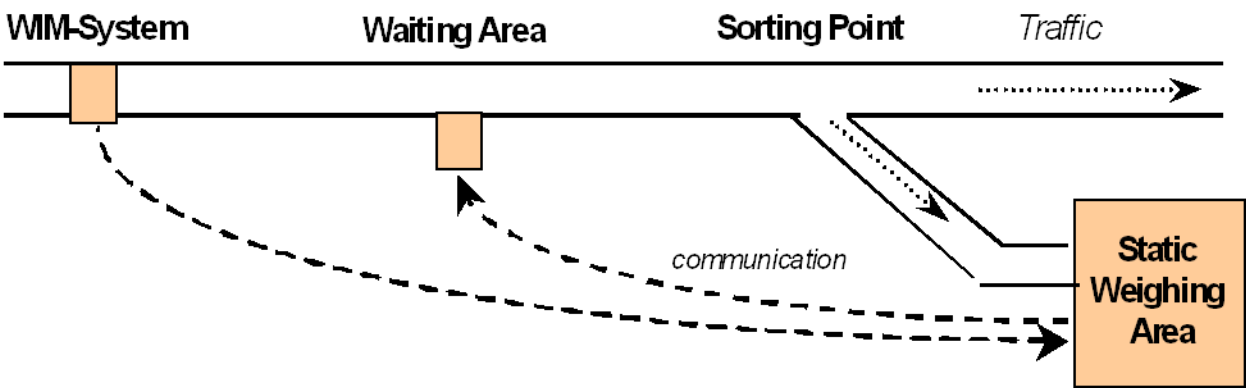

Figure 3: Pre-selection using WIM

Company Profiling, in this case a network of WIM-systems stores all measured data, including the pictures of the vehicle and licence plate number, 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 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 will start with sending a letter warning a company that in the last period a number of overloading violations have been detected. During the following in company visit 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.

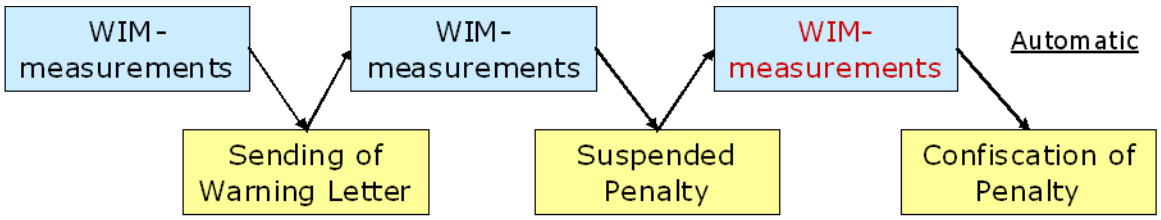

Figure 4x: Procedure of company profiling

In case the data measured by the WIM-system will be used as a basis for further legal action a certified data quality management is required. Advantages of the company profiling approach are that the all enforcement activities are focussed on 'problem' companies resulting in a very efficient use of enforcement recourses. Secondly this approach is aimed at increasing the compliance with loading regulations instead of 'just writing tickets' which result in good cooperation of most transport companies.

Direct Enforcement, means that the (evidence for the) prosecution of an overloaded vehicle is directly based on the measurement by a weighing system. The procedure from the WIM measurement to legal prosecution can be completely automated and is similar to that of automatic speed enforcement. 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.

Direct enforcement combines a high efficiency (wit a hit rate > 99% and operational 24/7) with a high effectiveness (a small number of enforcement personal required). This makes it specially suitable for highways very high truck volume. Disadvantage is that in almost all countries current WIM systems are not legally certified for direct enforcement.

1.4 Why enforcement

An effective weight enforcement will result in a significant reduction of the number of overloaded vehicles and the severity of their overload and consequently a reduction of the negative effects of overloading.

Reduced damage to roads and bridges, overloaded trucks have a major impact on the quality of the road infrastructure. Resulting in serious pavement damage, like cracking and rutting, and increased bridge fatigue damage. The pavement damage is calculated from the sum of the axle loads to the fourth-power, which means that one overloaded truck has the same impact as 200.000 person cars. Overloaded trucks reduce the operational lifespan of the road infrastructure forcing earlier and more extensive maintenance. A reduction in overloading means a reduction of the costs for maintenance of the roads. At the same time it will result in an improved quality of the entire road network with fewer disruptions because of road maintenance works.

Figure 5: Severe rutting in road pavement

Increased traffic safety, overloaded trucks are more likely to be involved in an accident and cause more severe damage that legally loaded trucks. They have longer braking distances, reduced stability and reduced vehicle control, resulting in a higher risk for accidents. In case of an accident, an overloaded truck will have a bigger impact on the other road users and will usually result in more serious damages and casualties. Experience from enforcement agencies shows that in many cases overloaded trucks also violate other traffic regulations such as exceeding the maximum driving hours. A reduction of overloading by heavy vehicles will result in a reduction in the number and severity of the accidents on the roads.

More fair competition in transport, using overloading severely interferes with the principle of fair freight transport among different modes of transport like road, rail and water, as well as among road transportation companies. The illegal use of overloaded trucks enables companies to run fewer trips or use cheaper vehicles leading to lower costs and higher profits. This gives such companies an unfair advantage over companies operating correctly loaded vehicles which may have to end their operation. A reduction of overloading will result in a more equal playing field among transport companies and stronger position of legally operation companies.

1.5 Why Data Quality Management

Data quality management is defined as the combination of checks, procedures and activities necessary to guarantee the minimum quality of WIM data. The WIM data may be used by different users as input for different applications or studies. Following the rule of "Garbage in = Garbage out" the quality of any application or study is as good – or bad – as the quality of its input. In case of WIM data because of wear and tear on the system its quality is often unknown which makes the results of the application questionable at best.

In case of the application for the design of new roads and bridges both over- and under dimentioning of new designs because of incorrect loading data will result in a waste of public resources. Developing a future transport policy or making a planning for road maintenance works makes no sense when it is based on questionable loading information. Even if the input data is not necessary wrong, the fact that the quality of the data is not known makes the output result questionable. This is simply not good enough when considering the huge budgets involved in the construction of new roads or the maintenance of existing ones is involved.

When the WIM data is used for the enforcement of overloading and when used especially for company profiling the quality of the WIM data is essential. Without good quality data it will be impossible to make useful company profiles, make the selection of the most overloaded ones and use the registrations for further prosecution.

A proper data quality management is only possible through a combination of; high quality measurement systems (both static and WIM), accepted procedures for: measurements, maintenance, IT and enforcement and the right organisation of people, responsibilities and means.

2 Data quality management

This chapter will describe the general structure of the data quality management system for WIM data in Brazil. The relations will be described between different parts of the DQM and the network of WIM systems and application of the data. To be able to give an overview of the structure and relations in DQM the description will be a simplification of reality.

2.1 Structure

The objective of the DQM system is to allow the end-users to use WIM data without worries about the quality of the data they are using and consequently about the quality of the results of their calculations, research, analyses, reports, etc. The data from the network of WIM systems will be collected in a central data base and the end-users only want to use 'good-data'. ,It may be possible that different users will have different criteria for the quality of the data, some applications may required 'better' data than others. For now only one quality level will be assumed.

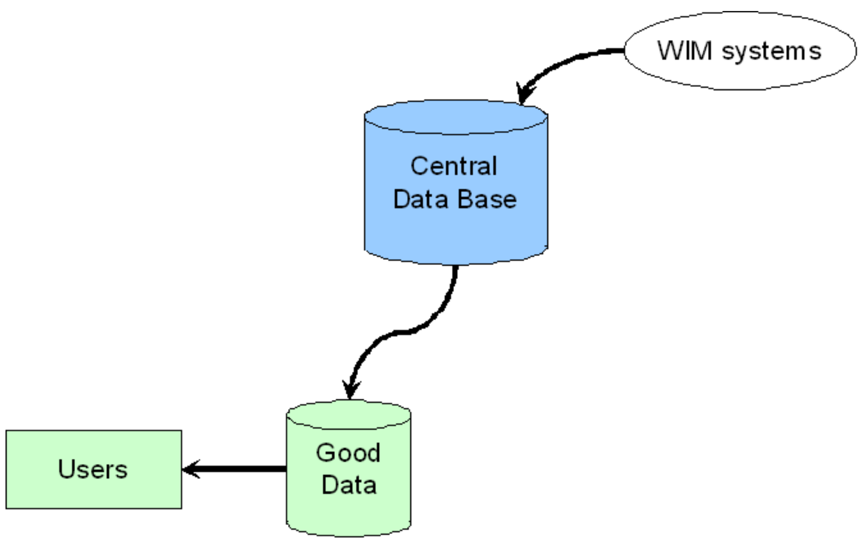

Figure 6: End-users want to use good data only.

It is the purpose of the DQM system to guarantee that only good data is provided to the end user. This may mean that some of the measured data will not be made available to the end users because its quality is considered insufficient. The Data quality management has a direct relation with the Quality Checks that distinguish between 'Good' and 'Bad' data, with the 'Bad data' itself to determine the reasons for this and with the maintenance of the WIM systems.

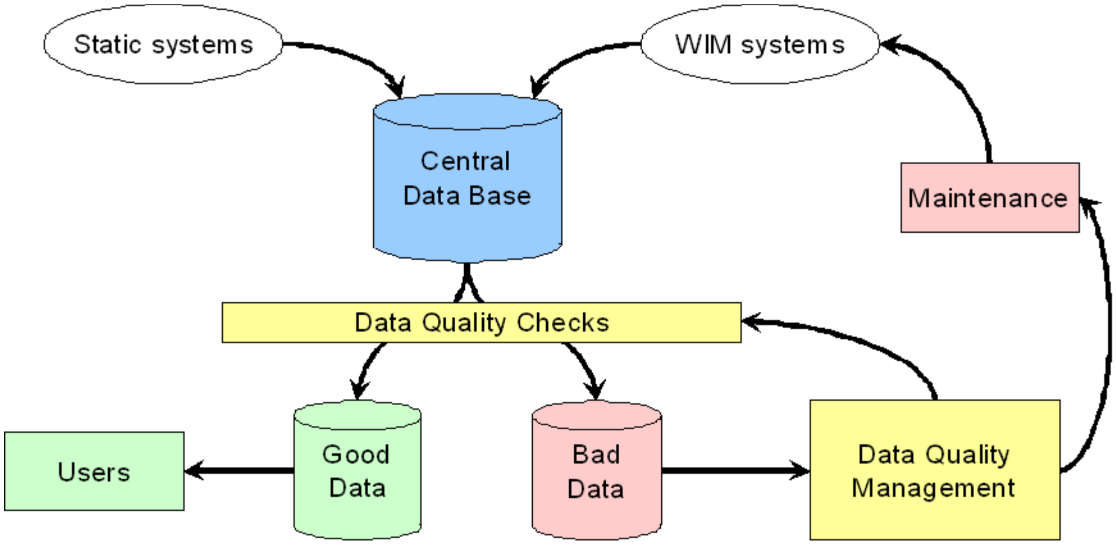

Figure 7: Relations with data quality management.

The five main activities of the data quality management are:

1. Performing the quality checks on all WIM data;
2. Analysis the problems with the bad data;
3. Analysis of the maintenance records of the WIM systems involved;
4. Advising on the maintenance (and calibration) of the WIM systems and;
5. Development of better quality checks.

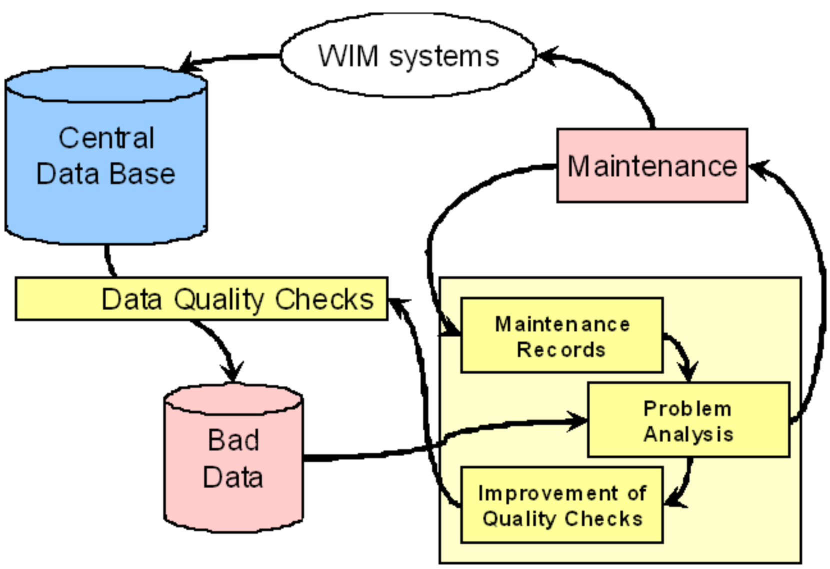

Figure 8: Activities of the data quality management

2.2 Procedures

To be able to guarantee the quality of the data for the end user the activities in the data quality management should be well described in certified procedures. Also all other activities of all other elements in the collection, storage and use of the WIM data should be well described in certified procedures. procedures. If only one of the activities is not well described it means that the quality of the end result cannot be guaranteed, hence all is for nothing. In reality some activities / processes may be more critical for the quality of the data used by the end user. For now all activities/procedures are considered of equal importance, hence need to be described well.

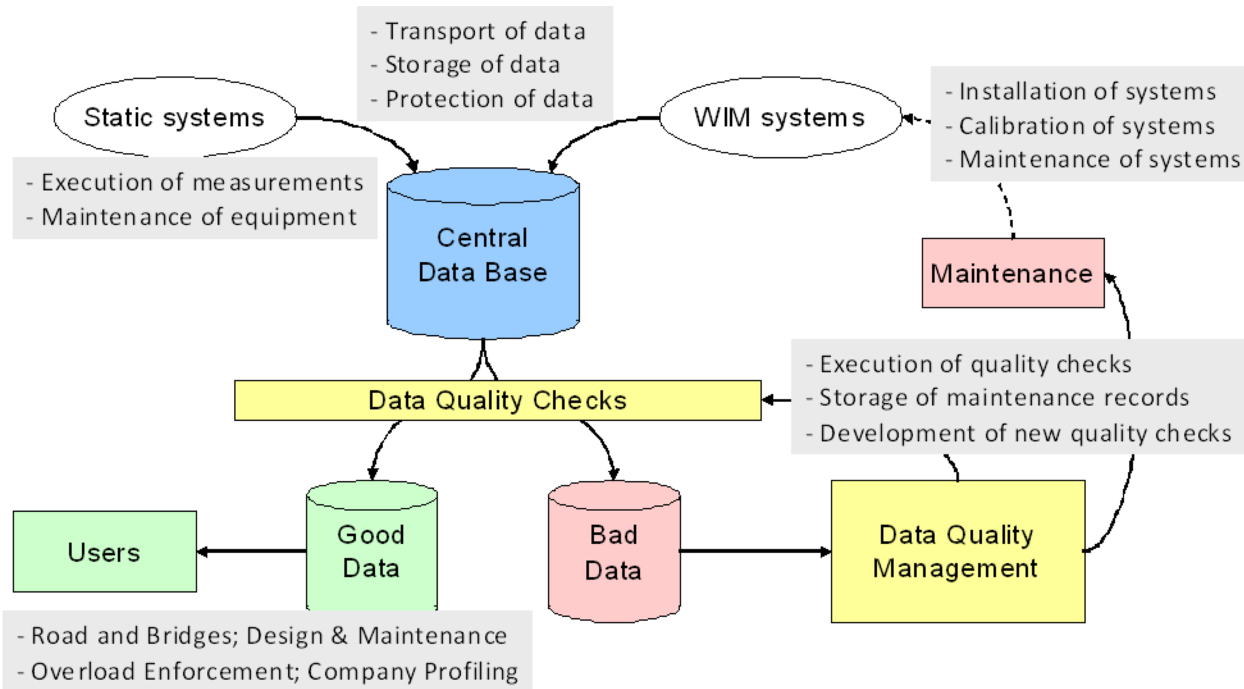

Figure 9: Procedures in and around data quality management

Other activities that need to be well described in formal procedures are:

- The execution of the weight measurements with the static (or low speed WIM) weigh bridges by the enforcement agencies;
- The maintenance and calibration of the static weigh bridges;
- The transport of the measured data − both WIM and static − from the measurement sites to the central data base;
- The storage of the measured data in the central data base, the access to the data and the protection of the data;
- The way the WIM data is used in design codes for new roads and bridges and in the planning of maintenance of existing ones;

- The way the WIM data is used for enforcement, how are the company profiles determined and how is this information used in the prosecution of violators.

2.3 Organisation

A critical aspect of the whole data quality management methodology is the organisation of the various activities and responsibilities over the organisations involved. This involves both the organisation of activities within the area of responsibility of one of the organisations and the cooperation between the different organisations (especially the exchange of information). In this document three different areas of responsibility are distinguished. In reality the organisation will probably be more complex with more organisations involved with partial responsibilities. It is important that there will always be one organisation that has the overall responsibility of each of the three area and one that is responsible for the process as a whole. The three areas of responsibility are:

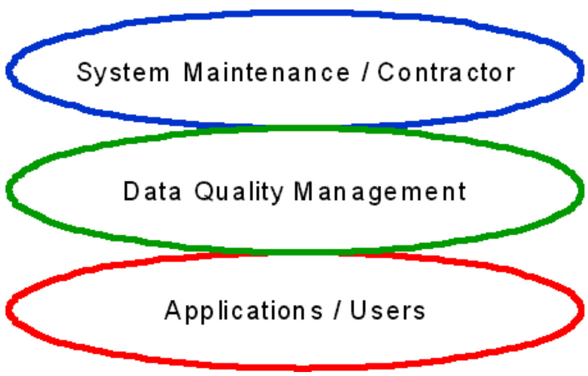

Figure 10: Three main responsibilities

- In blue, the maintenance and replacement of the measurement systems (both static and WIM) and the technical infrastructure of the data collection (communication and data base). This would typically be a responsibility of a contractor;
- In green, the core of the data quality management with the execution and development of quality checks, problem analysis and advice for maintenance. This would be typically be a responsibility of an independent specialised institute;
- In red, the use of the WIM data for various applications by different end users. This is typically the responsibility of DNIT both for design and maintenance of infrastructure and enforcement of overloading.

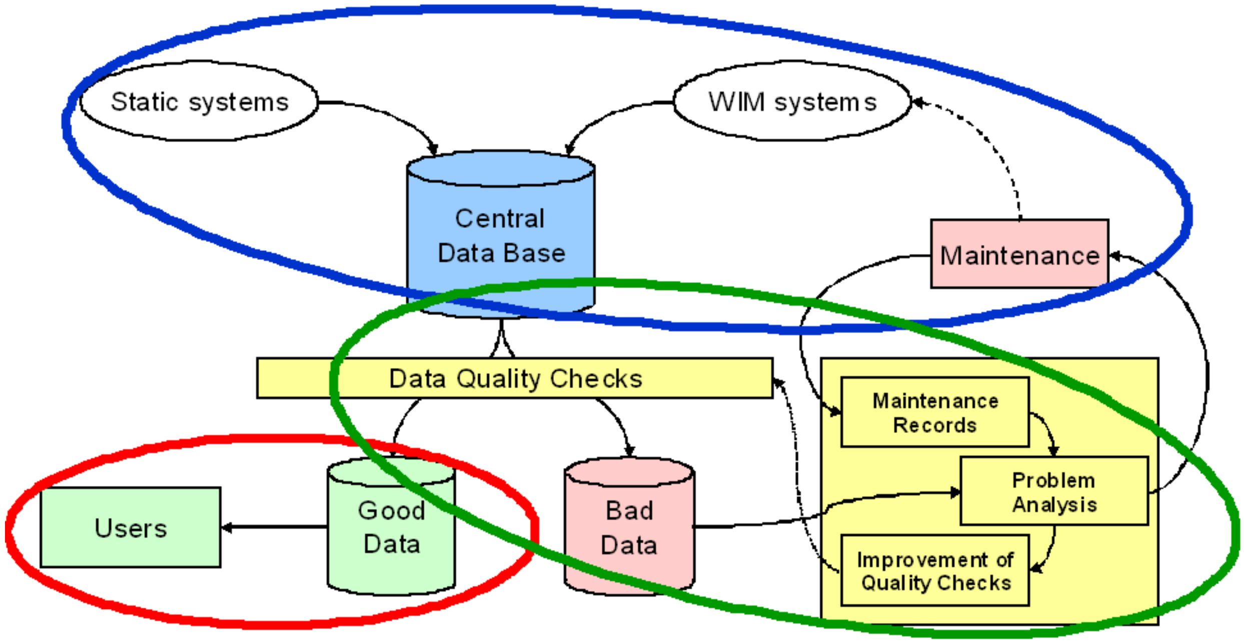

Figure 11: Responsibilities in data quality management

3 Implementation in Brazil

The implementation of a data quality management system for DNIT will take place in the coming years. The required procedures and quality checks will be developed in the WIM-DQM project that Labtrans in doing for DNIT. The methodology of the data quality management can be used both for the network of traffic counters (PNCT) and for the network of WIM systems (PIAF). The guarantee of the WIM data is based on two parts; permanent quality checks and periodic calibration.

3.1 Permanent quality checks

These are permanent statistical checks of a large number of indicators that are representative of the correct operation of the WIM system. A few of the possible indicators are: the average value and distribution of the weights of all and/or specific types of vehicles and specific axles of vehicles. When static measurements are available then the relative measurement error of the corresponding WIM system can also be determined. The quality of the registrations in general will be determined by checking other - not WIM related – indicators, e.g. the number of detected vehicles per hour/day/week, the number of pictures taken, the number of recognised licence plate numbers, the number of full registrations and the distribution of the vehicle types.

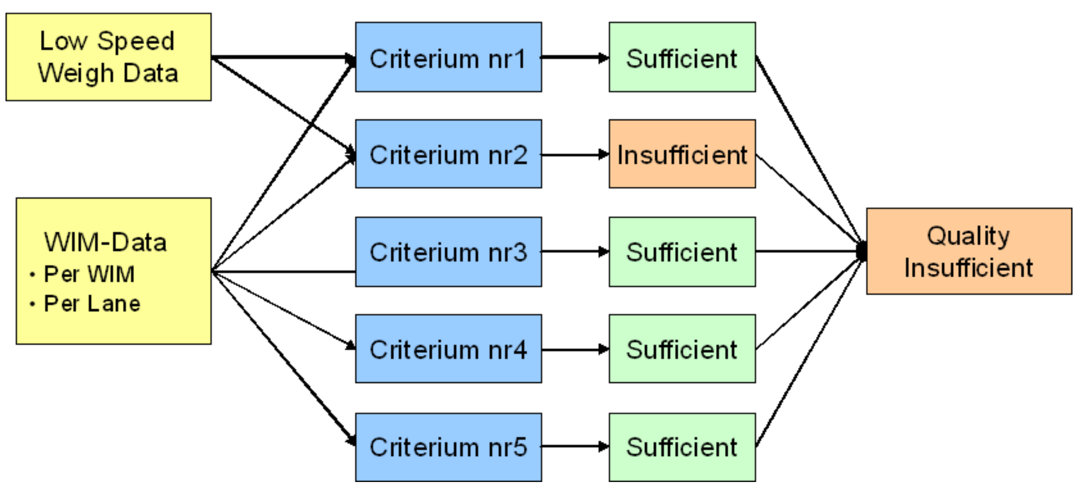

Figure 12: Permanent quality checks

Characteristic for these checks is that the average quality of the data is constantly determined based on the recent past of the measurements. Starting point is that from experience it shows that the performance of WIM systems will only chance slowly (e.g. deterioration because of wear and tear). Characteristic for these checks is that the relative chance with respect to the past will be determined.

3.2 Periodic calibration

This is an inspection − and possibly an adjustment − of the performance of a WIM system that is traditionally done every number of months (typically 3, 6, 12 or 24 months). Using one or more calibration vehicles the difference between a WIM system and a static reference will be determined. Characteristic is that this way an absolute error with a hard metrological reference is determined. If possible both the calibrations of the WIM systems and the static reference scales should be done by one organisation. This way it can use its experience and the information from the statistical checks to determine the optimal frequency for the periodic calibration. WIM systems with a stable performance over the months require a less frequent calibration than systems with a less stable performance.

3.3 Examples of quality checks

The following examples of possible quality checks are based on existing DQM procedures from other countries USA,, South Africa and the Netherlands. These examples are intended to show how the quality checks will work, the exact performance indicators that will be implemented in Brazil may differ.

3.3.1 Stability of steering axle.

The first example of a useful performance indicator for quality checks is the axle load of the steering (1^{st}) axle of a fully loaded 5 axle tractor semi-trailer combination. Experience has shown that the axle load for these axles is quite stable and shows little variation (± 0,75ton) around the average value of 7,5ton. On a monthly basis the percentage of such axles that fall outside the bandwidth 6,75 − 8,25ton (7,5 (± 0,75ton) is calculated. As long as this percentage is below 95% the data will pass this criteria and is considered 'good data'. The data will fail the criteria when this percentage is more than 95%. In this case the data is marked 'insufficient' and will be send for further problem analysis.

In the example shown in the graph below, the trend in the measurement data suggests that there is some kind of malfunctioning with one of the sensors of the WIM system. Therefore the organisation responsible for the maintenance is advised to physically check the sensor on site and if possible make repairs (eg. grinding the pavement) or if not possible to replace the sensor.

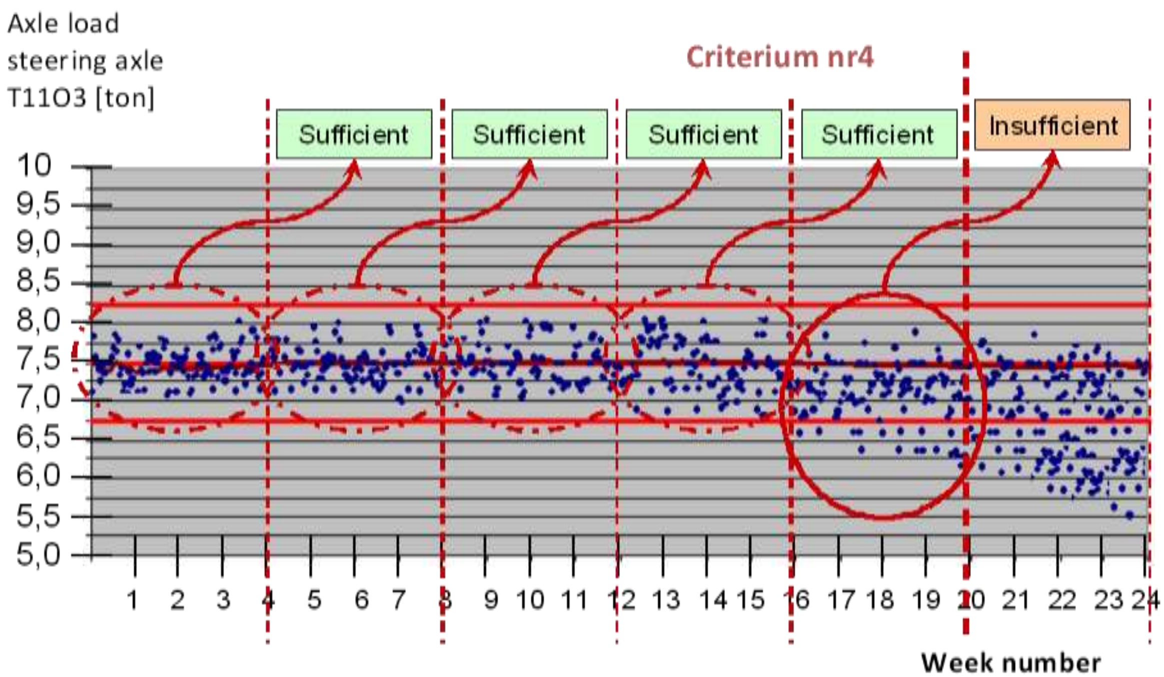

Figure 13: Checking stability of 1st axle of T11O3, error detection

The DQM will continue to check the performance of the WIM in question. After maintenance the performance of the system is improved and again meets the criteria. When this is detected by the monthly quality check the quality of the data is again switched to 'sufficient'.

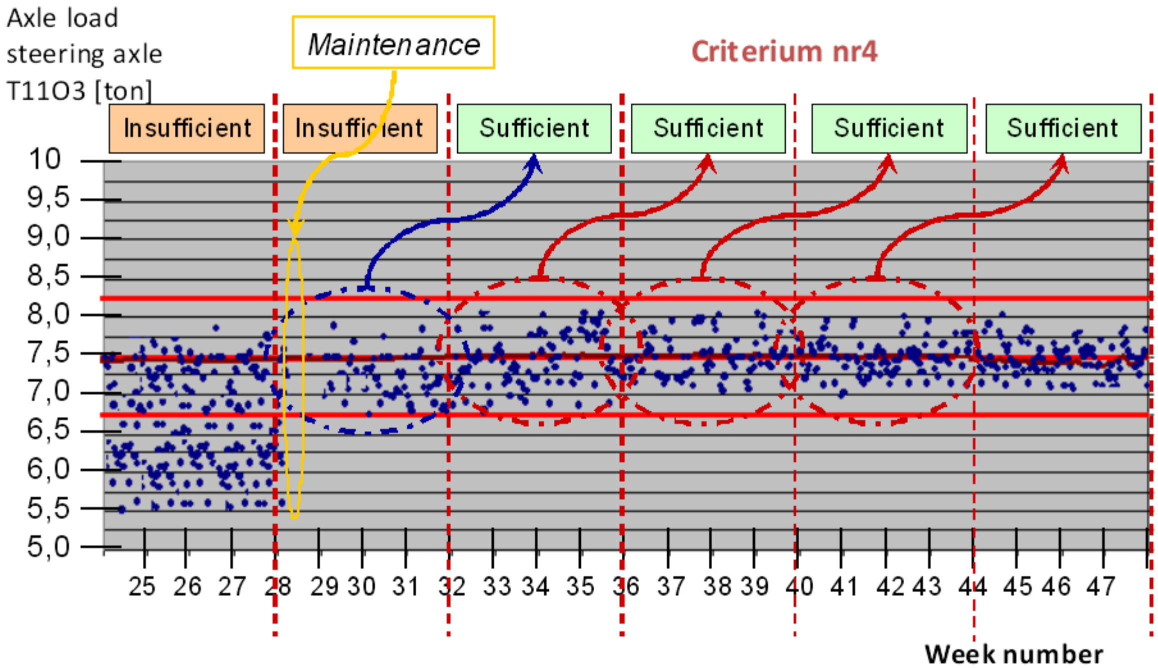

Figure 14: Checking stability of 1st axle of T11O3, after maintenance

3.3.2 Difference between LS and HS weighing.

The next example is in fact one of the most powerful quality checks available since it is based on a direct comparison between the WIM data and the static or low speed reference measurements. The only down side to this criteria is that it is sensitive to the quality of the static (low speed) measurements. If there are mistakes in the way the static measurements are done this cannot be detected by the DQM and will have a highly disruptive effect on this criteria.

In this case the criteria is the stability of the measurement error, the difference between the measurement of the high speed WIM and the low speed reference (enforcement) scale. When well calibrated the average value of this error should be 0 with a certain variation. The criteria is that 95% of the errors should be inside a bandwidth of ± 7,5ton. As long as this is the case the quality of the data will be considered as 'Sufficient'.

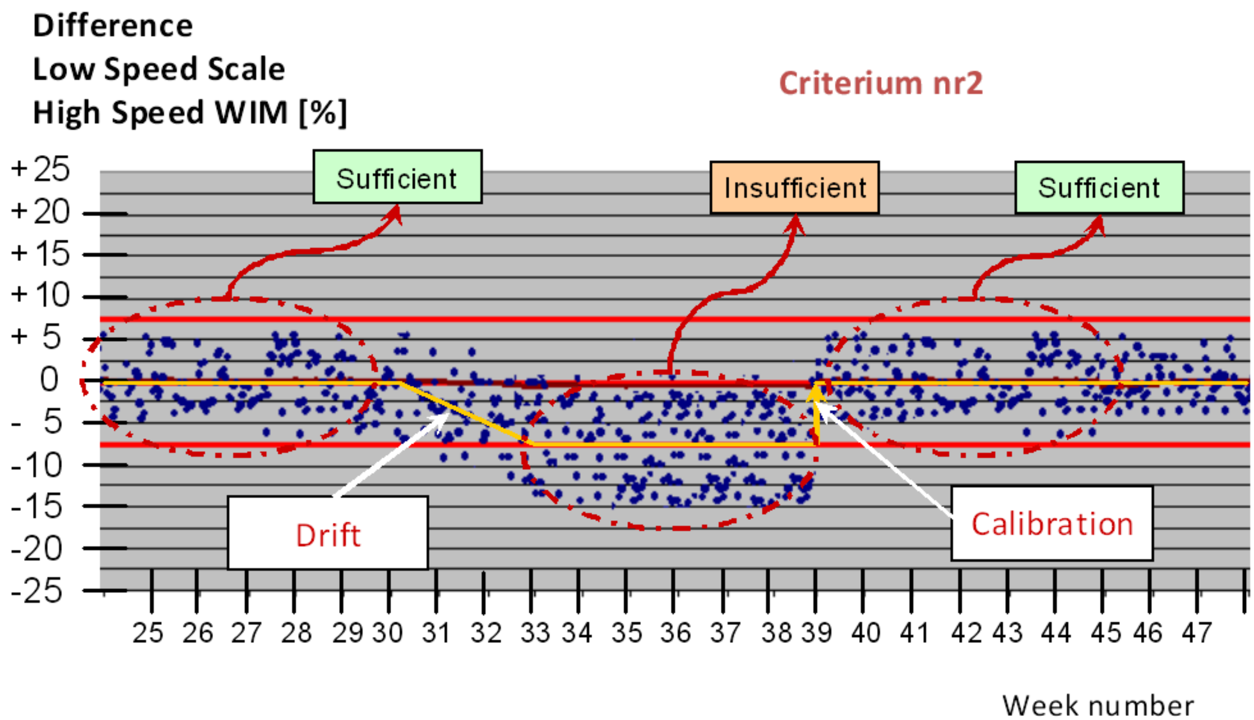

Figure 15: Difference LS and HS weighing

In the example above around week 28 the average error of the system starts to drift away and stabilises again a few weeks later. Since now more than 5% of the data falls outside the required bandwith the data will fail quality check and will be classified as 'Insufficient'. Analysis of the data suggest a change in the environment of the system, eg. a deterioration of the pavement conditions that has stabilised again. Therefore the organisation responsible for the maintenance is advised to do a calibration of the system.