European Commission

DG VII - Transport

4th Framework Programme Transport

Weigh-in-motion of
Axles and
Vehicles for
Europe

RTD project, RO-96-SC, 403

Weigh-in-motion of Road Vehicles for Europe (WAVE)

Report of Work Package 3.1

Durability of WIM systems in Cold Climates

Vägverket
Swedish National Road Administration

February 2002

THE PROJECT

'WAVE' (**W**eigh-in-motion of **A**xles and **V**ehicles for **E**urope) is a research and development project of the fourth Framework Programme (Transport). Concerned with the weighing in motion of road vehicles, the project ended in June 1999 after two and a half years of steady work. Thanks to an integrated programme with a fruitful collaboration between the partners, and complementary contributions from the participating organisations, significant scientific and technical progress was made and very many results were achieved.

1. Origin of the project

During the COST 323 action (WIM-LOAD, 1993-98), part of the activities of COST Transport, it emerged that further research on WIM was necessary to address the latest requirements of road managers and decision makers. In 1994, the 4th Framework Programme of the European Commission was presented, with a specific "Road Transport" programme. Part of the latter was entitled "Road infrastructure" and a task of this was "Monitoring of factors affecting pavements and structures to support existing and future harmonisation legislation in respect of axle and vehicle weights" (task 7-4/27).

To address this task, a proposal for a large research project, 'WAVE' (Weigh-in-motion of Axles and Vehicles for Europe) was submitted to the Commission by a consortium of 11 partners from 10 countries, following the first call in March 1995. A majority of the partners were already participants in the COST 323 action. After a positive review by the experts and a negotiation phase in Autumn 1995, the project began in September 1996, after a 6 month delay for administrative reasons.

2. Objectives

The objective of the 'WAVE' project was to effect a significant step forward for those responsible for road networks, through the following actions :

1.1. Improve the capacity of conventional WIM systems to accurately estimate static loads from measurements of dynamic impact forces applied by axles, through use of arrays of sensors whose combined results can allow for the dynamic interaction between vehicle and pavement.

1.2. Develop and improve the functioning and accuracy of bridge-based WIM systems through more sophisticated vehicle/bridge interaction modelling and data processing.

2. Develop common data structures, formats and quality assurance procedures to facilitate the exchange and comparison of WIM data throughout Europe, to increase confidence in such data and to provide reliable management information to decision makers.

3.1. Perform tests of WIM systems to assess their durability and performance in various climatic conditions, particularly in cold regions where pavements deform and are weaker during the thaw and sensors are susceptible to studded tyres and de-icing salt.

3.2. Develop standardised calibration methods and procedures by improving existing methods and extending their applicability to all European climates and types of WIM system.

4. Develop and implement a new WIM technology, based on an innovative fibre optic sensor which has considerable potential in terms of quality and the extent of information provided and its insensitivity to harsh climatic conditions.

This project constituted a strategic policy initiative to confirm the Europe's leadership in WIM. It led to the development of new technologies such as advanced multiple sensor and bridge WIM systems, a quality assurance procedure to be implemented in a pan-European database, data about the behaviour of WIM systems in harsh environments, an improvement in calibration procedures and the development of a new European optic-fibre WIM technology. That will help road and transport decision makers.

3. Project organisation and means

The consortium involved 6 Contractors and 5 Associate Contractors:

Coordinator: Laboratoire Central des Ponts et Chaussées - LCPC - France

Contractors

Cambridge University Engineering Department - CUED - United Kingdom

Trinity College Dublin - TCD - Ireland (but some of the work was subsequently completed by staff at University College Dublin - UCD - Ireland)

Road and Hydraulic Engineering Division - DWW - The Netherlands

Alcatel Contracting - ALCO (9/96-5/98) / Alcatel CIT Saintes (6/98-6/99) - France

Swedish National Road Administration - SNRA - Sweden

Associated Contractors

Belgian Road Research Centre - BRRC - Belgium

Technische Universität Muenchen - TUM - Germany

Technical Research Centre of Finland - VTT - Finland

Swiss Federal Institute of Technology - ETH - Switzerland

Slovenian National Building and Civil Engineering Institute - ZAG - Slovenia

All together, more than 15 senior scientists and engineers, 25 Ph.D. students, post-doctoral or young engineers or researchers, and many technicians were involved in WAVE. Some sub-contractors were SME (Small or Medium Enterprises), manufacturers and/or vendors of WIM systems or services; they were therefore self-motivated and interested in the output and deliverables of the project.

The project was planned for 24 months, from September 1996. A 9 month extension was subsequently accepted by DGVII, which lead to a project completion date of June 1999.

The complete project was organised in 4 main research areas, each of which was divided into two or three parts to give a total of nine work packages (WPs). The WPs were sub-divided into tasks. Each task consisted of work with a specific deliverable or output to be used in another task. Each specific WP covered one of the main objectives of the project and a basic need in Europe. The four main research areas were consistent areas, but had relationships between them. Each WP worked towards providing more efficient and accurate WIM systems and more reliable traffic load data.

The detailed organisation of the WPs is described below:

WP1. Accurate estimation of static weights using WIM systems

WP1.1. Multiple Sensor WIM (MS-WIM) - *leader: CUED / co-leader: LROP/LCPC*

a. New and improved theories
b. Validation using experimental data
c. Tests of MS-WIM systems
d. Specifications and legal issues

WP 1.2. Bridge WIM systems (B-WIM) - *leader: TCD*

a. Increased Accuracy for Typical Bridges
b. Extension of B-WIM to Orthotropic Decks
c. Extension of B-WIM to Other Bridges
d. Dynamic Analysis for Typical Bridges
e. Calibration

WP2. Quality, management and exchange of WIM data - *leader: DWW*

WP2.1. WIM data quality assurance

a. Analysis of existing quality systems
b. Site quality
c. System quality
d. Calibration procedures
e. Data quality

WP2.2. WIM data format and database structures

a. Submitted data format
b. Harmonisation procedure
c. Description of two database levels
d. Database management and maintenance

WP3. Consistency of Accuracy and Durability

WP3.1. Durability of WIM systems in cold climates - *leader: SNRA*

0. Preparatory work in advance of the project start
a. Reporting previous experience on the subject matter
b. Inviting WIM manufacturers to the test
c. Final decision on test site localisation
d. Site preparation
e. WIM installation
f. First summer test
g. Winter test
h. Second summer test
i. Random traffic test

j. Final report

WP3.2. Calibration of WIM systems - *leader: VTT*

a. State of the art report
b. Test of calibration devices and procedures
c. Specification of the calibration procedures

WP4. Optical fibre WIM systems, technology for the future - *leader: LCPC*

WP4.1. Sensor Design

a. Feasibility
b. Characterisation and testing
c. Calibration
d. Mathematical model (1)

WP4.2. Optoelectronic Head

a. Design
b. Multiple sensor head
c. Long-term performance
d. Prototype improvements

WP4.3. Data Acquisition and Processing Unit

a. Data acquisition and treatment
b. Mathematical model (2)
c. Validation and Report

A total budget of 1.5 million Euros was allocated to the WAVE project, of which 0.75 million Euros was provided by the European Commission. The total time spent on the project was nearly 30,000 man-hours, i.e. 20 man-years. The personnel cost represents 69% of the total budget. A mid-term seminar was organised in September 1997 in Delft, The Netherlands (WAVE, 1997) and a Final Symposium in Paris (May 1999), in order to widely disseminate the results of the project. In addition, much of the results were presented at the Second European Conference on WIM organised through the COST 323 action. A Web site was prepared by the COST 323 Action and hosted by ZAG (http://www.zag.si/wim/). A CD-ROM was prepared (edited by the BRRC) to present all the reports and output of the project.

Several large testing facilities or bridge and road test sites were used in the project. Two road sections were instrumented with multiple-sensor arrays, in the UK and France, for testing MS-WIM systems. For the calibration of these arrays, instrumented lorries and pre-weighed lorries were used. Several bridges of different type were instrumented in France, Germany, Sweden, Slovenia and Ireland to develop and test B-WIM systems. For WP3.1 in Sweden, a road section of 0.5 km was instrumented with five WIM systems, and a static weighing area with a large weigh-bridge was used.

4. Project output

New theories, models, algorithms, and procedures have been generated, prototypes built, and field tests performed. New prospects have been opened up for weighing using multiple sensors and instrumented bridges, an innovative technology has been developed using optical fibres and optronics, and there have been significant advances in the calibration of the systems and in the quality and management of weigh-in-motion data. Experiments on roads fitted with sensors and on instrumented bridges have yielded highly valuable quantitative information on the durability, performance, and precision of many types of weigh-in-motion system.

As happens in most active and innovative research projects, many questions have been answered and others asked, opening up new prospects. The scope of weigh-in-motion has been expanded to encompass new needs in the checking of vehicle weights, thanks to a substantial improvement of the levels of precision, and in the design and management of road infrastructure, thanks to new approaches to the instrumentation of roads and bridges.

In addition to performing the research and attaining the project's objectives, the consortium has attached special importance to dissemination of the knowledge and results acquired, both within the scientific community and to the users and industrial builders of the systems. The fallout from such a project is almost as much a matter of "making known" as of "know-how".

Overall results of the project are presented in the General Project Report, published by the LCPC. Detailed results of each WP are presented in each WP's report, which are published by the WP leader's organisations.

Report on the WP 3.1

Contributors to the different chapter were:

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1. INTRODUCTION

During the past few decades, many European countries have witnessed a great increase in traffic within the road network. A considerable proportion of this increase is comprised of heavy vehicles. Furthermore, the maximum permitted axle load has also been raised in some European countries like Sweden and Finland. All in all, these changes have meant an increased rate of damage and an accelerated deterioration of the road network.

In countries with ground frost, it has been the general conception that pavement deformation is largely due to the effect of heavy vehicles using roads during the spring thaw. On the other hand, countries in Central Europe have quite naturally seen this type of road damage as the result of traffic on soft, warm asphalt in conjunction with the summer season. Both the traffic density and the average temperature are higher at that time, meaning that the damage is observed right away.

Seeing that the traffic density is increasing steadily, there has been a greater interest in charting both the gross weight and the axle load of heavy vehicles. To be able to weigh vehicles in motion accurately has therefore become mandatory. One of the objectives is to be able to determine the relation between road damage, vehicle weight and other variables that can affect the origin of damages. It is important to know the consequences of the national legislation on the maximum vehicle weight and axle loads.

Knowledge relating to axle loads is also needed in order to make prognoses on the development of traffic at all levels and to be used as parameters in new construction and in the maintenance of roads. Moreover, up-to-date information on axle loads should be gathered continuously as regulations, legislation, vehicle design and other conditions, change.

2. ORGANISATION OF THE WORK, MEANS AND SCHEDULE AND LINKS WITH OTHER WORK PACKAGES.

2.1 Objectivs

The objectives included testing the capability of existing and future WIM systems to operate effectively in cold, northern and mountainous climates under harsh conditions as well as testing existing calibration procedures in both temperate and cold climates. The work aims at the improvement of initial calibration methods and automatic self-calibration procedures, and will contribute to the WP3.2 of WAVE (Calibration of WIM systems).

The specific objectives of this test concerns the evaluation and reporting of the performance and durability of existing and prototype WIM systems in cold climate conditions, with special focus on the following points:

- durability of the WIM systems under harsh winter conditions
- short and long term accuracy
- overall rugged design of the sensor (resistance to cold temperatures and salt, possible resistance to frost heave and the physical impact of snow ploughs),
- sensor behaviour in relation to variations in pavement temperature,
- sensor and electronics simplicity of installation, maintenance and repair,
- functionality in calibration procedure,
- telephone data transfer functionality,
- long time availability of the WIM systems,
- how easily improvements can be implemented by the manufacturers with regard to performance and capability of the existing and prototype WIM systems (sensors, electronics and software),
- improvement of the calibration procedures,
- comparison of road sensor WIM systems with a bridge WIM system.

2.2 Organisation

As part of the WAVE project (WP3.1), CET was managed by the Swedish National Road Administration (SNRA), which responsibility entailed setting up all necessary site facilities. VTT (Technical Research Centre of Finland), a contractor associated with the SNRA in WAVE, was appointed to be in charge of the data analysis with respect to the scientific objectives of the

WAVE project under the supervision of the project's Scientific Committee. ETH (Eidgenössische Technische Hochschule, Zurich), the other contractor associated with the SNRA in WAVE contributed to the WP3.1 with data obtained on a complementary test run in a mountainous area in addition to sharing its experience and providing assistance to SNRA and VTT. A bridge-WIM system has also been tested. The work, started at the Civil, Structual & Environmental Engineering department at Trinity College, Dublin, and later continued at the department of Civil Engineering at University College Dublin, performed a test of a Bridge–WIM system at the test site.

3. DESCRIPTION OF THE TEST SITE IN SWEDEN

3.1 Selection criteria and geographical location

A number of criteria, such as easy access from an airport, road quality, traffic flow, access to electricity and telephone utilities and proximity to a suitable bridge (for the bridge WIM) were used in the selection process. It was also a requirement that the climate at the chosen test site included periods with snow and ground frost.

As the traffic volume is rather low in this part of the country, the only possible road was E4, (European Highway 4) which is the main road connection to the northern part of Sweden and Norway. The site was located at Alean, 20 km south of the city of Lulea and 950 km north of Stockholm. Kallax Airport (Lulea) is located only 15 km from the test site (Figure 1).

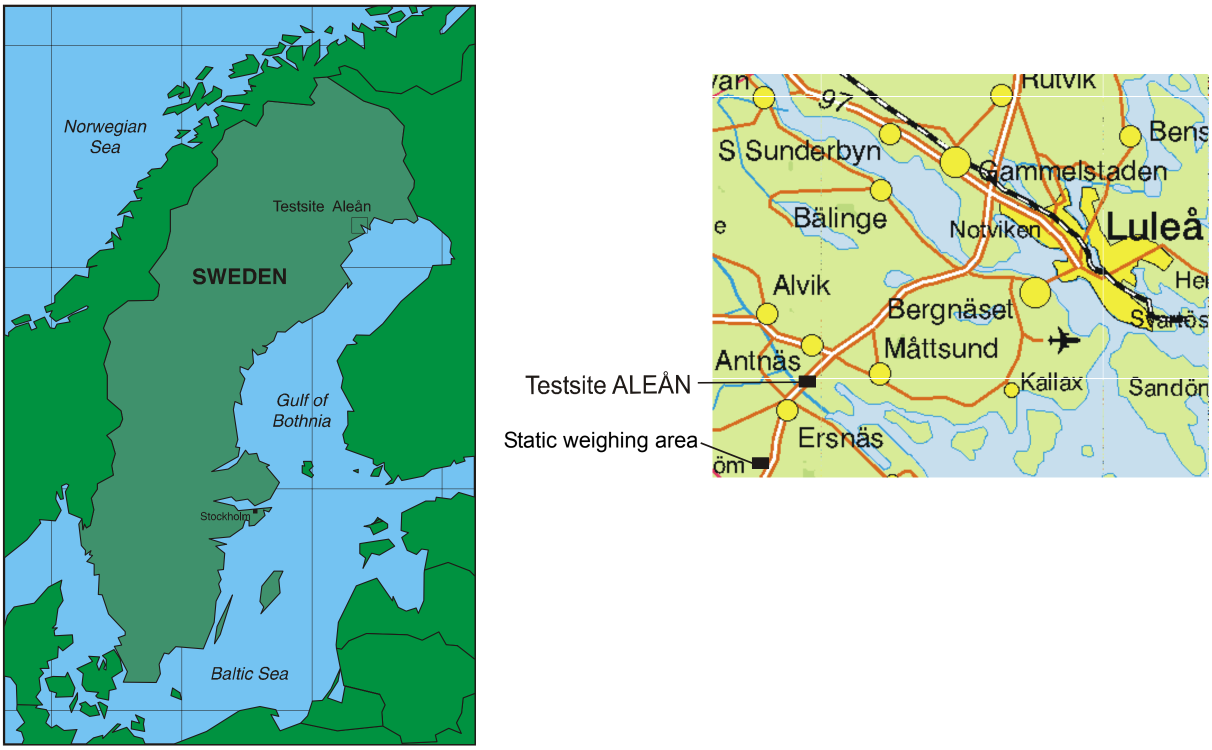


Figure 1. Aleån test site, geographical location.

3.1.1 Pavement and road conditions and test site classification.

The road at the test site is 13 metres wide in total and has two lanes. The road is absolutely straight for 2.5 km as it is built for use as a military airfield in the event of war.

The road was repaved in June 1996. After adjustment of the profile, the road was given a new wearing course of 24-32 mm SMA 11. As is standard procedure in connection with road repair or repaving, road surface condition measurements were performed immediately subsequent to these road works. The values obtained were good (see Table 1) - class II for a WIM site according to the European Specification.

Table 1. June 1996 pavement characteristics at the Alean test site

Criterion	Long. slope	Transv. slope	Rutting	Deflection	Evenness
Alean values	< 1%	2.5%	< 1 mm	0.35 mm	1.7 mm/m
Max. class II	2%	3%	7 mm	0.35 mm	2.6 mm/m
Max. class I	2%	3%	4 mm	0.20 mm	1.3 mm/m

Deflection measurements were performed in June 1996 using the KUAB Falling Weight Deflectometer (FWD). The measurements showed a homogeneous road with a typical central deflection of 0.35 mm. The pavement thickness was measured in June 1996 through sampling along the test site. The thickness varied between 90 mm and 190 mm.

3.1.2 Climatic conditions.

Between November and May, the average temperature over a 24-hour period is normally below 0°C. During the spring season, the uppermost layers of the roadway are exposed to repeated cycles of freezing and thawing. There are extensive amounts of precipitation during this period, mostly in the form of snow. The road is ploughed and usually free of ice, at least in the wheel tracks. Salt is spread principally at the beginning and end of this period.

3.1.3 Weather information system.

A road weather information system (RWIS) for the automatic collection of weather data was installed at the test site. This type of station is used by the SNRA at several hundred places along the state road network. These stations are connected to the telephone network and deliver up-dated weather information to a database at the SNRA Head Office in Borlänge every half-hour.

Two sensors that measure the temperature in the roadway are connected to the RWIS station. One of these is installed immediately below the road surface and the other at a depth of 20 cm. Air temperature and dew point temperatures are also measured. The accuracy in the measurements for the air and pavement temperatures is +/- 0,3 C. For the dew point temperature the accuracy is +/- 0,6 C.

From the SNRA National Information Center, the test site temperature data can then be retrieved and used for temperature dependency analysis.

The Figure 3 shows an example of the great variations in the temperature at the test site. In the air but also in the pavement on two levels.

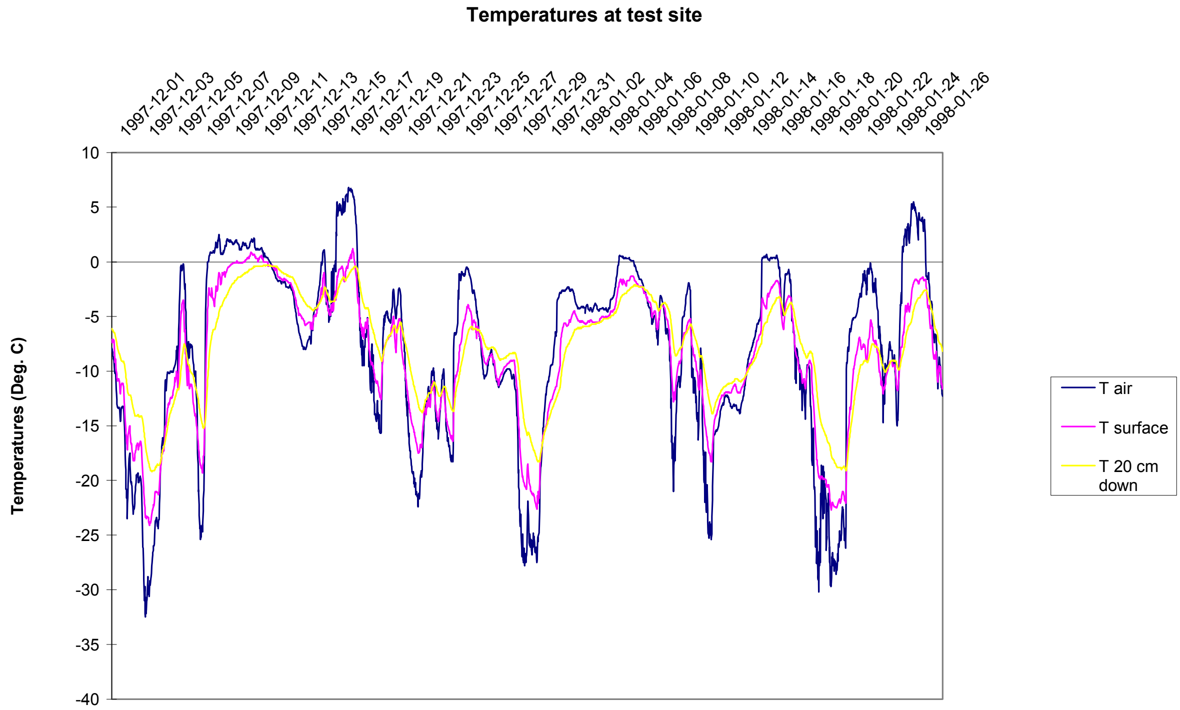


Figure 2. Alean test site, temperature diagram for the period Dec 1st 1997–Jan 26th 1998

3.1.4 Traffic characteristics.

The traffic density at the site is 350 heavy vehicles per day in each direction. The speed limit for heavy vehicles is 80 km/h. According to local traffic culture in Sweden, vehicles on 13-metre wide roads (like the one at Alean) generally make use of the shoulders to facilitate being overtaken. For our purposes, this meant our having to use cones to steer vehicles onto the traffic lane.

3.1.5 Test site preparations and facilities.

The test site is situated at the south end of the “airfield” near a slab bridge used for testing a bridge-WIM system. There are crossroads at both ends of the 2.5 km long road stretch comprising the test site, making it possible for vehicles to turn around. The test vehicles need only run less than 5 km for one crossing of the WIM systems. During low traffic periods the test vehicle can perform U-turns, which speeds up the process.

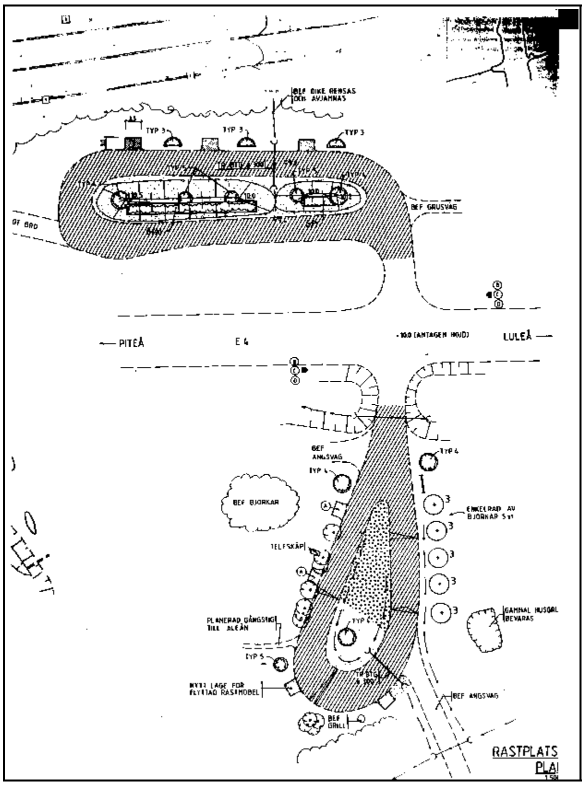


Figure 3. The test site including resting area.

Figure 4. The Aean test site, southbound direction

The initial plans were to store the electronic instruments in a common cabinet. However, in order to avoid unnecessarily long distances between the sensors and the electronics as well as in an endeavour to maintain fair and realistic conditions for all parties, it was decided that each manufacturer would provide its own roadside cabinet. For road safety reasons these cabinets were placed 10 metres away from the shoulder. Two telephone lines were provided to each cabinet in order to facilitate testing of the modem connection. Each manufacturer could check the functioning of his communication link on site through connecting the modem to his own cabinet.

A 230 VAC connection was provided to each roadside cabinet. The installation was done so that each individual cabinet had its own fuse, which meant that an electrical fault on one piece of equipment would only knock out that particular

3.2 Participating WIM-systems.

Four systems, as shown in the following table, were installed on June 6th and 7th 1997. The lane was opened again in the afternoon of the 7th.

Table 2. Pavement WIM systems installed at Alean June 6 th and 7th, 1997

Manufacturer	**Sensor type**	**System name**	**Acronym**
Pietzsch Automatisierungs-technik GmbH Postfach 652, 76260 Ettlingen, DE	Bending Plate (strain gauges)	DAW 100	PAT
Kistler/Golden River *Sensor:* **Kistler Instrumente AG** Winter-thur, P.O. Box 304 CH8408 Winterthur, CH *Electronics:* **Golden River Traffic Ltd,** Churchill Road, Bicester Oxfordshire, OX6 7XT, UK	Piezo quartz module	LINEAS 9195B1 Marksmann 660	KI GR
Datainstrument AS P.O. Box 64, 5035 Bergen, NO	Piezoceramic nude cable Vibracoax, ∅ 3 mm	Datarec 410	DI
Omni Weight Control Ltd Yhteistyönkatu 1 FIN-53300 Lappeenranta, FI	Bending beam (Steel structure with a plate supported by instrumented beams, fixed on a concrete slab)		OWC

There was a slab bridge at the end of the test site to be used for Bridge-WIM experiments, the results of which will be presented further on in this report.

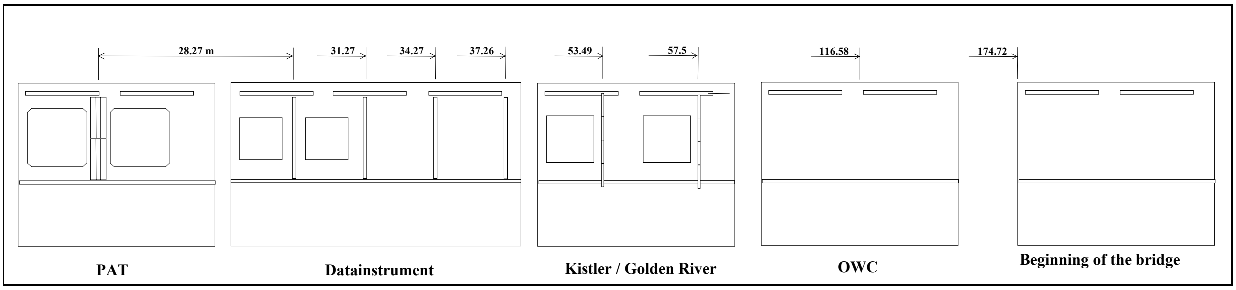


Figure 5. Four pavement WIM-systems installed at the Aleån test site

3.3 Pietzsch Automatisierungstechnik GmbH (PAT)

3.3.1 Installation components

The pavement installation consisted of two 1750 mm long and 500 mm wide bending plates with two inductive loops, one on each side. The sensors and induction loops were connected to a cabinet located 10 meters from the roadside. WIM-electronics, a standard modem, heater and cabling had been pre-installed in the cabinet at the PAT premises in Germany.

Participation status	Marketed system
Manufacturer	**Pietzsch Automatisierungstechnik GmbH (PAT)** Herzstrasse 32-34, D-76260 Ettlingen, Germany
Sensor type	Bending plate with strain gauges
System name	DAW 100
Communication software and template used	DFA200 Ver. 5.37 on IBM-PC DOS 6.2. The manufacturer provided the software.
Modem supplied by the manufacturer	US Robotics Sporster Voice 33.6 Fax modem

3.3.2 Installation procedure

Initially, a groove 1800 mm long, 680mm wide, and 80 mm deep in addition to slots for the induction loops were made. The groove and slots were cleaned under high water pressure and subsequently dried using compressed air equipment and a liquefied petroleum gas burner. A steel frame was placed in the groove and embedded in epoxy. The sensors were then mounted in the frame and connected to the roadside cabinet through flexible tubes embedded in the pavement. Two telephone lines and 230VAC connections were installed in the roadside cabinet.

The installation was carried out by two persons from PAT who arrived on site with a well-equipped work vehicle.

SNRA assisted by providing skilled workers, an asphalt cutting machine, air pressure tools, cleaning equipment and a liquefied petroleum gas burner for drying the cleaned groove and slots.

3.3.3 System electronics

The system electronics consisted of European format cards inserted in slots in a standard rack together with a power supply unit. This rack was then mounted into a smaller steel box, which in turn was installed in the roadside cabinet, also containing a standard type of modem. An electronic heater was installed in the cabinet.

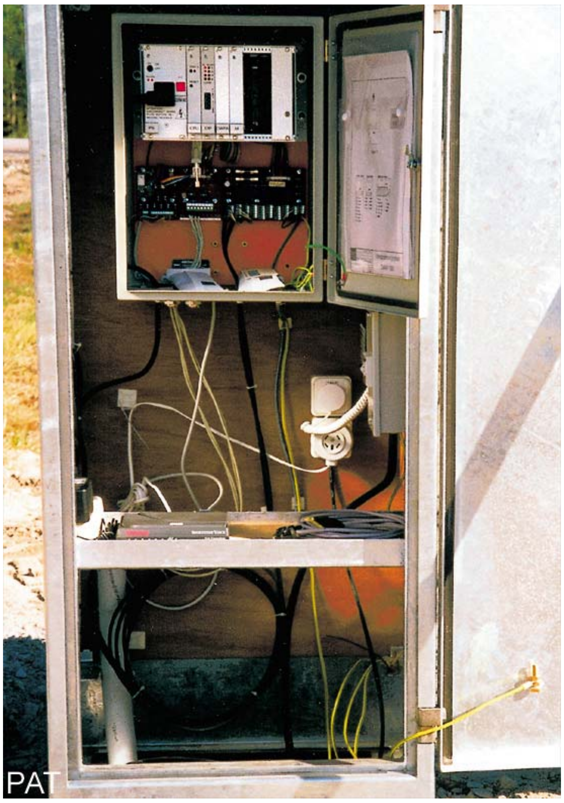


Figure 6. Roadside cabinet for the PAT equipment at Alean.

Figure 7. Bending plates from PAT during installation at Alean.

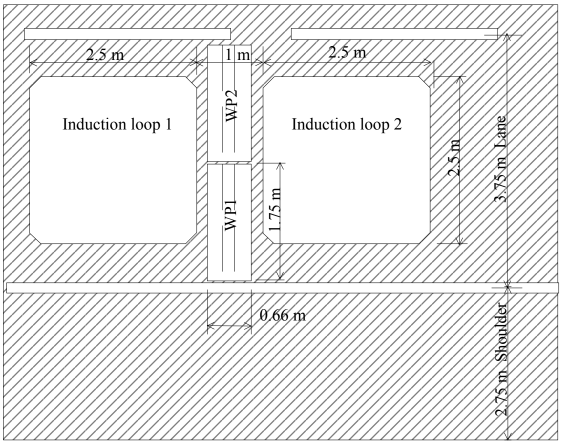


Figure 8. PAT Installation

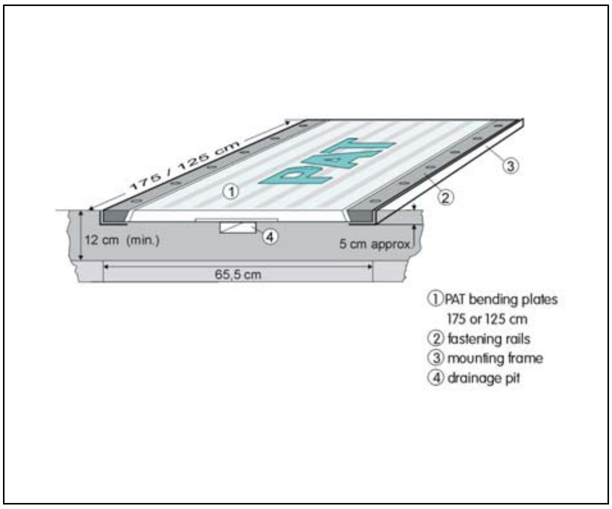


Figure 9. Cross-section of a bending plate from PAT.

3.3.4 Communication software and data collection

Customised communication software was provided by PAT. It was used on a laptop PC under MS-DOS 6.2.

3.4 Kistler Instrumente AG Winterthur/ Golden River Traffic Ltd (KI/GR)

Participation status	Prototype combination with a marketed sensor from Kistler and a marketed system from Golden River
Manufacturer of the sensor	**Kistler Instrumente AG Winterthur**, P.O. Box 304 CH8408 Winterthur, Schweitz
Sensor type	Quartz Module
Sensor designation	LINEAS 9195B1
Manufacturer of the electronics	**Golden River Traffic Ltd,** Churchill Road, Bicester, Oxfordshire, OX6 7XT, United Kingdom
Electronics designation	Marksmann 660
Communication software and template used	The program TERMINATE on IBM-PC DOS 6.2. The manufacturer did not provide the software.
Modem used for the communication	US Robotics Sporster 28,8 Faxmodem**.** The modem was not supplied by the manufacturer

3.4.1 Installation components

The installation in the pavement consisted of two sensors and two induction loops. The sensors were connected to a cabinet located 10 meters away from the roadside.

3.4.2 Installation procedure

Initially, two grooves, each 4050 mm long, 50 mm wide, and 70 mm deep as well as slots for the induction loops were made. See Figure 12.

The grooves and slots were cleaned under high water pressure and subsequently dried with compressed air. A cabinet provided by the manufacturer was installed at the roadside. The sensors were connected to this cabinet through cables. Two KISTLER employees did the installation of the sensors. Two telephone lines and a 230VAC connection was installed in the roadside cabinet.

The SNRA assisted by providing skilled workers, an asphalt cutting machine, air pressure tools, cleaning equipment and a liquefied petroleum gas burner for drying the cleaned grooves and slots.

The heater was installed in June 1998. According to the manufacturer, heating was not necessary as far as the WIM electronics was concerned, but it was for the modem, which was not specified as being able to withstand the temperatures that could be expected in an unheated environment.

3.4.3 System electronics

The electronics were completely encased. The modem on the other hand was freely accessible and of standard type.

3.4.4 Communication software and data collection

The manufacturer provided no software. The test organiser therefore used the program TERMINATE on IBM-PC under DOS 6.2.

Figure 10. Installation of the KISTLER sensor.

Figure 11. Marksman 660 from GOLDEN RIVER

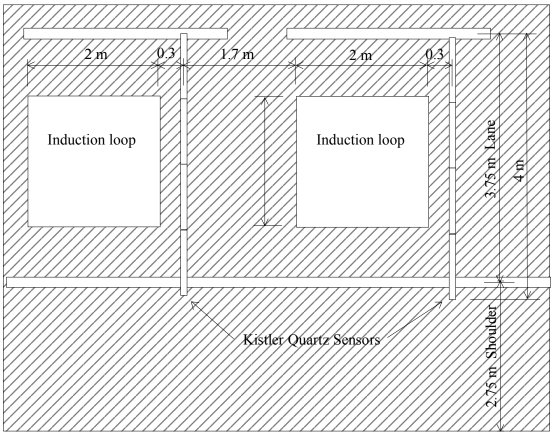


Figure 12. KISTLER/GOLDEN RIVER Installation

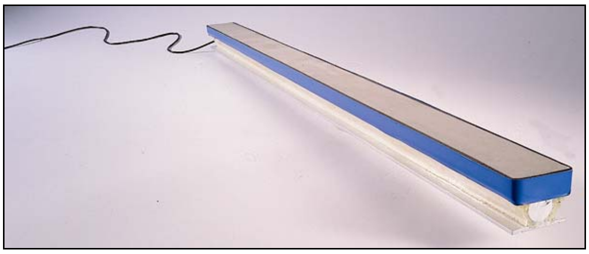


Figure 13. LINEAS quarts sensor from KISTLER

3.5 Datainstrument AS (DI)

Participation status	Marketed system
Manufacturer	**Datainstrument AS** P.O. Box 64, 5035 Bergen, Norway
Sensor manufacturer	Philips
Sensor designation	Piezoceramic nude cable Vibracoax, ∅ 3 mm
Electronics designation	DR410 EC WIM
System software and version	TWIN2F14.HEX
Communication software and template used	Datarec (DR) 1.0N provided by the manufacturer. Platform-used PC with DOS 6.2.
Modem used for the communication	US Robotics Sporster 28,8 Faxmodem. The modem was provided by the manufacturer

3.5.1 Installation components

The installation at ALEÅN consisted of two systems connected to one electronic box. Each system had two weighing sensors. The two systems made common use of the two loop detectors as illustrated in the drawing below. A cabinet provided by the manufacturer was installed at the roadside and the sensors were connected to this cabinet through cables. Two telephone lines and a 220VAC connection were also installed in the roadside cabinet. No heater was needed in this instance.

3.5.2 Installation procedure

The sensor was installed by one person from Datainstrument with SNRA assistance.

Fours slots each 3600 mm long, 10 mm wide and 50 mm deep were cut in the pavement for the sensors. The slots were cleaned under high water pressure and subsequently dried using compressed air and a liquefied petroleum gas burner. The sensors were then placed in the slots and embedded in epoxy. Two squares measuring 1800mm x 1800 mm were cut for the loop detectors. The SNRA assisted by providing skilled workers, an asphalt cutting machine, air pressure tools, cleaning equipment and a liquefied petroleum gas burner for drying the cleaned slots.

3.5.3 System electronics.

The electronics were completely encased. The modem on the other hand was freely accessible and of standard type.

3.5.4 Communication software

The manufacturer provided customised software, which was used on a PC laptop under MS-DOS 6.2

Figure 15. DATAINSTRUMENT WIM sensor installation.

Figure 14: DATAREC 410 from DATAINSTRUMENT

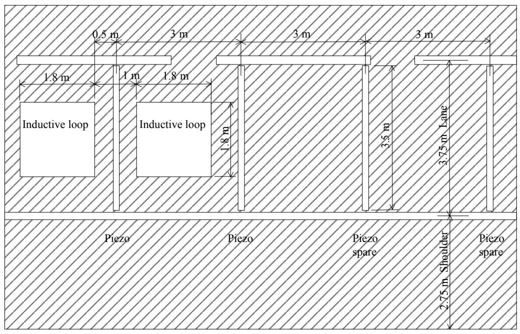


Figure 16. DATAINSTRUMENT Installation drawing

3.6 OY Omni Weight Control Ltd (OWC)

Participation status	Prototype system
Manufacturer	**OY Omni Weight Control Ltd** Yhteistyönkatu 1, 53300 Lappeenranta, Finland
Sensor type	Bending beam (Steel structure with a plate supported by instrumented beams, fixed on a concrete slab)
Communication software and template used	The Terminal program belonging to Windows 3.11 on IBM-PC under DOS 6.2.
Modem used for the communication	US Robotics Sporster 28,8 Faxmodem**.** The modem was not provided by the manufacturer

3.6.1 Installation components

The sensor consisted of a bending beam steel structure instrumented with strain gauges. The sensor was placed on its concrete slab base beneath the surface of the road. Once installed, the entire sensor, which was hermetically enclosed, was completely protected and covered by the asphalt pavement surface.

A cabinet provided by the manufacturer was installed at the roadside and the sensors were connected to this cabinet through cables. Two telephone lines and 230VAC connections were also installed in the roadside cabinet.

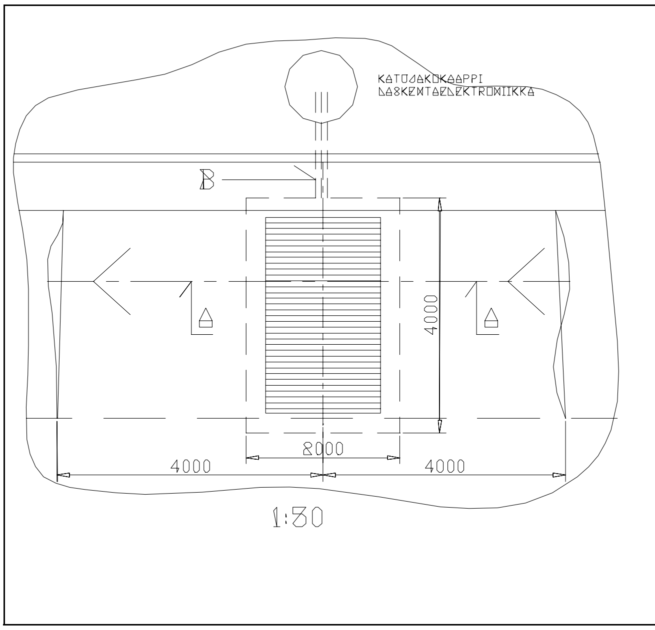
3.6.2 Installation procedure

Initially, a hole was dug large enough to contain the sensor on its concrete slab base. Gravel was then used to level off the bottom and ensure that it was horizontal and at the correct distance from the road surface. The entire unit was then placed in position and the hole filled with gravel and ultimately covered with asphalt, which was compacted according to normal maintenance and repair practice. The sensor consists of a steel construction equipped with strain gauge instruments. The entire sensor is then covered with asphalt and ends up at the same height as the surrounding pavement.

The SNRA assisted by providing skilled workers, an asphalt cutting machine, a power shovel to dig the necessary hole and level it off prior to putting the sensor in place. The SNRA also assisted with the asphalt pavement works once the sensor was in place.

Figure 17. OMNI WIM sensor instal-
lation

Figure 18. Installation ready



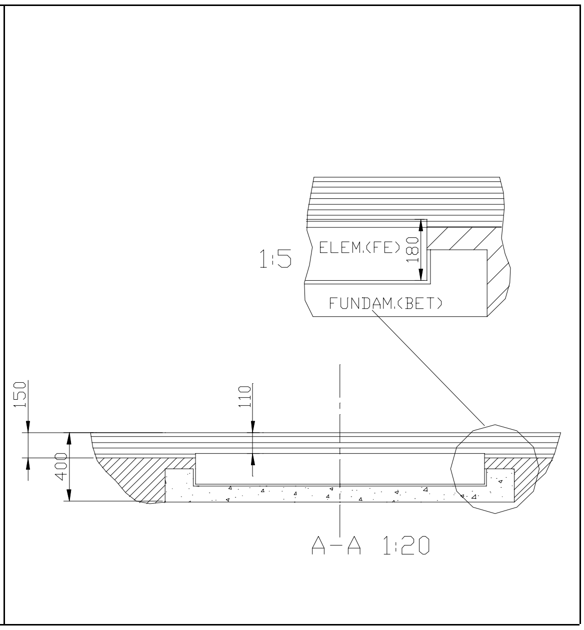


Figure 19. OMNI sensor installation seen from above

Figure 20. Cross section

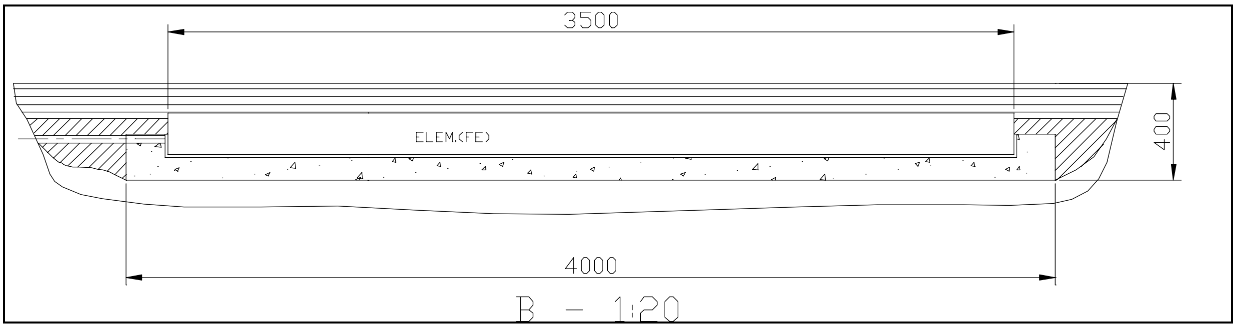


Figure 21. OMNI WIM sensor. Cross section

3.7 Bridge WIM system

A Bridge WIM system also participated in the test. The bridge selected for instrumentation is at the Southern end of the test site. It is a two-span integral bridge with two equal spans of 14.6 m and is straight in plan as shown in Figure 22 and Figure 23. The bridge deck has a mid-span depth of 550 mm and is solid in cross-section. Traffic is carried by one lane in each direction with no central median.

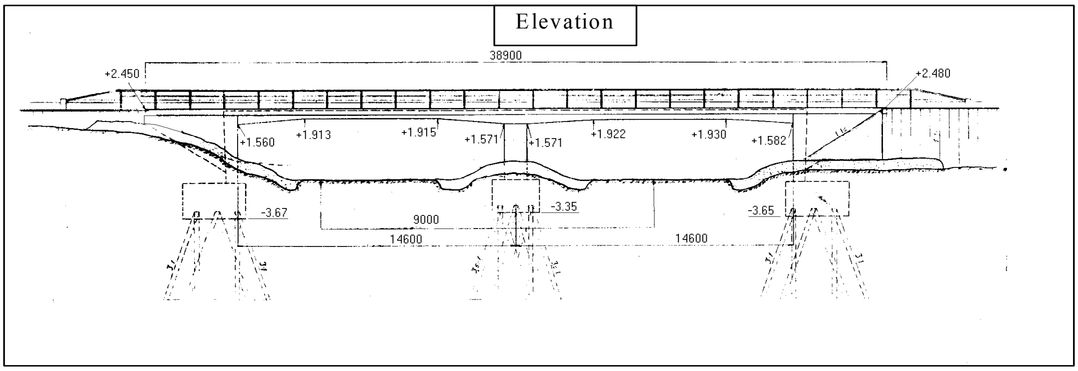


Figure 22. Elevation

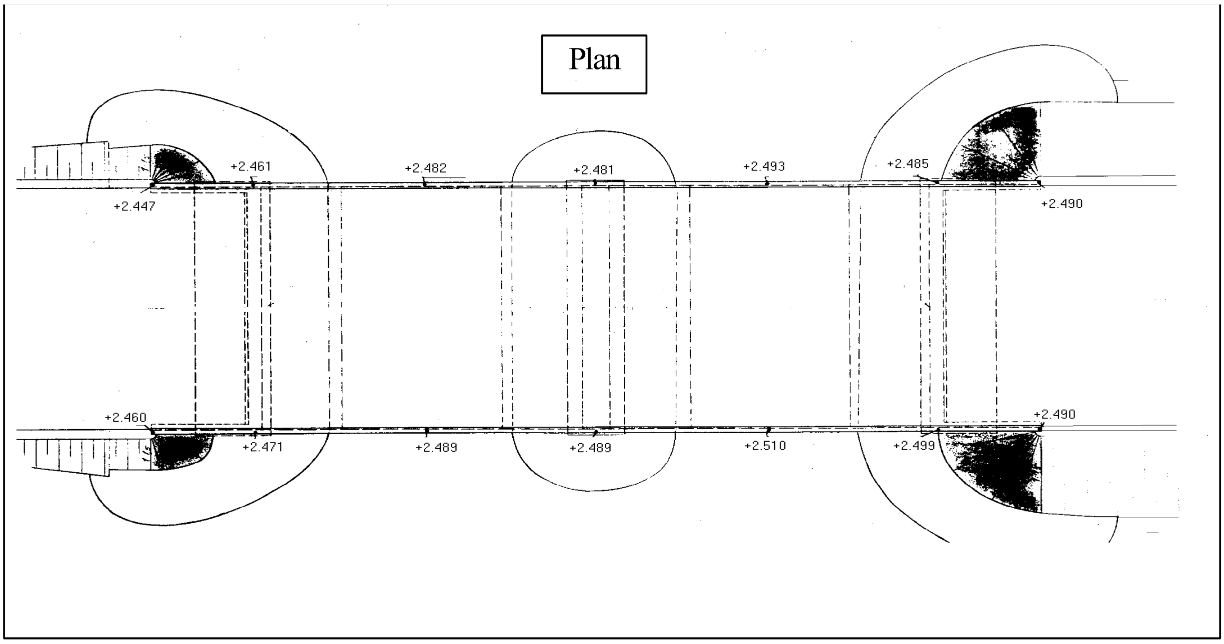


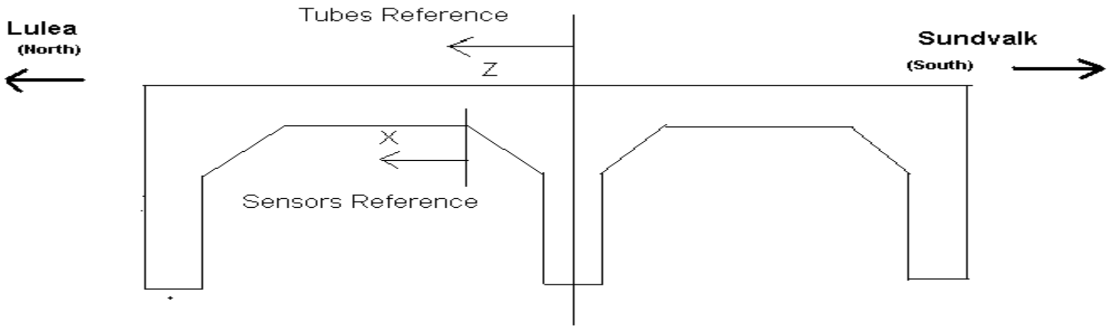
Figure 23. Plan View

On site, eight mechanical strain amplifiers were bolted to the centre of the soffit of the bridge under the southbound carriageway of the first (North) span. Pneumatic tubes were fixed across the southbound lane, one before the bridge and the second immediately at the end of the first span with a recorded distance between them. These tubes were fixed only at the edges of the road (for safety reasons), thereby permitting some movement of the tubes between the clamps. Pairs of tubes were joined using a connector at the centre of the road. The pneumatic tubes were connected to the pneumatic converter that was placed at a location to minimise the lengths of tube required. This, together with the cables from the mechanical strain amplifiers, was connected to the computer data acquisition equipment that was kept at the side of the road. A portable 220V generator provided electricity. The mechanical strain amplifiers were adjusted in order to amplify the strain readings to the greatest degree. The strain gauges and axle detectors were connected to National Instruments equipment, firstly to SCXI 1321 terminal blocks (four channels to each block), the terminal blocks being attached to SCXI 1211 modules and these in turn being attached to the SCXI chassis and to the laptop which recorded the data using Labview software.

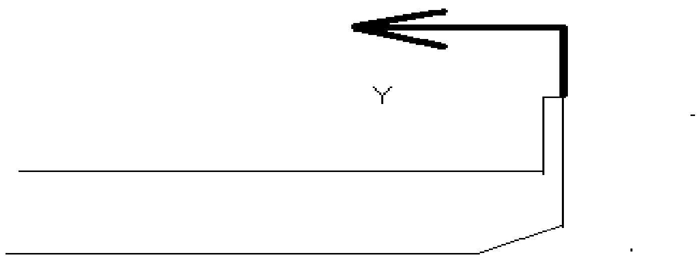
The Strain sensors were positioned at the same points for each test. The location of each sensor is given in Table 3 with reference to Figure 25. The pneumatic axle detectors were positioned differently for each test with the second detector always being at the centre of the support between the two spans. The location of the first detector is therefore defined by

Table 3. Strain sensor and axle detector locations.

Strain Sensor	X	Y	Axle Detector (Tube) Spacings
1	3.07m	0.973m	1st Summer Test
2	3.07m	2.156m	Z = 13.9m
3	3.07m	2.973m	
4	3.07m	3.977m	Winter Test
5	3.07m	4.97m	Z = 8.66m
6	3.07m	6.01m	
7	3.07m	7.507m	2nd Summer Test
8	3.07m	9.016m	Z = 15.69m



(a) Elevation



(b) Plan

Figure 25. Location of datum points for strain sensor and axle detector locations

the distances between them which are given in Table 3

4. TEST PLAN

4.1 Installation

Installation of the systems started on the morning of June 5, 1997. One traffic lane and shoulder were closed to traffic at 7 a.m. to enable manufacturers to make pavement markings for cutting the asphalt. At 8.30 a.m. the asphalt cutting operations were started simultaneously for all four installations. This was finished at 2.15 p.m. at which point work immediately commenced on installing the sensors. Work stopped for the day at 10.15 p.m. and the road remained closed during the night. The weather conditions were: 15-20 degrees Celsius and sunny.

On June 6 at 8 a.m. work on the installation was restarted and by 5 p.m. all the systems were installed and the lane was re-opened to the traffic. The weather conditions were the same as the day before.

SNRA offered support to the manufacturers by providing four asphalt cutting machines, tractors, an air compressor, air pressure tools and liquefied petroleum gas burners. It also provided the assistance of skilled workers and material for placing the induction loops. The weekend was used by some manufacturers to perform function tests on their systems.

4.2 System calibration

All manufacturers had been consulted in writing as to their wishes regarding the calibration. A consensus was then reached at the test site regarding the calibration runs. This is presented in Table 4. The following test vehicles provided by the SNRA, were used:

- 3-axle truck
- 6-axle semi-trailer with tridem axle (wide base tyres in the trailer)

The axle load was measured with the portable static axle scales and the results given to the participant manufactures. The calibration was performed on June 9th, from 11 a.m. to 2 p.m.

Table 4. SNRA test vehicles for calibration runs June 6th 1997

Vehicle	Load	Speed [km/h]	Runs
2-axle truck	Full	40	5
”	”	50	5
”	”	65	5
”	”	80	5

6-axle semi-trailer	”	50	5
”	”	65	5
”	”	80	5
			Total: 35

4.3 Calibration check for the participants

The purpose of the calibration check was to give the manufacturers the chance to fine-tune their systems. The calibration check was done in two parts: one directly after the calibration runs, and the other the following morning. The results were intended for internal use by the manufacturer and were never collected by the test organiser. Runs were done with test vehicles from SNRA and VTT.

4.3.1 SNRA test vehicles

The SNRA test vehicles as well as the instrumented vehicle from VTT were used for the check on June 9 (2.30 p.m. to 4.15 p.m.). Only the instrumented vehicle was used the following morning from 9.15 a.m. to 12.10 p.m. The axle load was measured on the static scale and the results given to the manufactures.

Table 5. Calibration check with the SNRA test vehicles June 9th 1997

Vehicle	Load	Speed [km/h]	Runs
2-axle truck	Full	40	2
”	”	50	2
”	”	65	2
”	”	80	2
6-axle semi-trailer	”	50	2
”	”	65	2
”	”	80	2
			Total: 14

4.3.2 VTT instrumented vehicle

The 3-axle instrumented vehicle provided by the Technical Research Centre of Finland (VTT) measured the instantaneous axle forces, which were exactly matched with the measurements made by the WIM systems. Thus, to a certain degree, it is possible to distinguish the effect of dynamic axle loading (unevenness of the road) and the real measurements obtained in the WIM systems. This may help in the understanding of some differences between results. The

VTT vehicle was only used in the first summer measurements in June 97. For more details about the VTT testvehicle see WAVE Wp 3.2.

Figure 26. Instrumented vehicle from VVT

Table 6. Runs with the instrumented vehicle from VTT June 10th 1997.

Instrum. vehicle	**Load**	**Speed [km/h]**	**Runs** (app.)
2-axle truck	Full	80	3
”	”	70	5
”	”	60	3
”	”	50	3
			Total: 14

5. MEASUREMENTS -TEST PERIODS

During 1997 and 1998, there were six short test periods as listed in the table below. Three different types of test were planned. Those planned as well as the final content of the tests are also shown in the table.

Table 7. Schedule and some results and test conditions for the Cold Environment Test

Test period	**June 1997**	**Dec 1997**	**Jan 1998**	**March 1998**	**April 1998**	**June 1998**
Dates	June 10,11,12	December 2,3	January 21,22	March 11,12, 13	April 29,30	June 15,16
Test type planned*	Test type 1*	Test type 1*	Test type 2*	Test type 1*	Test type 3*	Test type 1*
Results						
Number of test vehicles	2	2	1	3	1	2
Test vehicle runs	84	42	43	82	42	83
Post-weighed vehicles from the traffic flow.	123	44	58	137	0	148
Air temperature min, max and mean in degrees Celsius	Min: 8°C Max: 18°C Mean: 13°C	Min: -30°C Max: -20°C Mean: -25°C	Min: -28°C Max: -5°C Mean: -16°C	Min: -32°C Max: -1°C Mean: -17°C	Min: 2°C Max: 10°C Mean: 6°C	Min: 10°C Max: 26°C Mean: 18°C
Pavement surface Temperature min, max, mean in degrees Celsius	Min: 16°C Max:31°C Mean: 24°C	Min: -23°C Max: -16°C Mean: -20°C	Min: -22°C Max: -8°C Mean: -15°C	Min: -22°C Max: -2°C Mean: -12°C	Min: 6°C Max: 22°C Mean: 14°C	Min: 16°C Max: 42°C Mean: 29°C
Pavement 20 cm down Temperature min, max, mean in degrees Celsius	Min: 22°C Max: 26°C Mean: 24°C	Min: -18°C Max: -11°C Mean: -14°C	Min: -19°C Max: -11°C Mean: -15°C	Min: -16°C Max: -5°C Mean: -11°C	Min: 9°C Max: 12°C Mean: 11°C	Min: 18°C Max: 32°C Mean: 25°C

* Test type 1:

Population 1: Several test vehicles, with several loads (empty, half and fully loaded) and two speeds in each case;

Population 2: minimum 90 vehicles from the traffic flow.

Table 8. Content of test vehicle runs in test type 1.

Vehicle	**Load**	**Speed [km/h]** (app.)	**Runs**
2-axle truck	Full	50	8
”	”	80	8
”	Half	50	8
”	”	80	8
”	Empty	50	5
”	”	80	5
6-axle semi-trailer	Full	50	8
”	”	80	8
”	Half	50	8
”	”	80	8
”	Empty	50	5
”	”	80	5
			Total: 84

* Test type 2:

Population 1: One test vehicle, minimum 32 runs altogether with several loads and two speeds in each case;

Population 2: minimum 90 vehicles from the traffic flow.

Table 9. Content of test vehicle runs in test type 2 and 3

Vehicle	**Load**	**Speed [km/h]**	**Runs**
2-axle truck	Empty	50	5
”	”	70	5
”	Half	50	8
”	”	80	8
”	Full	50	8
”	”	80	8
			Total: 42

* Test type 3:

Population 1: One two-axle test vehicle, minimum 32 runs altogether with two loads (half and fully loaded) and two speeds in each case.

The vehicles in all populations were weighed axle by axle using portable scales and on the weighbridge to obtain the gross weights when possible.

5.1 Bridge WIM measurements

As the data collection was not automatic, the Bridge WIM system only participated in the tests when TCD/UCD staff were present, namely, in June 1997 (1^{st} Summer), March 1998 (Winter) and June 1998 (2^{nd} Summer). In all three cases, the system was re-installed and re-calibrated. Data from strain transducers was recorded by staff from Trinity College Dublin as the post-weighed trucks passed over the bridge and was stored for subsequent post-processing. The resulting raw data was later analysed independently by staff at TCD/UCD and ZAG using different Bridge WIM algorithms.

Repeated runs of two calibration trucks provided by the Swedish National Roads Administration were used to calibrate the system for each of the tests. Once calibration was carried out, there was no further adjustment of the mechanical strain amplifiers for the remaining period of the tests. Traffic control was not used during these passes. Due to the low volume of traffic on the road, the truck was the only vehicle present on the bridge for most passes. Any of the truck passes which were affected by other vehicles being present on the bridge were not used for calibration. The total numbers of passes (of both calibration trucks combined) are given in Table 12. The first Summer test was performed from 10^{th} to 12^{th} of June 1997. However only data from Wednesday 11^{th} and Thursday 12^{th} was recorded due to problems with the data acquisition system on June 10^{th}. The Winter test was performed from 11^{th} to 13^{th} March 1998. The second Summer test was performed on the 15^{th} and 16^{th} June 1998. Table 12 gives a summary of the data acquisition. A 4 Hz analogue filter was utilised in the data acquisition for the 1^{st} Summer and the Winter tests. It will be shown that this resulted in a loss of definition in the bridge response and therefore, virtually unfiltered data was used for the 2^{nd} Summer test. Eight strain sensors were used and four pneumatic axle detectors giving a total of 12 channels of data.

Table 12: Summary of test sampling frequency and other details

Test	No. Channels	No. Strain Gauges	No. Axle Detectors	Sampling Frequency	Filter	No. Calibra-tion runs
1st Summer (June 97)	12	8	4	250hz	4Hz	29
Winter (March 98)	12	8	4	500hz	4Hz	76
2nd Summer (June 98)	12	8	4	500hz	10kHz	63

6. STATIC WEIGHING EQUIPMENT

6.1 Measurements of the static axle load

The static reference weighing was conducted about 2 km downstream from the test site. The area was equipped with a weighbridge owned by the SNRA and used mostly by truck drivers for information about their loads. On the Swedish road network there are about 30 such places. It is calibrated and approved for weight regulation enforcement.

This site was chosen for performing reference measurements on vehicles selected from the traffic flow as well as on the test vehicles.

When the police stopped a vehicle selected from the traffic flow, the person having made the selection at the test site was contacted and given confirmation that the vehicle had been taken aside. It was then placed in a queue to be weighed at the weighbridge. Subsequent to this, the vehicle was placed in a new queue for reference measurements using portable wheel load scales. Each individual wheel was weighed here and the results were entered manually on a record sheet.

6.2 Weighbridge

The weighbridge is 3 meters wide and 8 meters long with an accuracy of +/-20kg. It is heated during the winter to ensure proper functioning of the weighbridge. Despite this, at the test in March 1998 it was discovered that enough snow had accumulated underneath to prevent its proper functioning. It was calibrated again after being repaired.

The normal weighing procedure can be described using the following example. A three-axle truck with a four-axle trailer is stopped. Such a vehicle combination is quite common in this area. Its maximum length can be 24.5 metres with a maximum gross weight of 60 tonnes. Figure 27 and Figure 28 show such a vehicle.

To begin with, the front axle is weighed prior to weighing the entire truck without the trailer. Then it is the turn of the rear axles of the truck (normally a bogie with or without the trailing axle being lifted up, depending on the load). This is followed by weighing the first, and then the second trailer bogie. All this information is recorded manually.

Figure 27. Weighbridge from the manufacturer FLINTAB at the weighing area 2km south Alean.

Figure 28. Weighing area.

6.3 Axle weight measurements using portable scales

The dimensions of the weighbridge made it impossible to weigh individual single axles within a group of axles. This meant that portable wheel load scales had to be used. For the tests in June 1997, November 1997, April 1998 and June 1998, portable wheel load scales from HAENNI were used. For the test in January 1998 and March 1998 scales from TECHNOSCALE were used.

Weighing vehicles on the portable scales works extremely well at temperatures above 10° C. At temperatures below this there is a problem that the brakes will freeze while the vehicle is waiting to be weighed which means that the brakes will be affected to a greater or lesser extent when the driver subsequently rolls onto the axle scales. This makes it difficult to position the vehicle correctly while the remaining torque from non- released brakes can also lead to a certain degree of erroneous measurement results.

Further, in the winter period, as there is sand on the ground to counter the effects of the snow, the pavement is not perfectly flat.

6.4 Portable wheel load scales from HAENNI, Switzerland

The Haenni scales are a thin aluminium construction based on hydraulic cells. The plastic mats that are included ensure the same height (17 mm) on adjacent axles. The scales are used in pairs and can be connected to a PC for collecting measurement results. These portable scales were provided by HAENNI's Swedish representative TEAMATOR AB in Stockholm.

Manufacturer	HAENNI
Model	WL 103
Range.	0...10t
Application	Measurement of wheel and axle loads of vehicles with pneumatic tires
Temperature range	-20...+60°C
Accuracy	OIML No. 76 Class 4, optionally with HAENNI works test report or intended for official test.
Execution	Al alloys, water resistant IP 65 (IEC 144).
Supply	Integrated rechargeable power source, for 60h operation. Recharge (and operation) by 12V car battery or AC adapter
Data in- and output	RS 232 C
Electrical connection	Plug
Weight	17 kg (0...10t, 0...15t)
Platform height	17 mm (0...10t, 0...15t)

Figure 29. Information from the datasheet provided by the manufacturer.

Figure 30. Portable Wheel Load Scale HAENNI WL 103

Figure 31. Wheel load weighing at Alean with portable scales from HAENNI

6.4.1 Experience from using the HAENNI scales

The thin 17 mm construction has substantial advantages over thicker models. In cold climates where there often is snow and ice, it means a lot that the vehicle, and especially the trailer can easily roll onto the scales without having to take a run at it. The component plastic mats that ensure the same height of 17 mm on adjacent axles also usually means that the ensuing forward movements can be executed without any problem.

The HAENNI scales have LCD displays, implying on the whole that they take very little electric current. This is a clear advantage compared to scales that use an LED type of display (light-emitting diodes). When it is dark, however, a flashlight is needed to read LCD displays.

During the two-day test in December 1997, the portable scales did not work well under the prevailing extremely cold conditions (between –20 and -30 degrees Celsius). According to the manufacturer, the problem emanated from the fact that the hydraulic oil in the scales was too old and had absorbed too much water. These small amounts of water greatly retarded the stabilisation of the hydraulic oil and created lasting after-effects. The scales had to be frequently reset at zero by switching them on and off. The scales were later serviced and worked excellently during the test in June 1998.

6.5 Portable wheel load scales from TECHNOSCALE, Finland

Portable wheel load scales from the Finnish manufacturer Technoscale were used during the test periods in January 1998 and March 1998. The police from Kemi, (Finland) provided a fully equipped traffic police control van, with two police officers who were officially sent on a “static weighing mission” to the WIM test site in Sweden.

This support was given during the tests in January and March. The system used is based on a procedure whereby all the axles are weighed, first on the towing vehicle first and then on the trailer. It is well known that this procedure gives more precise results, especially when weighing the gross weight. At least 10 scales are needed for this purpose.

Manufacturer	TECHNOSCALE OY
Model	EVOCAR-2000
Max load	10000 kg (for the type used)
Scale division	50kg (for the type used)
Accuracy	Council directive 90/384/EEC EN 45501 and OIML R76
Temp. Range	-20ºC - + 40ºC
Connection	RS 485
Measures	670 x 460 x 45mm*
Weight	19,8 kg

Figure 32. Information from the manufacturers datasheet

Figure 33. Portable wheel scale EVOCAR 1 from TECHNOSCALE

6.5.1 Experience from using the Technoscale portable scales

In order to be able to use the scales on icy surfaces, it was first necessary to lay down a steel grid on which to place the scales. These were then held in position at the sides with two angle-iron bars that were welded to the grid. Figure 34. The combined height of the grid and scale (45 mm + 6 mm) meant that there sometimes was a problem when heavy four-axle trailers had to be pulled up on the scales by a towing vehicle driving on an icy surface. In any event, all the towing vehicles had to take a run at it in order to get up on the scales with the trailer. It happened all too often that the trailer rolled over and we had to start again from the beginning.

Figure 34. Portable wheel scales from TECHNOSCALE in use at the weighing station.

7. DATA COLLECTION AND AND PRE-PROCESSING

7.1 Vehicle selection and identification procedures.

Basically there were two data sets, one from the static measurements and another from each WIM-system. Each WIM-system measured all the passing vehicles including passenger cars. These two data sets were matched by comparing passing time of the vehicles and number and weight of axles.

The vehicles taken from the traffic flow to be weighed were selected at the test site when crossing the WIM systems. The most important criterion for selection was that the vehicle travelled at a central position in the lane. The crossing time was recorded together with a short description of the vehicle; e.g., ”SCANIA, blue with trailer”. A police officer waiting 2 km downstream was called on the walkie-talkie and asked to stop the blue SCANIA so that it could be weighed on the static scales. When and if the blue SCANIA was stopped, the police officer called back, confirmed that this specific vehicle was stopped and gave the vehicle registration number. The confirmation and registration number were written down at the selection site together with the previously recorded crossing time and description. The real-time clocks in the different WIM systems and the watch that was used at the selection site were all synchronised to the exact second. This procedure made it easy to tag the post-weighed vehicles in the WIM systems files.

The time was recorded in the same way for the test vehicle crossing the WIM systems as for the vehicles selected from the traffic flow. By synchronising the time in the same way as described before, it was subsequently easy to tag the test vehicles in the WIM systems files.

7.2 Data collection and preprocessing

Prior to the test, the organiser sent a request to the manufacturers asking them to provide the WIM-data in a specific format. The aim was to collect vehicle-by-vehicle data from the different systems in a format that would facilitate its being imported into a common database from which data was later extracted.

Immediately subsequent to each of the six short test periods, WIM data was retrieved via modem from each individual system. The systems had been programmed to generate files containing data on each vehicle’s crossing. The data retrieved was first converted from binary format to ASCII format (except for OMNI, where the data was retrieved in ASCII format.)

7.3 Post-processing of data from pavement systems

7.3.1 Database for research analysis.

Data received from WIM-systems was checked and compared with the data collected at the post weighing station. Time and number and weight of axles were compared to get the matches between post-weighed (true data) and WIM measured data. This procedure was done by using a database program and SQL-language, which was used for making the queries. Vehicles being clearly identified from post weighted vehicles and WIM-systems were classified as first category data (certain). The data may still be doubtful due to some other reason, which will be handled later in the report. Vehicles which were clearly matched to WIM data but number of axles differed by one were classified as second category data (doubtful). The data, which could be matched but was totally wrong, for instance number of axles differed by two or more was classified as third category data (poor). Vehicles, which were statically weighed but could not be found from the WIM data, fell into category "missing vehicle".

Percentage of test vehicles in categories 1 and 2 can be seen in Figure 35. Percentage of post-weighed vehicles in categories 1 and 2 is shown in Figure 36.

All WIM-systems were working during the whole test period. OWC started to provide data from the 2nd test day June 1997 due to software modifications. Kistler/Golden River could not provide data during the December 1997 test because the interface was disabled by accident.

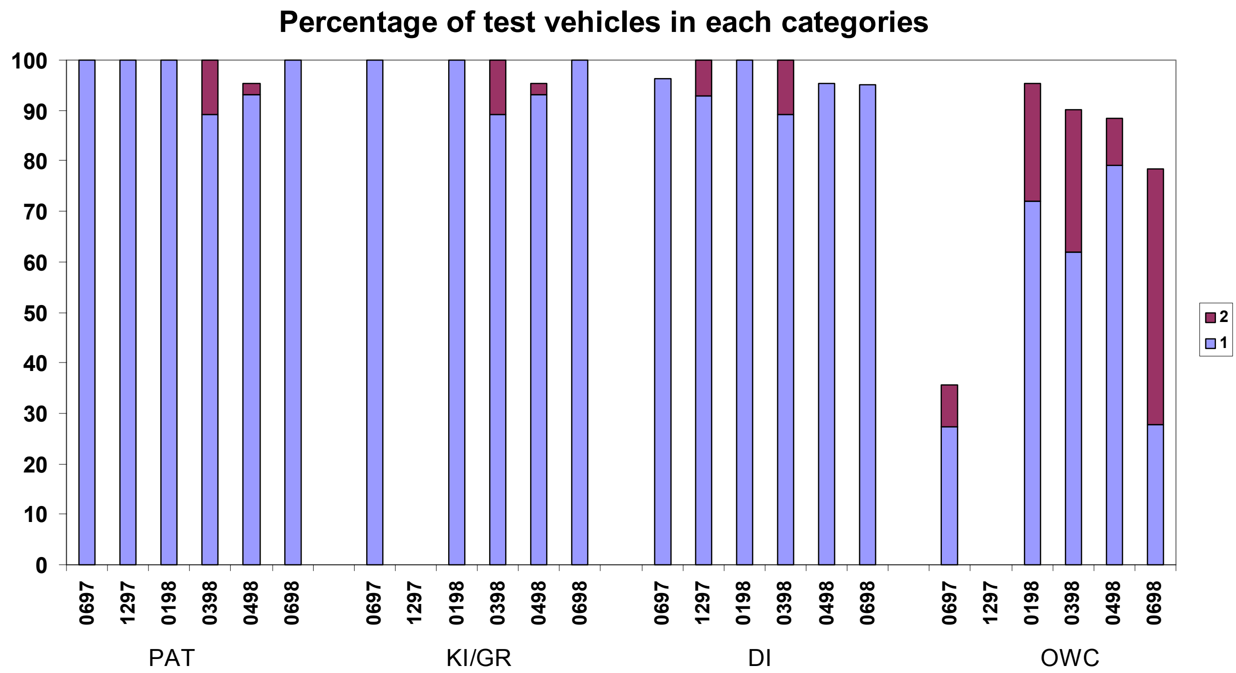


Figure 35. Percentage of test vehicles in each category.

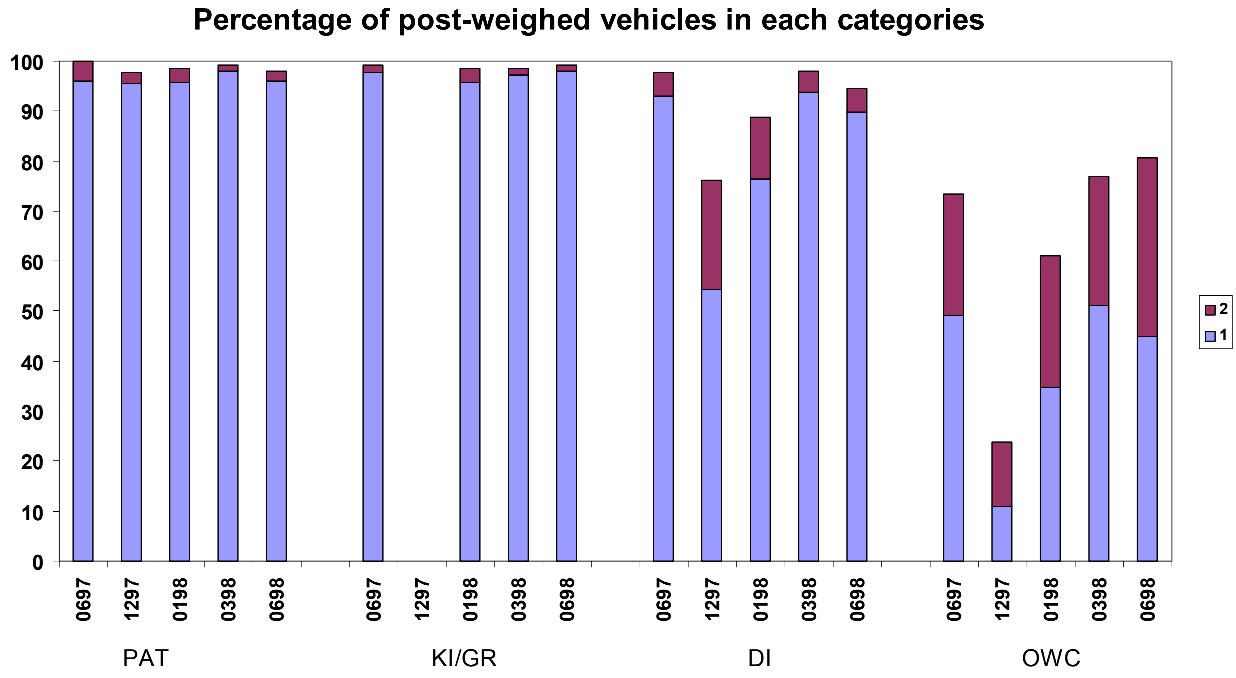


Figure 36. Percentage of post-weighed vehicles in each category.

It was surprisingly difficult to match the vehicles measured at the static weighing station and vehicles from each WIM-system. The information at the weighing station included the axle loads and thus the number of axles was available. The information from the WIM-systems varies depending on each WIM-system but usually each one has time, axle load, spacing between axles, number of axles and speed.

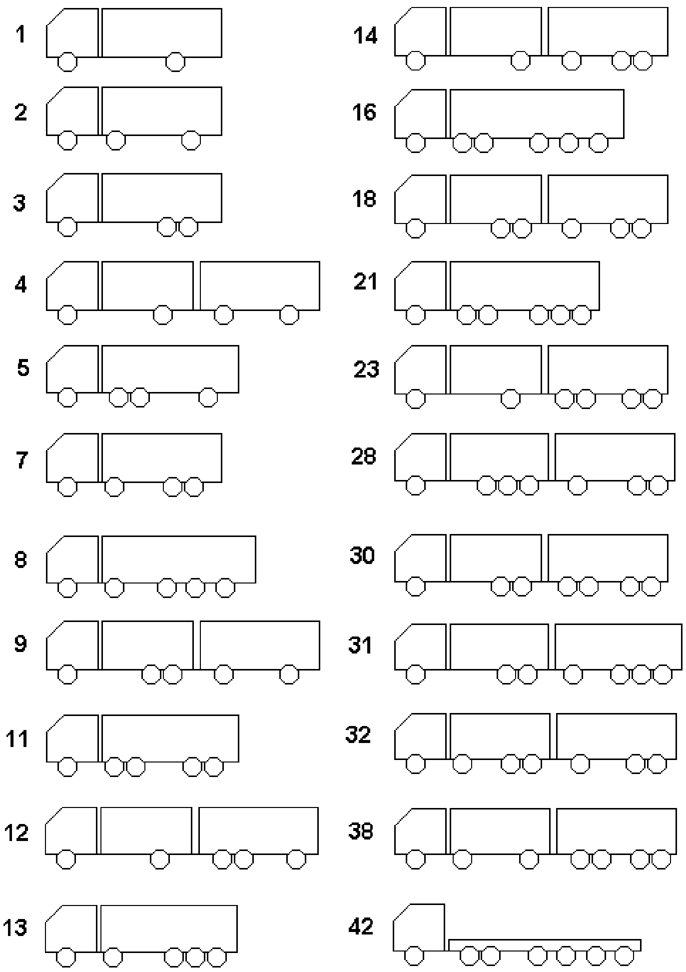


Figure 37. Vehicle types recorded in CET.

Post-weighed data was divided into 22 vehicle types (silhouettes, Figure 37) to make it easier to sort out single axles, axle groups and single axles in axle groups from the data. Classification into types was based on Golden River measurement data. The decision about using Golden River data as the first identification criteria was based on measurements on VTT's own test vehicle in June 1997. Known axle spacings of the test vehicle were compared to Kistler/Golden River and PAT measurements. Kistler/Golden River had better results. For measurements in December 1997 the classification to types based on PAT data because Kistler/Golden River results were lost. The number of recorded vehicles within different types is shown in Table 13.

Table 13. Number of vehicles within different types (silhouettes).

Vehicle type	June 1997	December 1997	January 1998	March 1998	June 1998	Total	Percent-age
1	29	10	12	21	16	88	16.4
2	1			1	1	3	0.6
3	7	2	2	9	7	27	5.0
4	7	4	3	3	3	20	3.7
5	1		1			2	0.4
7	3			1		4	0.7
8				1		1	0.2
9	3	1		3	5	12	2.2
11	1			2	3	6	1.1
12			1			1	0.2
13	6	3	2	9	7	27	5.0
14	3	1	2	1	5	12	2.2
16					1	1	0.2
18	7	3	5	9	9	33	6.1
21	6	4	2	4	5	21	3.9
23	15	4	11	16	23	69	12.8
28			1	2	1	4	0.7
30	39	13	24	61	61	198	36.8
31		1	2			3	0.6
32			1			1	0.2
38					1	1	0.2
42			3		1	4	0.7
TOTAL	128	46	72	143	149	538	100

The classification to types was based on the measured axle spacing and weight of steering axle. The limit value for axle spacing was chosen to be 220 cm. The types were constructed from different combinations of axle spacing (either equal or greater than 220 cm or less than 220 cm). Weight of steering axle had to exceed 1000 kg in order to avoid passenger cars.

It was discovered that there are very few category 1 vehicles, which every WIM-system was found together. Some of the vehicles in category 2 could be moved into category 1 by making small changes in the data. Doing this some more results could be achieved.

Some vehicles were in category 2 because a WIM-system had measured axles of an axle group together. The measurement could be restored to category 1 when moving axles that are behind the falsely measured axle one cell further in data table i.e. giving zero load value for the missing axle. This data of course cannot be used when calculating axles of an axle group but all other single axles or axle groups were available for further analysis.

Vehicle classification system (recording vehicle silhouettes) is essential especially when heavy vehicle silhouettes in traffic flow are very inhomogeneous. That is not perhaps so important in Central Europe where vehicles have less axles, are smaller and more similar.

Further studies should be improved by having such information. The observer who decides which vehicles will be taken to the study marks the silhouette number and the silhouette number is marked at the static weighing station, too. It will not add work but is very useful and saves a lot of time later during the analysis.

7.3.2 Database for the WIM Specification analysis.

The Belgian Road Research Laboratories (BRRC) prepared software for the test analysis. This software called “PESAGE”, in Visual Basic 5.0, allows to transform all file layouts in a common layout, to compare the system files to the static file, to calculate the relative values and to calculate the accuracy of the WIM system after checking the normality of the distribution and skipping out the outliers, if required.

Except in some rare cases, the data received from SNRA came in the original format (TXT format) and the software PESAGE brought them to a common layout by moving the columns.

After checking the chronological presentation of the static files (post-weighed vehicle data and test vehicle data), the comparison is done by answering to the software the number of WIM systems, their name, their estimated timing gap between the static and the system file and their estimated maximal relative error. By safety and to avoid some problem in the recognition, these two last values were taken as big as possible. At this stage, only the data with the good number of axles, with timing and a gross weight with an acceptable discrepancy (defined by the answers to the software) between the system and the static file were taking into account.

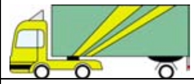
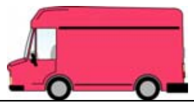
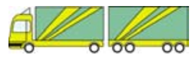
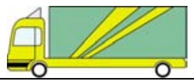
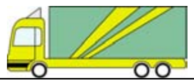
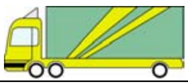
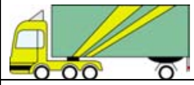
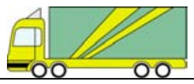
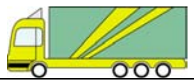
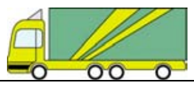
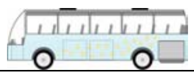
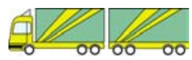
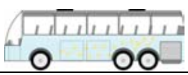
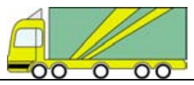
With good answers to the software, around 98% of the vehicles are well identified.

A manual checking is still required to understand why the software did not accept the vehicle identification. The most important reasons are that no vehicle was identified by the system in the timing period or that there is a difference of axle number between the static and the system files. Also, in one or two cases, the problems came from the static file where a vehicle was written without passage timing or without axle loads.

Several times, two types of static systems were present, the weighbridge and portable wheel systems. In this cases, a comparison between both static systems were done by comparing the part of the vehicle measured at once on the weigh-bridge to the sum of those same axles coming from the portable systems and by calculating the relative values between them. If the relative value is higher than 5%, the vehicle is skipped out the static file, in this way, the systems are not penalised by such measurements.

After the comparison, the next step is the calculation of the relative values where the proportion of single axles and of axles of groups are defined by vehicle types, the classification includes 34 categories (Table 14) and is based on the Kistler/Golden River system, on the Pietzsch system and if necessary on the Datainstrument system, never on the Omni Weight Control system as no inter-axle distance was recorded. If the inter-axle distance is lower than 2.2 m, the axle is defined as a single axle. At this stage, a vehicle identified by a system with a violation code (this is the case of Pietzsch system), is marked in the file in a cyan cell. During the calculation of the accuracy, such a cyan cell is counted for the identification rate but is not taken into account for the accuracy.

Table 14: Vehicle classification used for the different analysis

V		S21		R23	
Cte		S22		R24	
C2		S23		R32S	
C3(12)		S24		R32T	
C3(21)		S31		R33	
C4(22)		S32		R42S	
C4(13)		S33		R42T	
C4(121)		S34		R34S	
Bus		S43		R34T	
B3		R22S		R43	
C5		R22T			

For the calculation of the theoretical accuracy, the normality distribution is checked and outliers are eliminated, those are written in a green cell and are not taken into account for the accuracy analysis but well for the outlier rate. This theoretical analysis is rarely done by a customer and defines the best available accuracy on this site for the system after elimination of all doubtful vehicles.

The Table 15 presents the number of post-weighed vehicles per period for each system and the total number coming from the static file (after elimination of doubtful static values). The number of violation code (VC) vehicle is written.

Table 15: Number of identified post-weighed vehicles per each system

	Static	**KI/GR**	**DI**	**PAT**	**OWC**
June 97	123	122	120	119 + 4 VC	60
December 97	44	No data	22	38 + 6 VC	3
January 98	58	58	47	57 + 1 VC	29
March 98	137	136	130	131 + 6 VC	67
June 98	148	144	139	141 + 6 VC	68

7.3.3 Comparison between the databases

The two databases mentioned above were built separately for the WIM Specification analysis at the BRRC and for research analysis at the VTT, respectively. Due to different objective of these two analyses also the evaluation of collected data was carried out by both parties independently. Later the databases were compared and checked together. Number of equally identified post-weighed vehicles can be seen in Table 16. The last column includes all post-weighed vehicles, which were fallen in categories 1, 2 or 3 in the data check done by VTT. PAT and Kistler/Golden River did not have problem to recognise properly chosen vehicles from the traffic flow. Big differences on Datainstrument and especially on OWC figures are due to large amount of missing vehicles (see Figure 36 above).

Table 16. Number of mutually agreed post-weighed vehicles between BRRC and VTT. Number of VTT's data in last column.

	PAT	DI	KI/GR	OWC	VTT
June 1997	123	120	122	60	128
December 1997	44	22	No data	3	46
January 1998	68	53	67	32	72
March 1998	143	137	143	73	143
June 1998	148	139	144	69	149

7.4 Post-processing of data from Bridge WIM systems

The data was processed independently in ZAG and TCD/UCD using different Bridge WIM algorithms. The algorithm developed by ZAG is known as SiWIM while that developed in Trinity College Dublin and University College Dublin will be referred to as DuWIM.

7.4.1 TCD/UCD Post-Processing (DuWIM)

The recorded binary files were first converted into text files using a Labview program. The files were then converted into a Turbo C binary format. The same program called Voltage (by Gonzalez) was used to extract the files and convert them into a Text format that could be opened in Excel. The Excel files were further manipulated and the strain readings were used to measure axle and gross vehicle weights using the DuWIM algorithm based on Moses' work.

Some strain sensors were significantly more sensitive to the effects of individual axles than others, as is illustrated in Figure 38 (this may be due to the transverse position of the sensor relative to the position of the vehicle wheels). Therefore, for the 1st summer test, the results of only one strain sensor, No. 4, were used for all the DuWIM analysis. For the winter test, six of eight strain sensors, Nos. 2 – 7, appeared to give good distinct responses to individual axles and were used. For the 2nd summer test, a comparison was made to determine whether or not it is beneficial to omit some sensors from the analysis. Thus, in one DuWIM analysis, all eight gauges were used while in another, only one sensor, No. 6, was used.

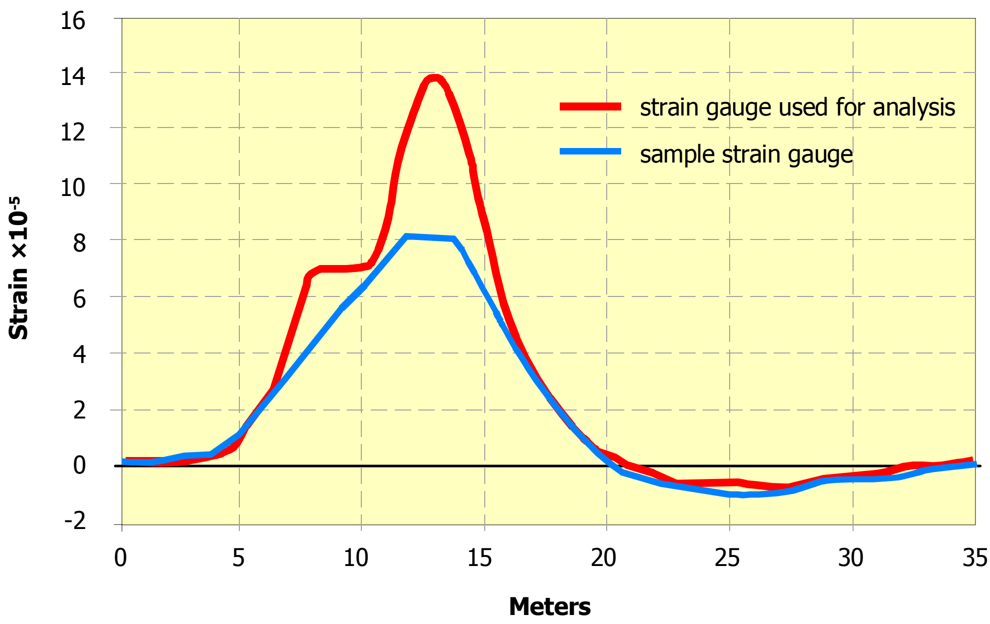


Figure 38: Comparison of response of different strain gauges to three axle truck

Moses' algorithm uses an influence line to generate an 'influence response' due to the truck which is compared with the recorded strain. To achieve good accuracy from B-WIM algorithms, it is imperative that the influence line is as close to reality as possible. The different approaches used to find a good influence line in this work included simple theoretical influence lines, theoretical influence lines incorporating rotational springs at the supports and experimental influence lines.

7.4.2 Simple theoretical influence lines

Using the STRAP structural analysis package, a simplified frame model of the Bridge was developed and a theoretical influence line was obtained. For the model it was assumed that the central pier was fixed at its base while the abutments were assumed to be pinned at their bases as illustrated in Figure 39. The modulus of elasticity was taken to be 30×10^6 kN/m^2. The second moments of area were assumed to vary in accordance with the varying depths of the members. The resulting influence line is illustrated in Figure 40 where it can be seen that an axle travelling over the second span has little effect on strain gauges located at the centre of the first span.

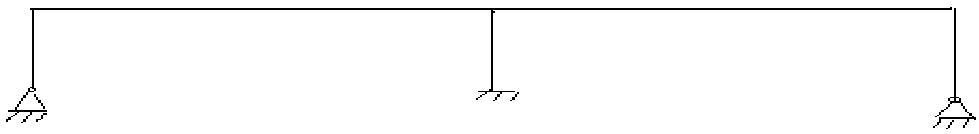


Figure 39: Outline of computer model for simple theoretical influence line

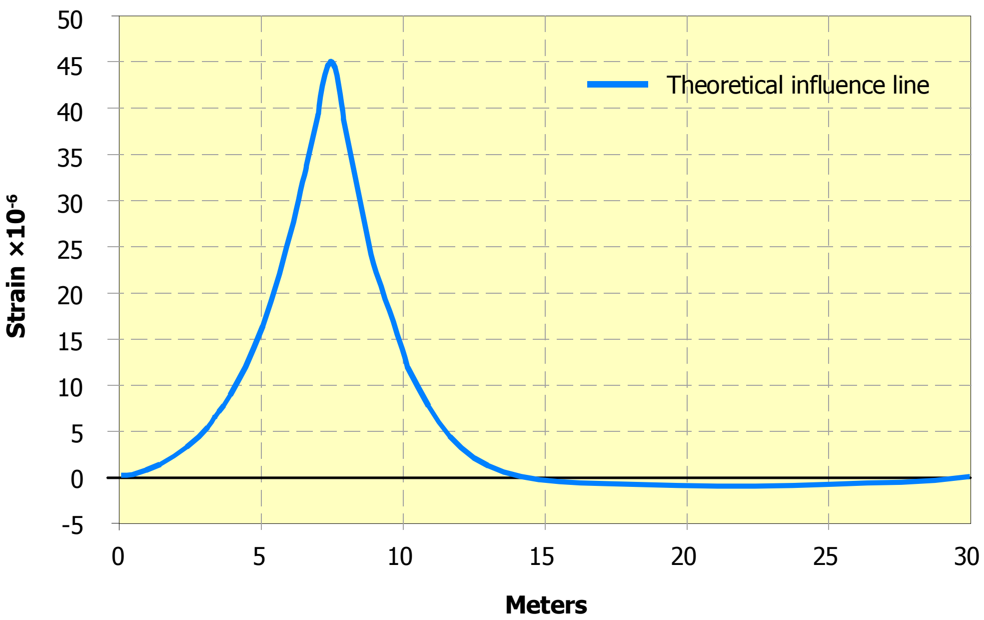


Figure 40: Simple Theoretical Influence Line

To check the validity of the influence line, it was used to generate theoretical responses to the calibration trucks with known axle loads, going over the bridge. The results are compared with the corresponding measured responses in Figure 41. It can be seen that there is reasonably good agreement between theoretical and measured responses in the first half of the graph where the values are dominated by the influence line ordinates for the first span of the bridge. In the second half of the graph however the agreement between theoretical and measured responses is much worse. This is due to an assumed rotational stiffness component from the pier in excess of the actual value.

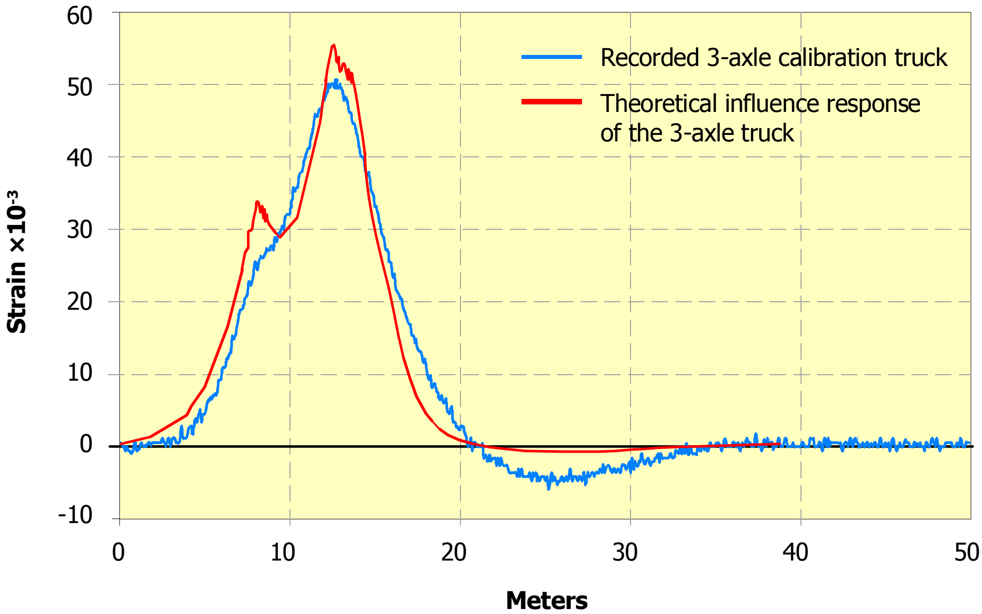


Figure 41: Comparison of actual and theoretical influence responses for a three axle truck

7.4.3 Use of rotational springs and other modifications for the low speed influence line

For the 1st Summer test the influence line was re-calculated using rotational springs to represent the stiffnesses provided to the bridge deck by the central pier (and assuming that the supports were pinned). A spreadsheet was used to develop this model and to determine the precise values of the rotational spring which gave the best match between theoretical and measured responses to all runs of the calibration trucks at 50 km/hr. The optimal spring stiffness value was used to generate a new influence line, illustrated in Figure 42. The resulting influence responses gave a much better agreement with the recorded trucks travelling at 50km/hr as can be seen in Figure 43. The influence line of Figure 42 was used in the calculation of the axle weights of the 50km/hr calibration trucks and also for any of the pre-weighed trucks that were travelling at speeds close to 50km/hr.

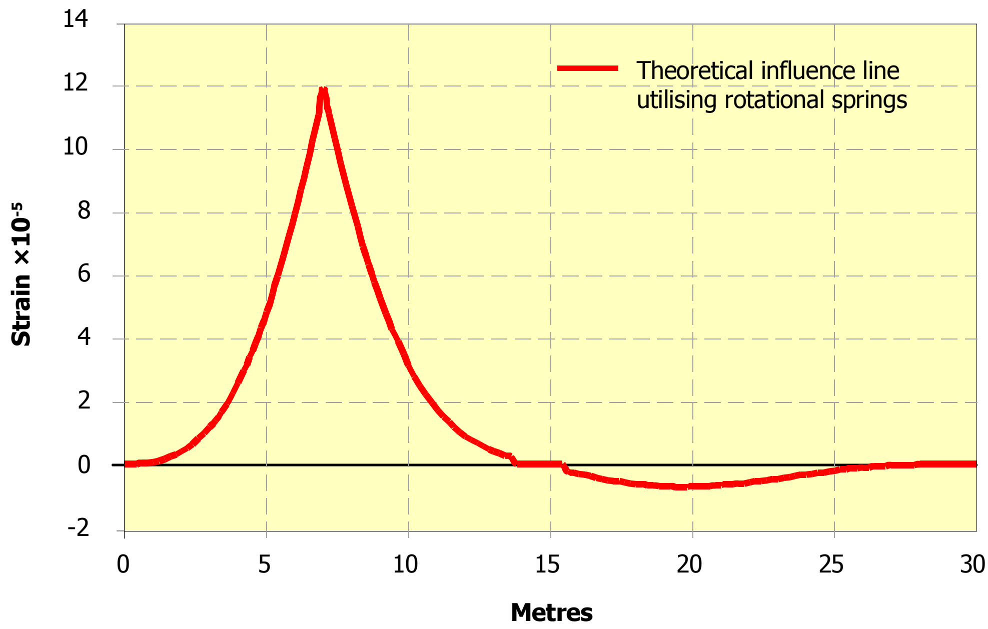


Figure 42: Modified theoretical influence line utilising rotational springs appropriate to the trucks at 50km/hr

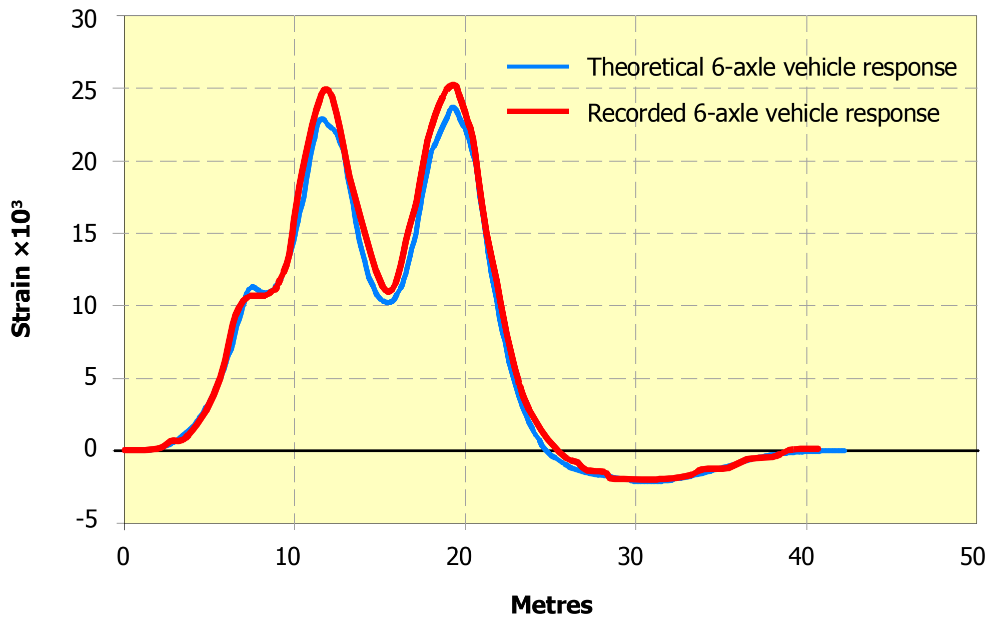


Figure 43: Comparison between modified theoretical influence response and recorded truck at 50km/hr

7.4.4 Experimental Influence lines

While the modified theoretical influence lines gave good results at 50 km/hr for the 1st summer test, it became apparent while the faster calibration trucks were being analysed that the influence response was sensitive to truck speed as can be seen from Figure 44. It is evident in this figure that the peaks of strain from the axles at the midpoint of the bridge are lower for the 80 km/hr truck and less well defined than for the 50 km/hr truck. For example the steering axle has a noticeable effect at 50km/hr but is less obvious at 80km/hr. The 80km/hr curve is also noticeably ‘broader’ than the 50 km/hr one.

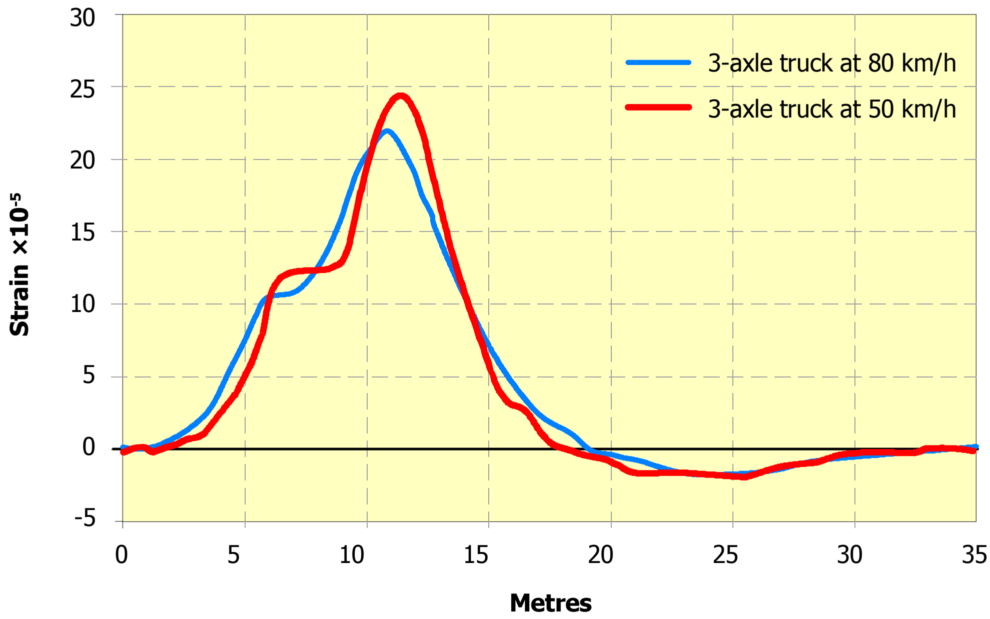


Figure 44: Comparison of the same truck at different speed under a 4Hz filter

7.4.5 Effects of Filtering

It was found that the link between influence response and speed was associated with the fact that the data in the 1st Summer and Winter tests had been filtered at 4 Hz by an analogue filter in the data acquisition system. In the early stage of the measurements it had been expected that this filter, which was the only one available in the system, would eliminate the noise and thus improve the quality of signals. The results of the first summer and the winter tests however showed that frequencies up to 30 Hz could not be neglected. It can be clearly seen in Figure 46, which represents a measured strain signal in the frequency domain, that the major frequency components are between 0 and 4Hz but that a significant portion of the signal is at frequencies in excess of 4 Hz. It can therefore be expected that a 4 Hz filter will adversely affect the accuracy of the signal.

This is confirmed in Figure 45, which shows typical influence responses at different speeds using unfiltered data from the 2nd Summer test. In this case speed had little or no influence on this *unfiltered* data. Furthermore, a raw, unfiltered signal from the 2nd Summer test was filtered with a digital (Butterworth) filter in Matlab in the 4-7 Hz transition band. The filtered and the unfiltered signals are graphed with in Figure 47. It can be clearly seen that the applied filter caused a major loss of definition in the peaks, which relative heights also decreased considerably. This confirms that filtering at 4 Hz, as was done in the 1st Summer and the Winter tests, reduced quality of the recorded data and consequently lowered accuracy of the calculated gross vehicle weights and particularly the axle loads.

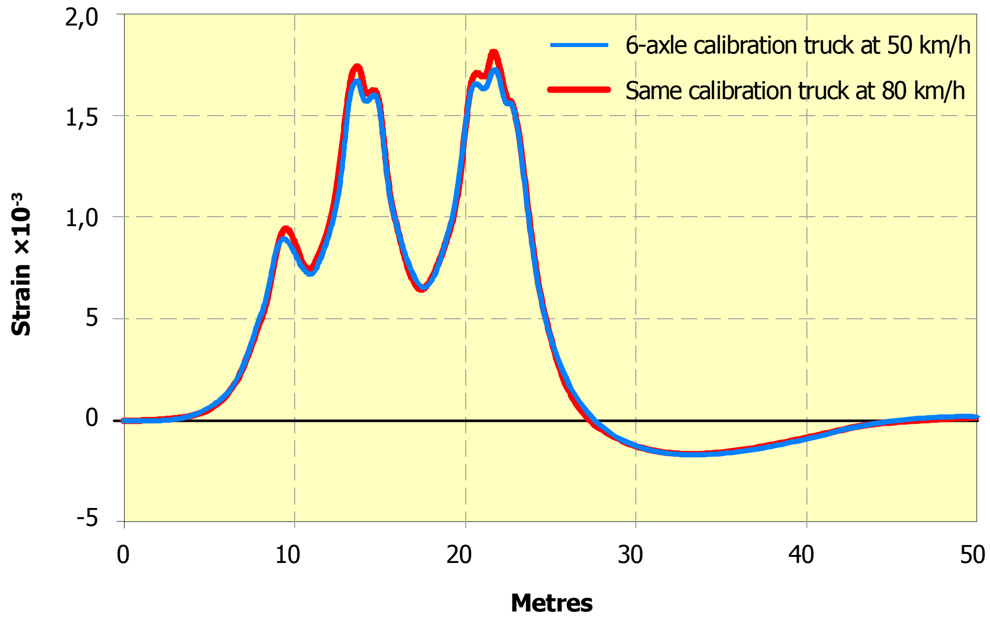


Figure 45: Comparison of the same truck at two speeds without a filter

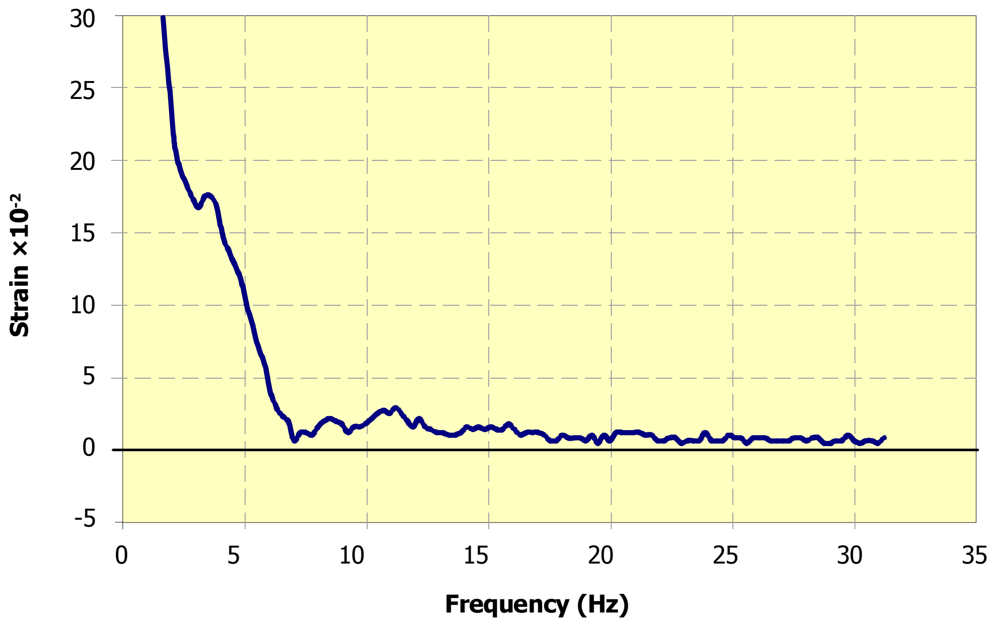


Figure 46: Six axle truck signal in frequency domain

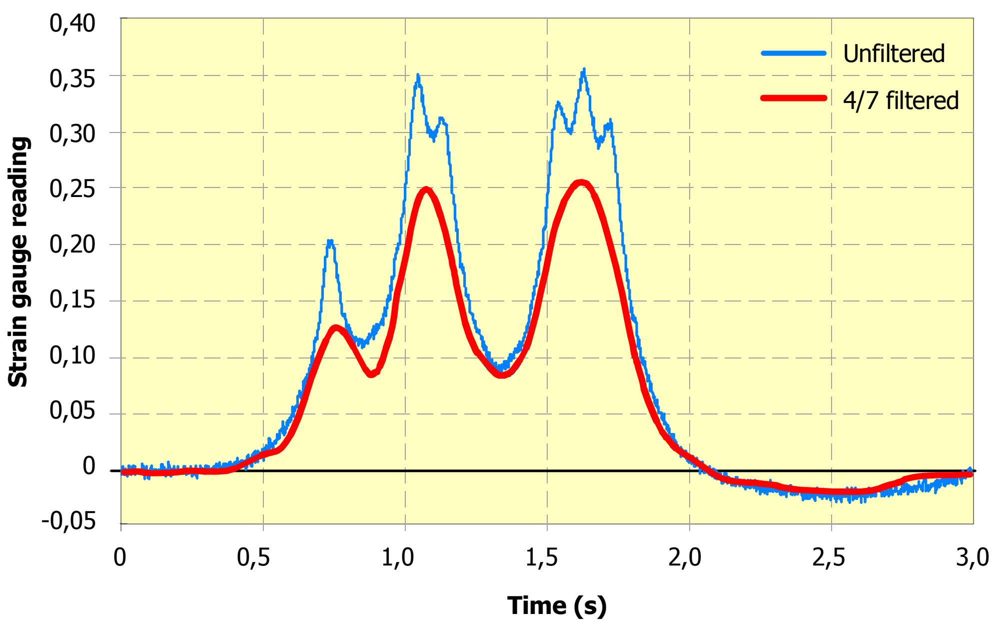


Figure 47: Comparison of filtered and unfiltered data for filter with 4-7 Hz transition band

7.4.6 Experimental Influence Lines

The simple theoretical influence line provided a good match to measured calibration trucks at 50 km/hr. However, the majority of the random traffic trucks in the first summer test were recorded at about 80 km/hr which necessitated the development of a new influence line for higher speed trucks. This influence line was derived from the experimental responses by trial and error. For the first summer test there were only 29 good calibration truck runs of which half were at 80km/hr. Taking all the runs of the fast three axle trucks, a mean truck response was obtained. The modified theoretical influence line used for the 50 km/hr trucks was used as a starting point. The influence line curve was then modified point by point, until its influence response matched the mean 80 km/hr calibration truck response – see Figure 48. At this stage the influence line was checked for accuracy. This was done by considering all the 80 km/hr runs of the six axle calibration truck which were found to give a good match. The influence line used for all the fast trucks in the 1st Summer Test is shown in Figure 49. It can be seen that it shares many common points with the modified theoretical influence line used to analyse the low speed vehicles.

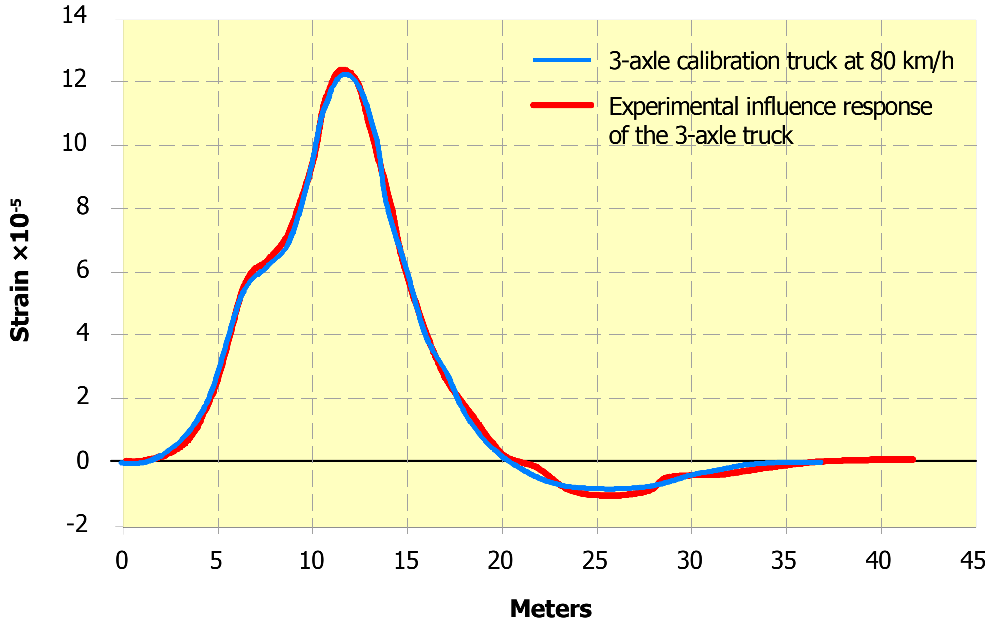


Figure 48: Comparison of experimental influence response with actual recorded truck

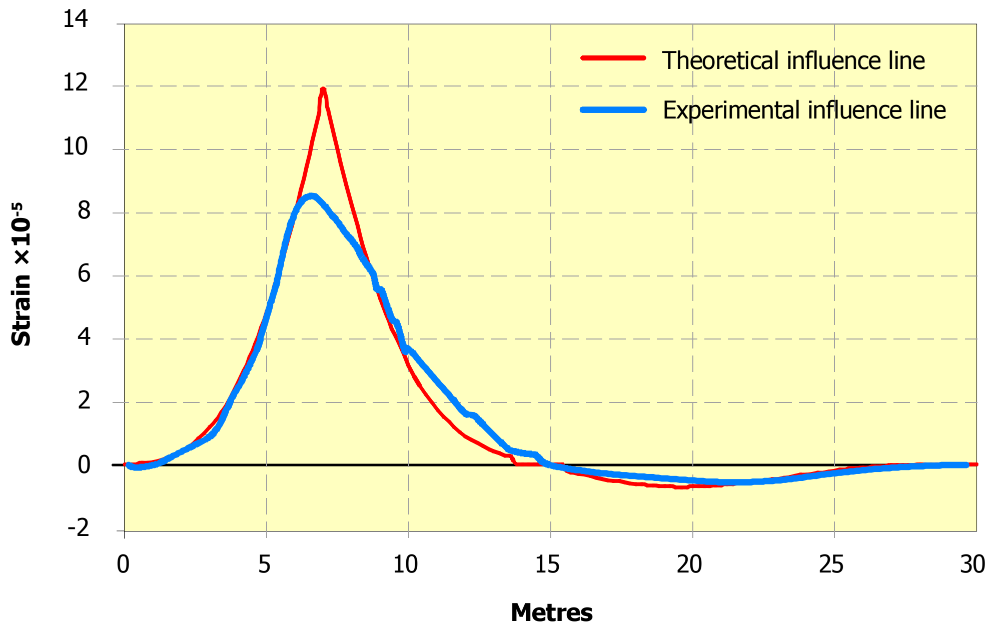


Figure 49: Comparison of experimental and modified theoretical influence lines for 1st Summer Test

There were two types of calibration truck used for the winter and 2nd summer tests with three different weights for each of the two truck types so an influence line and its response could be checked graphically many times. Experimental influence lines were applied to analyse all the random traffic and fast calibration trucks in the 1st summer test. For the Winter test new experimental influence lines for the different behaviour of the bridge in sub-arctic Winter conditions were obtained (the evidence suggested that the frozen soil resulted in greater stiffnesses at the bases of the abutments and piers). The two influence lines were both obtained using the method (outlined above) that was used to obtain the 80km/hr influence line for the 1st summer test. They are illustrated in Figure 50.

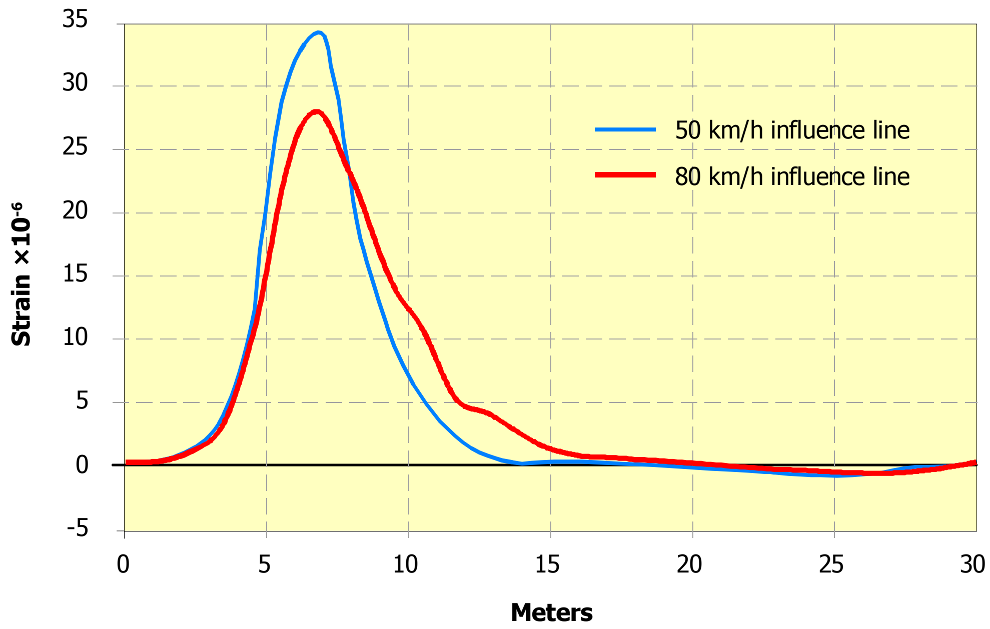


Figure 50: Low- and high-speed experimental influence lines for winter test

Only one influence line was required for the 2nd summer test as data was unfiltered and the response was insensitive to speed. This influence line, illustrated in Figure 51, was also obtained experimentally.

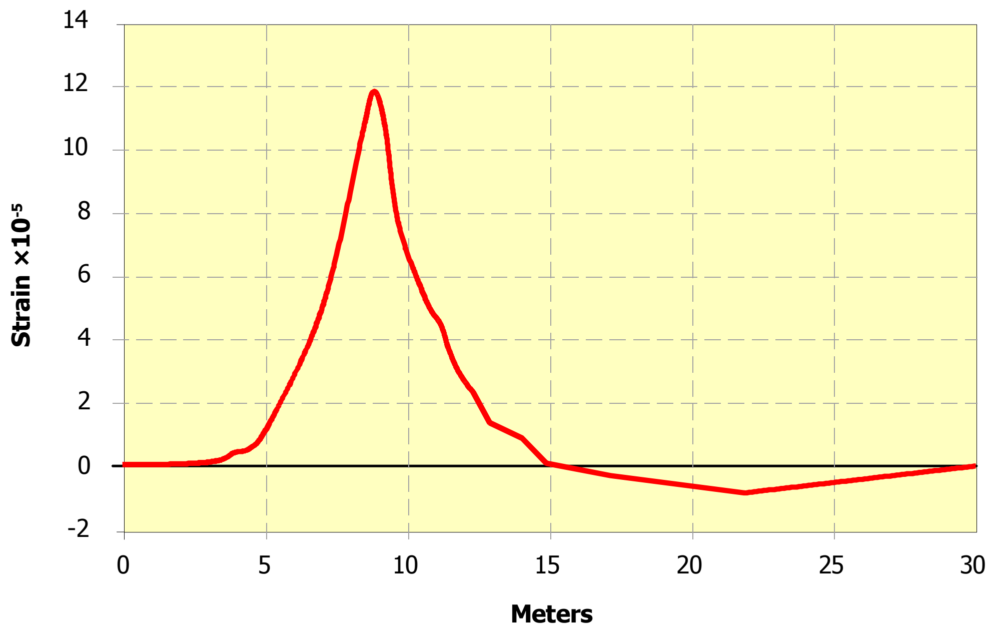


Figure 51: Experimental influence line for 2nd Summer test

7.4.7 ZAG Post-Processing (SiWIM)

Bridge WIM measurements were part of the Cold Environment Test (CET) in Luleå and were performed by Trinity College Dublin and University College Dublin. Part way through the project, the WAVE consortium appointed ZAG to independently evaluate recorded data from Luleå with the SiWIM software. The results are presented in detail on page 127. To prepare input data recorded by the Irish data acquisition system, for SiWIM processing, it was necessary to convert all recorded files into the ACQ file format (see WP 1.2 report). Before applying the bridge WIM algorithm, some difficulties due to the low-pass 4 Hz filtering, which smeared the axle detector signals of the first two weighing sessions in summer 1997 and winter 1998, had to be resolved. This was done by developing an algorithm that used up to 4th derivatives of the axle detector signals to identify all and not to miss any of the axle passes. Only simple conversion into the ACQ format was necessary in summer 1998 for the unfiltered data.

SiWIM software processes data in real time either from the direct data flow on the site or from the recorded ACQ files. The processed results are stored in ASCII files giving, for each vehicle, date and time of weighing, its class, velocity, gross weight, axle loads and axle spacings. Figures 52 and 53 illustrate two characteristic windows of the program:

- the *monitors* window, which follows and displays all measured channels and reports activities during the weighing process, and
- the *results* window, which displays time, class, velocity, gross weight, axle loads and axle spacings of a weighed heavy vehicle and time, class, velocity and axle spacings of light vehicles.

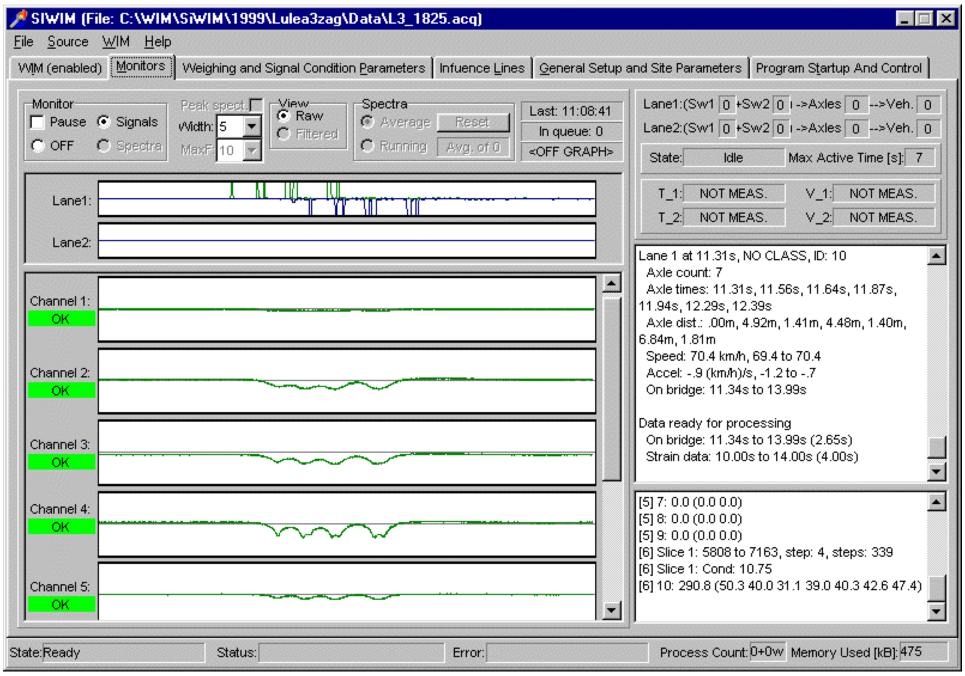


Figure 52: SiWIM software – the *Monitors* window

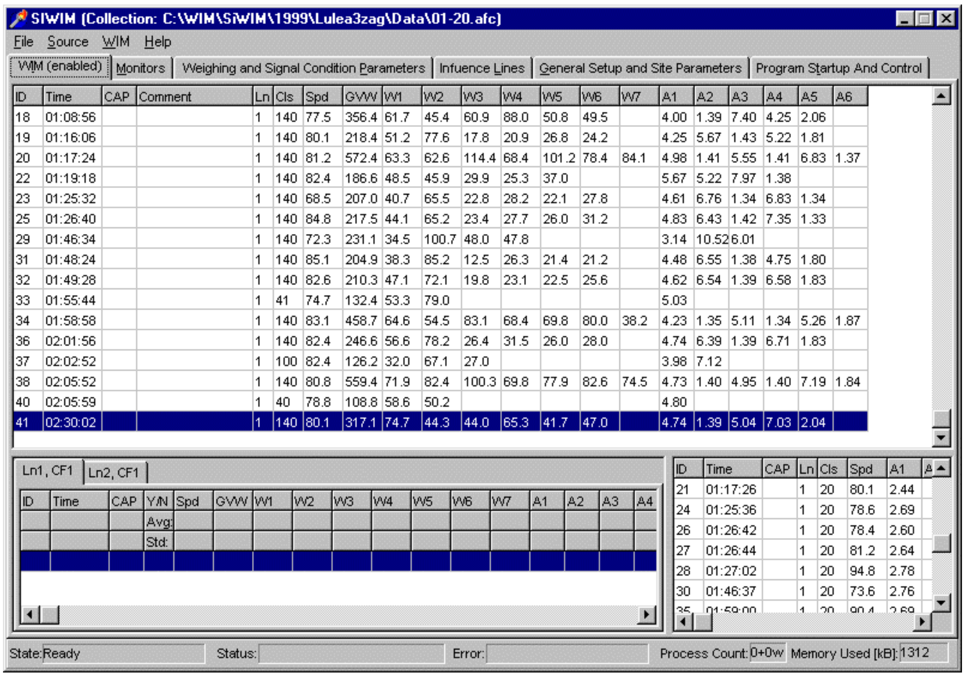


Figure 53: SiWIM software – the *Results* window

When evaluating data, an experimental influence line was used in all cases. Similar problems as with DuWIM calculations were observed, as the influence lines were dependent on the vehicle velocity, the main reason being the applied 4 Hz low-pass filter. As most of the vehicles were travelling with speed of around 80 km/h, the influence line from the corresponding calibration runs have been used.

8. TEST ORGANISATION AND MESUREMENTS IN SWITZERLAND

8.1 Test site and preparation of the test

8.1.1 General

This work is following a test of WIM sensors and WIM systems in Zurich-Hagenholz in the time period 1993 to 1995. The report of the Hagenholz test is published [1] within the COST 323 (WIM-Weigh-in-motion of road vehicles).

8.1.2 Initial situation

At the Hagenholz test site five different WIM systems were tested and compared with each other.

The following report deals with two installed WIM systems in two important traffic axis in Switzerland. The report does not deal with the collected WIM data during the installation period of these two WIM sites, only with the calibration and recalibration data. The periodically calibration tests were done in the time period from 1996 to 1998.

The Swiss Highway's Office (ASTRA, OFROU) together with the Swiss Federal Institute of Technology (ETH) checks these two WIM sites every year.

8.1.3 Pavement and road conditions

Longitudinal evenness

For classifying the test site the evenness is measured by the ETH-IVT equipment protractor. The results are shown in Figure 55. While driving down the road the angle between the three wheels contacting the road surface is measured electronically. The distance between the wheels is 1.00 m. The measurement is done in accordance with the Swiss standards on evenness measurements and requirements. (Swiss standard SN 640 520a + SN 640521b) the commonly used checking procedure of evenness in Switzerland.

The decisive result to describe the unevenness of this measurement is the standard deviation of the angle over a distance of 250 m or more. The angle is determined 40 times per meter.

The evenness is measured over a distance of 500 m before the WIM installation and 50 m afterwards.

Figure 54. Protractor from the IVT

Lateral evenness

The lateral unevenness is determined by measuring the maximum distance between a 3 m edge and the surface of the road. The measurement is done just after the WIM installation.

Skid resistance

The skid resistance describes the structure of the road surface but it is not directly affecting the dynamic load of the wheels. Nevertheless the results of the skid measurements give an image of the macrotexture.

Figure 55. The skid resistance is measured.

Table 17. Geometry and surface characteristics of the WIM sites

Description	Unit	Gotthard site		SanBernardino site	
		to South	to North	to South	to North
Pavement	type	Bit (flex)	Bit (flex)	Bit (flex)	Bit (flex)
Slope longitudinal	[%]	< 2	< 2	< 2	< 2
Slope transversal	[%]	< 3	< 3	< 3	< 3
Radius of curvature	[m]	> 1000	> 1000	> 1000	> 1000
Evenness, IRI	IRI	0.507	0.573	1.693	1.543
Evenness, slope angle, sw	o/oo	0.761	0.860	2.539	2.315
Rutting, 3m edge	[mm]	< 4	< 4	< 4	< 4
Deflection	[mm]E-2	NN	NN	NN	NN
Skid resistance	[-]				
Site Class		I	I	II (I)	II (I)

8.1.4 Traffic

Mean daily traffic Gotthard

The most important traffic data of the Gotthard axis are listed in Table 18 and Table 19. The results are based on the years 1996 and 1997 of the census point No 150. The quota of heavy traffic is high. Geometrical data are shown in Table 17 and are based on the year 1997.

Table 18. Traffic on the Gotthard test site

AADT	AADT	Highest AAMT	Highest week day	Highest Satur-day	Highest Sunday	Average annual daily heavy traffic on weekdays
Number of vehicles	17440	25527	32193	36488	31456	3330
Percentage of AADT	100%	146%	185%	209%	180%	19%

Table 19. Weekly traffic on the Gottard site classified by length (1997)

AADT	Average annual weekday traffic	N -> S	S -> N	< 6 m	6 – 12.5 m	> 12.5 m
Number of vehicles	16254	8303	7951	12276	1414	2564
Percentage of AADT	100%	51%	49%	76%	9%	16%

Mean daily traffic SanBernardino

The most important traffic data are listed in and Table 20 The results are based on the years 1996 and 1997 of the census point No 202 (Plazzas tunnel) and No 44 (San Bernardino). The quota of heavy traffic is not as high as in the SanBernardino route. Geometrical data are shown in Table 21 and are based on the year 1997.

Table 20. Traffic on the SanBernardino, Plazzas test site

AADT	AADT	Highest AAMT	Highest week day	Highest Satur-day	Highest Sunday	Average annual daily heavy traffic on weekdays
Number of vehicles	7698	12090	17099	20319	17959	980
Percentage of AADT	100%	157%	222%	264%	233%	13%

Table 21 Weekly traffic on the SanBernardino site classified by length (1997)

AADT	Average annual weekday traffic	N -> S	S -> N	< 6 m	6 – 12.5 m	> 12.5 m

Number of vehicles	4671	2453	2218	4021	356	295
Percentage of AADT	100%	53%	47%	86%	8%	6%

8.1.5 Climate

Climate Gotthard

The WIM-sensors are located inside the northern tunnel entrance near Göschenen. Göschenen is at the entrance of the valley Schöllenenschlucht leading to the Gotthard pass and the Gotthard tunnel. Göschenen is about 1100 m above sea level. In summer the average temperature is about 13°C in Winter about -3°C.

There is about 4 months in a year snow and the road outside the tunnel has to be salted.

The temperature ratio between day and night are damped by lack of albedo effects and sun radiation and the compensation effect of the long Gotthard tunnel.

Because of the tunnel, the concentration of harmful substance causing corrosion is very high because of the water the vehicles bring into the tunnel that is not washed away by rainfall.

Climate Plazzas tunnel

The WIM sensors are installed in the Plazzas tunnel. This tunnel is 300 m long and is located near Bonaduz (660 m above sea level). The average temperature is + 16°C in the summer and -1°C in the winter. Most of the vehicles driving northwards come down from the San Bernadino tunnel, its entrance is located 1610 m above sea level. In winter the road is heavily salted, and the concentration of corrosive substances is very high.

8.2 Test plan

8.2.1 General

In 1995 two WIM-Systems have been installed in important traffic-axes through Switzerland (Alpine transit routes). The first is installed in the Gotthard-Tunnel (Golden River), the second on the San Bernadino motorway (System PAT). Over one million vehicles are measured by single-axle-weights as well as by geometry every year as shown in

Table 18. Traffic on the Gotthard test site,

Table 19. Weekly traffic on the Gottard site classified by length (1997)

Table 20. Traffic on the SanBernardino, Plazzas test site,

Table 21 Weekly traffic on the SanBernardino site classified by length (1997).

Technical details and description of the sites is in chapter “WIM-systems” below. In this period (96,97,98) both WIM Systems were working with only very few interruptions.

8.2.2 Measuring periods

Once a year the accuracy tests of the WIM systems were realised in co-operation with the ASTRA and the Cantonal Police. The data of the accuracy-tests and the related report are listed in Table 22.

During each check in each direction and lane about 40 to 70 trucks were selected out of the heavy-traffic. The static weight and the geometry were measured and compared with the WIM-measurements collected from the WIM-datalogger. The detailed test procedure is described in chapter “Results from Switzerland” below.

8.2.3 Schedule

The action schedule is listed in Table 22.

Table 22. Schedule of the accuracy tests.

Year	Date	Gotthard	Remarks
1996	Oct 23.	WIM S-N	
	Oct 24.	WIM N-S	
1997	Oct 23.	WIM S-N	
	Oct 24.	WIM N-S	
1998	Oct 22.	WIM S-N	Replacement of the capacitive sensor by a Quarz sensor Kistler
	Oct 23.	WIM N-S	
Year	**Date**	**San Bernardino**	
1996	21. Mai	WIM N-S	System installed January 1996
	22. Mai	WIM S-N	
1997	27. Mai	WIM S-N	
	28. Mai	WIM N-S	
1998	12. Mai	WIM S-N	
	13. Mai	WIM N-S	

∗1) The system is installed

8.3 Test layout

8.3.1 Gotthard

The WIM system is installed on the motorway A2- the most important alpine transit axis in Switzerland. The system is installed at a two lane section of the A2-Motorway. The four lanes motorway is narrowed to two lanes just before the entrance of the Gotthardtunnel. The WIM system is installed not far from the northern entrance section. In the tunnel only two sensor-sets had to be installed. The sensors are exposed to the special tunnel air conditions and the use of salt but they are less stressed by temperature changes and rain.

The WIM installation for both directions is situated in the tunnel axes near niche 12. The static weight was done in a side tunnel. There is enough place for a lot of trucks waiting to be statically weighed. An electrical supply is also available.

Figure 59 shows the installation site of the Gotthard WIM system. A first installation of the sensors was done directly in the northern tunnel entrance. This installation was negative influenced because of the road geometry and because of frequent break actions of the drivers entering the tunnel. A small curve disturbed the operationability of the sensors. The S-curb just afterwards influences the driveability of the truck drivers going northwards. The wheels often missed the sensor and the results were very bad. That is why the WIM installation was shifted closer to the inside of the tunnel.

8.3.2 San Bernardino

The WIM system is installed on the motorway A13, the second important alpine transit axis. The bending plates sensors are situated in a 300 m long tunnel (Plazzas tunnel), in the north of the San Bernardino tunnel. The climate conditions are nearly the same as in the entrance of the Gotthard tunnel. The Data logging and the video control of the WIM system is located about 5 km southwards of the Plazzas tunnel. The situation is shown in Figure 56.

The static measurement is done directly on the motorway 5 km south of the WIM installation. During the calibration tests, the motorway was closed for the normal traffic; only the selected vehicles were directed to the static test site. The normal traffic was diverted over the exit and next entrance of the motorway A13. This traffic management allows a very comfortable static measurement procedure.

Southbound

Figure 56. Static weighing on the motorway, behind, trucks are waiting to be weighted. Two men are measuring the distance between the axles.

8.4 Technical description of the static weighing system

To measure the static weight, a scale plate for wheels (HAENNI; type WL 103) is used.

After the measurement of all wheels of the truck the data logger EC 100 gives an output on a paper with the gross weight, the single axle weight and the weight of a each wheel. It's no problem to weight tandem and triple axes because the pad has exactly the same height as the scale plates and the middle axle out of the triple axle is not lifted up.

The scale plates are calibrated officially every year, the guaranteed accuracy is better than ± 50 kg

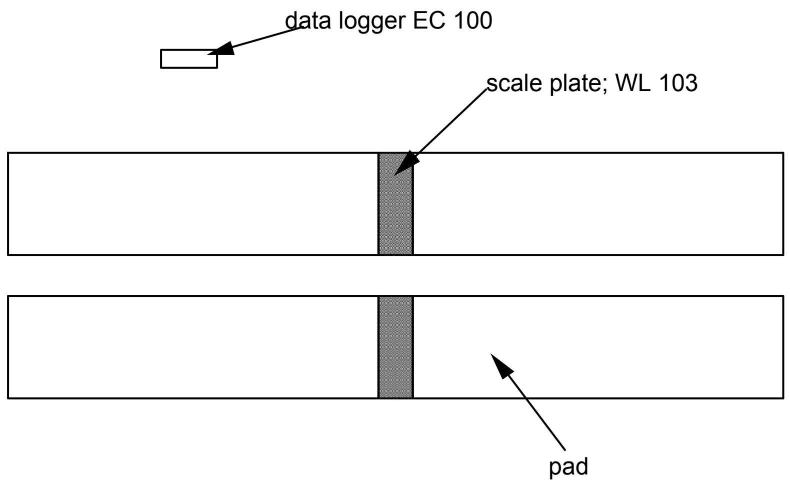


Figure 57. Schematic overview to the static weight measurement equipment (WL103) from HAENNI

Figure 58. Photographic view of the wheel bridge HAENNI WL 103

8.5 WIM-Systems

8.5.1 Technical description of the WIM-System at Gotthard

The system Golden River was installed in June 1995. The datalogger is a GR Marksman 660.

The system consists of four WIM capacitive strips (weighing sensors) and two inductive loops in each direction. Two of them are installed in one line to record the left and the right wheel.

In Spring 1995 the WIM system was installed in a curve, which was not suitable. In June 1995 the WIM system had to be displaced to a straight track, the same type of strip sensors (capacitive sensors) was installed. In June 1998 the sensors were replaced with Kistler Lineas Piezo-Quarz sensors. These sensors are manufactured in length of 750 mm and 1000 mm. Four of the longer ones were installed in the WIM system. These sensors are shorter than the Golden River sensors.

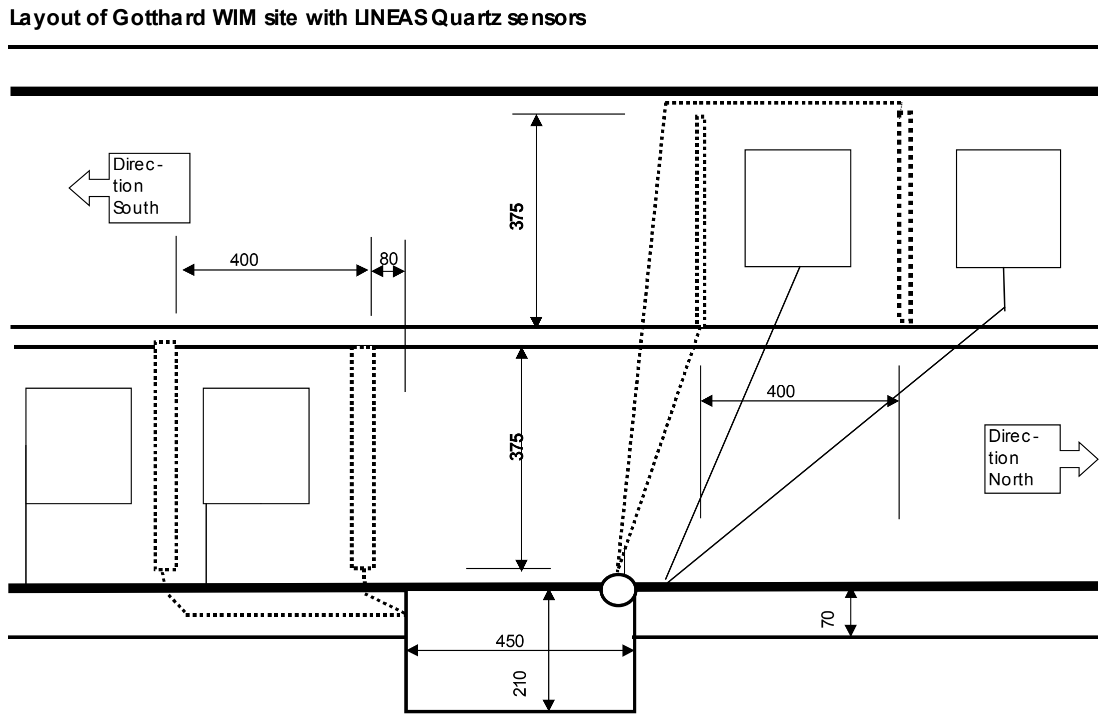


Figure 59. Schematic elevation of the Golden River capacitive strip sensor

8.5.2 Technical description of the WIM-System at San Bernardino

This WIM-system consists of two1.75x0.5 m bending plates manufactured by Pietzsch (System PAT) equipped with two inductive loops. The bending plates are fixed in a steel frame. The joints were filled up with epoxy resin. The data logger is a DAW 100. The WIM system was installed in January 1996 within two days.

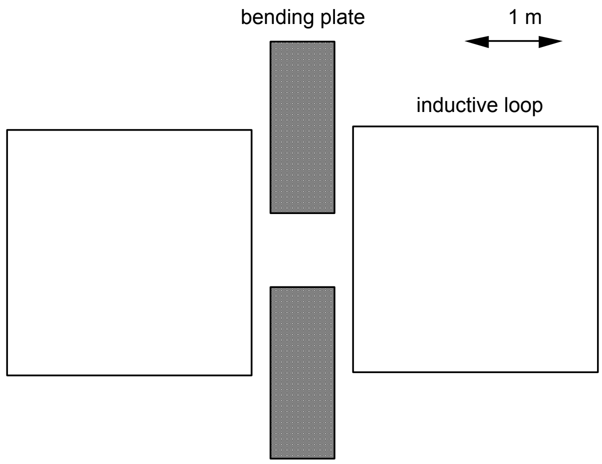


Figure 60. Schematic elevation of the PAT system with bending plates for one direction

9. RESULTS FROM SWEDEN

9.1 Accuracy analysis according to the WIM-specifications

9.1.1 Theoretical background

According to the COST 323 European Weigh-In-Motion specifications, accuracy classes are defined by the relative width of the confidence intervals with regard to reference weights, generally equal to static weights. The levels of confidence of these intervals vary according to the acceptance and verification test conditions. Four accuracy criteria concerning the weights must be taken into consideration:

- the gross weight
- the weight of single axles
- the weight of axle groups,
- the weight of axles in a group.

The test conditions influencing the required levels of confidence are: (a) the duration of the test and the environmental conditions, (b) the number of lorries and the loading and speed conditions used for the test, (c) the size of measurement samples per criteria:

- (a) environmental conditions: duration, climate, variability of external factors,
- (b) test programme: repeatability and/or reproducibility conditions,
- (c) number of measurements in the considered sample.

In compliance with COST 323 specifications, the environmental conditions are defined by:

(I) repeatability: test carried out during a same day or on several consecutive days, with stable meteorological conditions and a very low variability level of external factors,

(II) limited reproducibility: test carried out over several days or weeks, whether consecutive or not, with variable meteorological conditions and external factors, but taking place during the same season,

(III) full reproducibility: test carried out over several days or weeks, non-consecutive and spread over at least one year, or continuously for at least one year, in all the site's meteorological and external conditions.

The test programme conditions are defined by:

(r1) full repeatability: a single vehicle passes several times at the same speed, load and lateral position,

(r2) extended repeatability: a single vehicle passes several times at different speeds, different loads and with small variations in lateral position,

(R1) limited reproducibility: a small set of vehicles (2 to 10) pass several times, at different combinations of speed and load and with small variations in lateral position,

(R2) full reproducibility: a large sample of vehicles (some tens to a few hundred), taken from the traffic flow and representative of it, pass over the system, each of them only passing once.

Results of the post-weighed vehicles taken from the traffic flow were analysed in full reproducibility conditions (R2) and in environmental repeatability conditions (I) for each period separately and in limited environmental reproducibility conditions (III) in such a way as to cover the seasons for the Lulea Test.

Results of the test vehicles were analysed in limited reproducibility conditions (R1), full repeatability (r1) and extended repeatability (r2) for the environmental repeatability conditions (I) for each period separately and in limited reproducibility conditions (R1) in limited environmental reproducibility conditions (III) in such a way as to cover the seasons for the Lulea Test.

Data analysis was carried in three main steps:

- The first one is the identification in each data file of the selected vehicles. If the static file presented a doubtful vehicle data, like no timing, one load missing or different axle number, then this vehicle data was skipped out the file. Vehicles recorded with an error code were accounted but not considered (Pietzsch).
- The second one is the checking of the static values when two different static systems were available (several portable static scale versus the weigh-bridge). A relative difference of 5% in the static values of the group of axles measured at once was used as the criterion to eliminate the vehicle from the static file.
- The third step is the accuracy determination.
- A fourth step was realised with the post-weighed vehicles by an elimination of outliers based on statistical test (Dixon's test) and on a check of the gaussian distribution (Fisher's test, propriety of the gaussian distribution).

In the next tables, the first columns describe the statistics of the relative error $x_i = \frac{W_d - W_s}{W_s}$ where *n, Ident, m* and *s* represent, respectively, the number of data, the percentage of vehicles correctly identified by the system, the mean and the standard deviation. The remaining columns present the accuracy class for each criterion *class*, the tolerance of the retained accuracy class δ, the minimum width of the confidence interval δ_{min}, for the specified level of confidence π_0, this value converted to the gross weight scale δ_c and the level of confidence π of the interval $[-\delta,\delta]$.

A lower bound π, of the probability for an individual value of a relative error, taken randomly from a normally distributed sample of size n, with a sample mean m and standard deviation s, to be in the centred confidence interval $[-\delta; \delta]$, is given at the confidence level $(1-\alpha)$ by ([1]):

$$\pi = \Phi(u_1) - \Phi(u_2)\text{, with } u_1 = (\delta - m)/s - t_{\nu,1-\alpha/2}/n^{1/2} \quad \text{and} \quad u_2 = (-\delta - m)/s + t_{\nu,1-\alpha/2}/n^{1/2} \qquad (1)$$

where Φ is the cumulative distribution function of a Student variable,

and $t_{\nu,1-\alpha/2}$ is a Student variable with $\nu = n-1$ degrees of freedom. α is taken equal to 0.05.

As π_0 is the minimum confidence level required in accordance with test and environmental conditions, and size of sample, corresponding to the acceptable minimum probability that an individual relative error is within tolerances for the class of accuracy, for each sample corresponding to a criterion, and for the proposed (required) accuracy class defined by δ, the acceptance test is:

- if $\pi \geq \pi_0$, the system is accepted in the class δ;
- if $\pi < \pi_0$, the system cannot be accepted in the proposed accuracy class, and the acceptance test is repeated with a lower accuracy class (a greater δ).

***N.B.**: The probabilities π and π_0 are calculated at statistical risk (manufacturer's) α=5% on the estimation for average bias by m. In other words, this risk α corresponds to the probability of incorrectly rejecting a true accuracy class due to a bias estimated from abnormally high measurements (magnitude).*

The user (or client) risk is $(1-\pi)$, corresponding to the risk of having an individual measurement outside of the specified tolerance δ for the class adopted.

δ_{min} is the minimum value of δ, such that $\pi = \pi_0$ i.e. that an individual error is in the $[-\delta_{min}; +\delta_{min}]$ interval with a probability equal to the minimum required π_0.

When a class has been rejected only for a maximum divergence between δ_{min} and δ lower than 1 % of all criteria, the class is nonetheless indicated as almost attained (≈ class).

Due to the lack of space in the tables, Kistler/Golden River, Datainstrument, Pietzsch, and Omni Weight Control are respectively referred to as KI/GR, DI, PAT, OWC.

9.1.2 Post-weighed vehicles

Results presented in this chapter show the complete tables for the post-weighed vehicle population (for each season– Table 23 and Table 24).

Table 23. Post-weighed vehicle population – summer season (R2 - II)

** after elimination of the 10 vehicles identified with an error code*

	Relative error statistics						Accuracy calculation				
KI/GR	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	443	98	4,27	9,20	93,0	**C(15)**	20,0	19,3	14,3	94,1	**II , R2**
Axle of group	973	98	5,06	7,01	93,5	**B(10)**	20,0	16,2	8,1	98,0	
Group of axles	474	98	4,95	5,71	93,1	**C(15)**	18,0	14,0	11,0	98,6	**D+(20)**
Gross weight	266	98	4,39	6,86	92,6	**D+(20)**	20,0	15,4	15,4	98,4	**≅ C(15)**

DI	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	430	95	-29,28	26,98	93,0	**E(60)**	75,7	71,8	66,8	94,7	**II , R2**
Axle of group	948	96	-17,60	33,13	93,5	**E(65)**	76,3	71,1	61,1	95,3	
Group of axles	462	96	-18,05	32,39	93,0	**E(65)**	70,2	70,1	67,1	93,1	**E(65)**
Gross weight	259	96	-23,34	25,61	92,6	**E(65)**	65,0	63,7	63,7	93,3	

PAT	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	*432**	**100**	-1,41	7,44	93,0	**B(10)**	15,0	14,5	9,6	94,0	**II , R2**
Axle of group	*95**	**99**	-2,93	8,94	93,5	**B(10)**	20,0	18,0	9,0	96,1	
Group of axles	*463**	**99**	-3,09	7,92	93,0	**C(15)**	18,0	16,2	13,2	95,8	**C(15)**
Gross weight	*260**	**100**	-2,24	6,11	92,6	**C(15)**	15,0	12,4	12,4	97,1	

OWC	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	231	51	-13,47	13,45	92,4	**E(30)**	36,0	34,7	29,7	93,8	**II , R2**
Axle of group	385	39	-1,28	22,50	92,9	**E(35)**	47,0	43,1	33,1	95,2	
Group of axles	188	39	-2,06	17,86	92,2	**E(35)**	39,0	34,5	31,5	95,6	**E(35)**
Gross weight	128	47	-8,73	12,50	91,7	**E(30)**	30,0	28,6	28,6	93,3	

Table 24. Post-weighed vehicle population – winter season (R2 - II)

** after elimination of the 13 vehicles identified with an error code*

	Relative error statistics						Accuracy calculation				
KI/GR	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**

Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	class
Single axle	307	80	-5,44	8,90	92,7	**C(15)**	20,0	19,7	14,7	93,3	**II , R2**
Axle of group	748	83	-3,33	11,28	93,3	**C(15)**	25,0	22,5	12,5	96,0	
Group of axles	364	83	-3,19	6,62	92,9	**C(15)**	18,0	14,0	11,0	98,2	**C(15)**
Gross weight	194	81	-3,84	5,55	92,2	**C(15)**	15,0	12,7	12,7	96,8	

DI	**N**	**Ident**	**m**	**s**	π_o	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	335	87	-38,02	10,47	92,8	**E(50)**	60,0	54,5	49,5	97,6	**II , R2**
Axle of group	694	77	-32,87	13,45	93,3	**E(45)**	59,0	54,1	44,1	96,9	
Group of axles	338	78	-32,85	12,05	92,8	**E(50)**	55,0	51,8	48,8	95,8	**E(50)**
Gross weight	199	83	-35,55	8,71	92,3	**E(50)**	50,0	49,3	49,3	93,5	

PAT	**N**	**Ident**	**m**	**s**	π_o	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	372*	**100**	-17,44	7,32	92,9	**D(25)**	30,0	29,0	24,0	94,6	**II , R2**
Axle of group	833*	**100**	-17,62	8,52	93,4	**D(25)**	35,0	31,1	21,1	97,6	
Group of axles	403*	**100**	-17,68	6,71	92,9	**E(30)**	33,0	28,3	25,3	98,5	**E(30)**
Gross weight	226*	**100**	-17,52	5,54	92,4	**E(30)**	30,0	26,3	26,3	98,2	

OWC	**N**	**Ident**	**m**	**s**	π_o	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	167	43	-62,61	6,78	92,0	**E(60)**	75,7	73,3	68,3	96,1	**II , R2**
Axle of group	303	34	-58,54	5,80	92,7	**E(60)**	70,7	67,7	57,7	97,6	
Group of axles	150	34	-58,68	5,26	91,9	**E(65)**	70,2	67,0	64,0	97,8	**E(75)**
Gross weight	99	41	-60,44	6,38	91,2	**E(75)**	75,0	70,5	70,5	98,0	**≅ E(70)**

Only Omni Weight Control recognised and identified correctly less than 50 % of the vehicles. Pietzsch system identified 100 % of the vehicles, from those percentage, 23 vehicles (around 5%) presented a violation code and were skipped out the files before the analysis. The Kistler/Golden River system did not provide any results in December; the modem was not working properly due to faulty software settings. The Omni Weight Control system worked in December but not enough vehicles were correctly identified by the system to get a representative sample.

Table 23 and Table 24 illustrate the effect of the temperature on the systems by a lost of the accuracy, by a change of the sign (or of the value) of the mean. The automatic self-calibration of Datainstrument is not adapted to the local conditions (climate and traffic, inc. vehicles partially outside the lane) and Omni Weight Control would also need a calibration system and sensors (such as inductive loops) to identify more vehicles.

Figure 61 shows for the post-weighed vehicle population, the δ_{min} (minimum width of the confidence interval) and the accuracy class (with and without elimination of the outliers) for the gross weight criterion of each system, for the different test periods (environmental repeatability conditions (I)). The accuracy of a system depends on the number of data, on the mean and the standard deviation. Thus the Figure 61 depends on the Figure 62 which shows the evolution of the mean and standard deviation for the same criterion.

The problem of outliers and the justification of this accuracy model (based on a gaussian distribution) is highlighted from Figure 61 to Figure 70 where the relative error distribution is given per period and per system. One can see a move of the distribution in function of the temperature, the presence of bimodal distribution or other complex one.

During the winter each system got an higher mean but a smaller deviation, as Figure 62 shows.

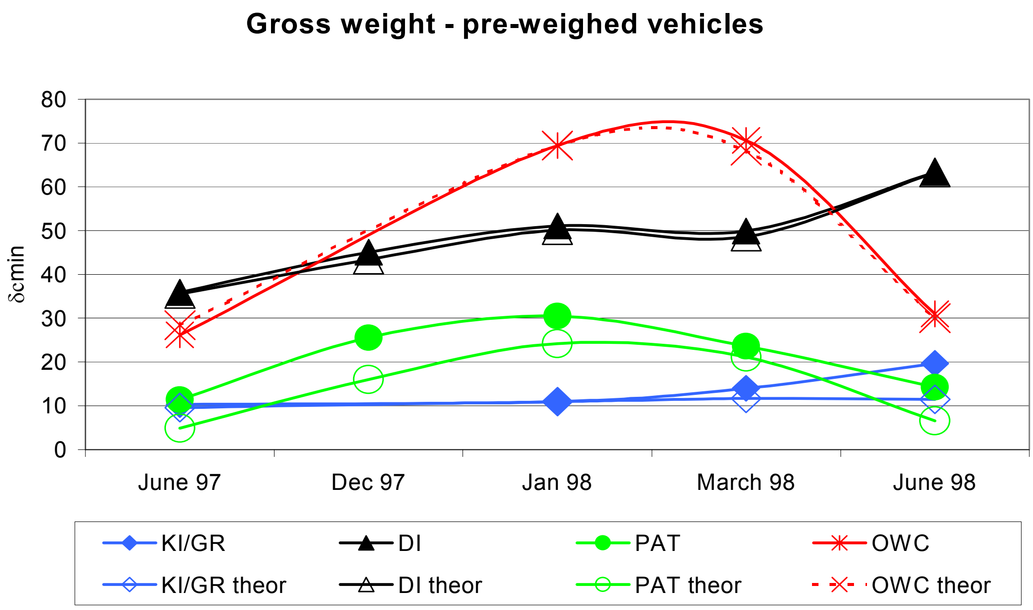


Figure 61. Accuracy class for gross criterion by system and period, for the post-weighed vehicle population, before and after outlier elimination (R2 - I)

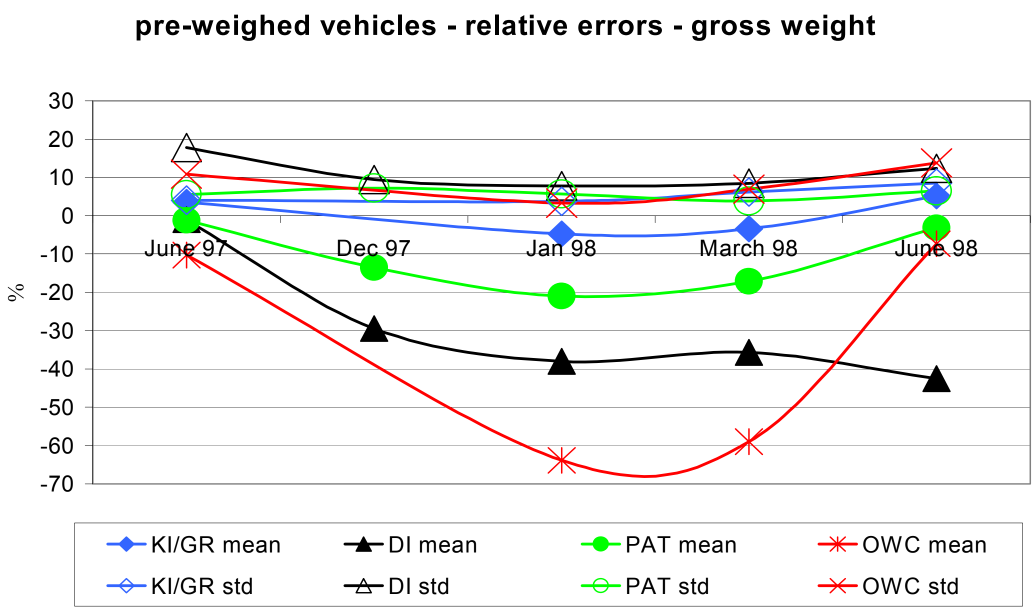


Figure 62. Mean and standard deviation of the gross weight criterion by system and period, for the post-weighed vehicle population, (R2 - I)

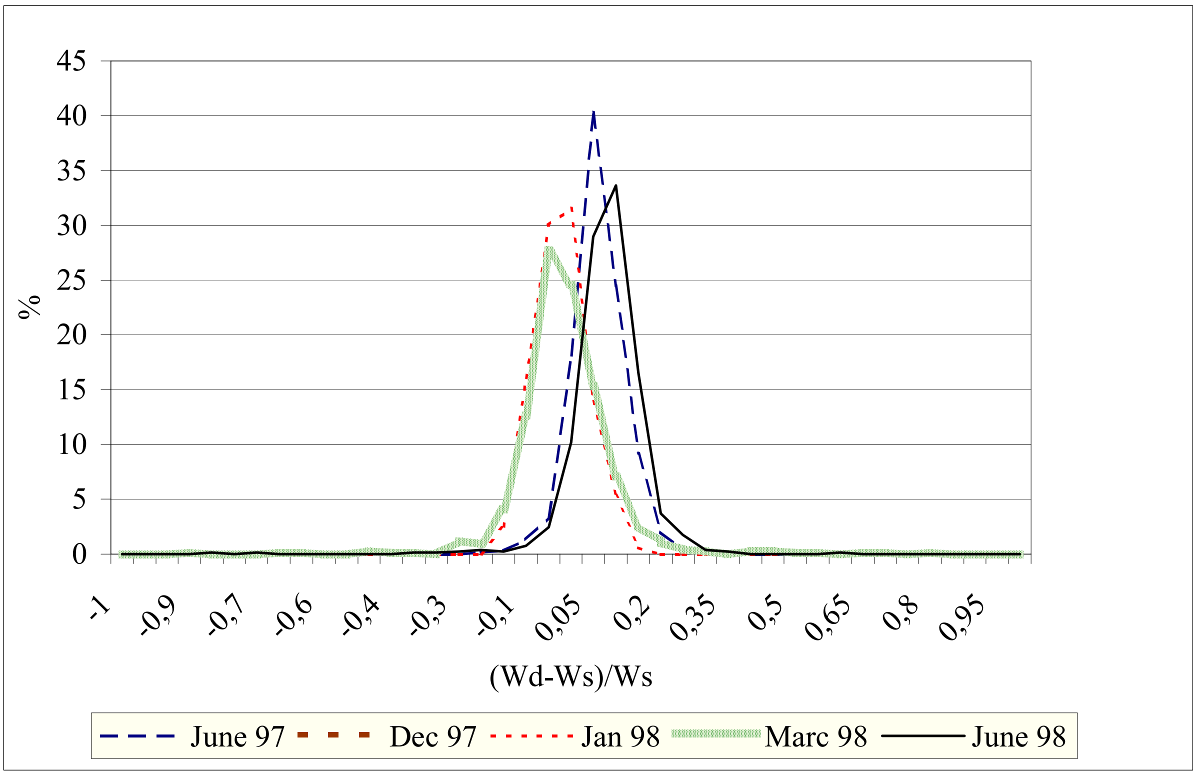


Figure 63: Distribution of relative errors for KI/GR system

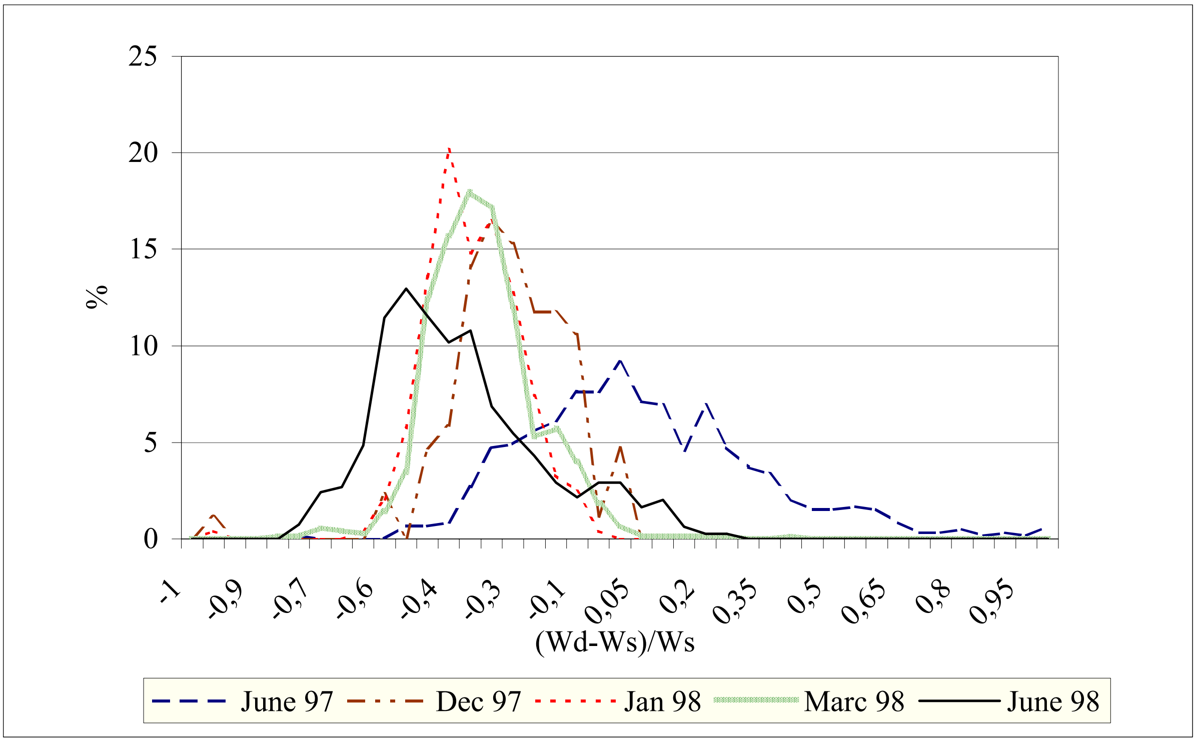


Figure 64: Distribution of relative errors for DI system

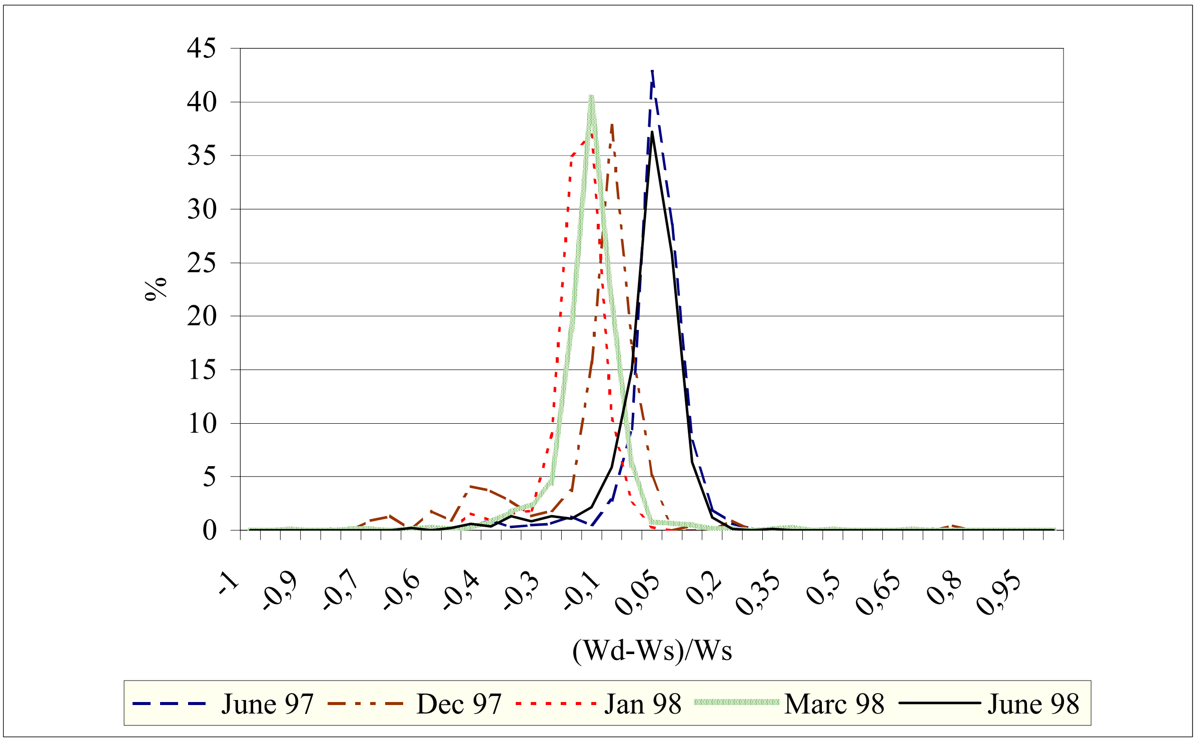


Figure 65: Distribution of relative errors for PAT system

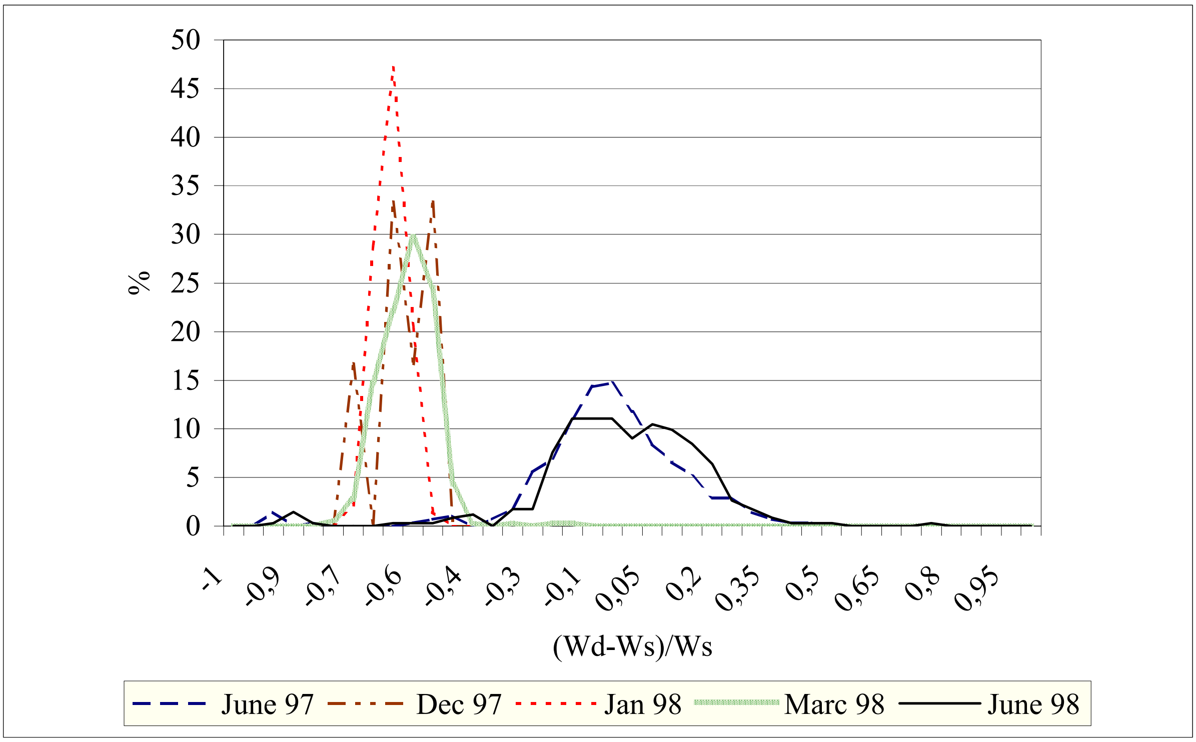


Figure 66: Distribution of relative errors for OWC system

9.1.3 Test vehicles

Results presented in this chapter show the complete tables for the post-weighed vehicle population (for each season– Table 25 and Table 26).

Table 25: Test vehicle population – summer season (R1 - II)

** after elimination of 1 vehicle identified with an error code*

	Relative error statistics						**Accuracy calculation**				
KI/GR	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	249	99	4,60	4,81	94,6	**B(10)**	15,0	13,0	8,5	97,9	**II , R1**
Axle of group	586	100	7,36	9,43	95,1	**C(15)**	25,0	23,9	13,9	96,2	
Group of axles	251	100	7,68	5,03	94,6	**C(15)**	18,0	16,5	13,5	97,2	**C(15)**
Gross weight	208	100	5,97	4,34	94,5	**C(15)**	15,0	13,6	13,6	97,3	

DI	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	class
Single axle	242	96	-44,49	17,48	94,6	E(60)	75,7	75,0	70,0	95,1	II , R1
Axle of group	563	96	-13,03	36,82	95,1	E(70)	82,0	80,1	70,1	95,7	
Group of axles	241	96	-14,13	34,89	94,6	E(75)	80,7	77,3	74,3	95,7	E(80)
Gross weight	201	96	-28,88	29,33	94,4	E(80)	80,0	80,0	80,0	94,5	

PAT	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	class
Single axle	*248**	99	-2,81	3,66	94,6	B+(7)	11,0	9,3	5,9	98,2	II , R1
Axle of group	*581**	100	-0,06	9,04	95,1	B(10)	20,0	18,6	9,3	96,7	
Group of axles	*249**	100	0,13	3,39	94,6	A(5)	7,0	7,0	4,9	94,7	B(10)
Gross weight	*207**	100	-1,23	3,01	94,5	B+(7)	7,0	6,7	6,7	95,7	

OWC	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	class
Single axle	116	46	-16,04	4,78	93,8	D+(20)	25,0	24,4	19,4	95,3	II , R1
Axle of group	167	28	-0,29	12,55	94,3	D+(20)	30,0	26,0	16,0	97,3	
Group of axles	71	28	-1,42	11,26	93,1	D(25)	28,0	23,7	20,7	97,1	E(30)
Gross weight	81	39	-10,32	9,06	93,3	E(30)	30,0	26,1	26,1	97,3	

The accuracy seems to be lower with the test vehicle population (limited reproducibility conditions) than with the post-weighed vehicle population (full reproducibility conditions) for the less accurate systems, such as Datainstrument and Omni Weight Control. However, these two systems present a bias and a standard deviation in excess of 25%.

Table 26. Test vehicle population – winter season (R1 - II)

	Relative error statistics						Accuracy calculation				
KI/GR	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	class
Single axle	134	66	-0,87	4,54	94,0	B+(7)	11,0	9,6	6,1	97,1	II, R1
Axle of group	336	91	1,38	9,77	94,8	C(15)	25,0	20,4	10,4	98,4	
Group of axles	150	90	1,51	6,04	94,2	B(10)	13,0	12,9	9,9	94,5	C(15)
Gross weight	124	74	0,71	4,48	93,9	B(10)	10,0	9,4	9,4	95,5	

DI	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	class
Single axle	195	96	-40,66	6,84	94,4	E(45)	54,0	52,6	47,6	96,4	II, R1
Axle of group	342	92	-38,14	9,55	94,9	E(45)	59,0	54,8	44,8	98,1	

Group of axles	155	93	-37,79	7,04	94,2	**E(50)**	55,0	50,1	47,1	98,8	**E(50)**
Gross weight	159	95	-38,22	5,86	94,2	**E(50)**	50,0	48,5	48,5	96,7	

PAT	**N**	**Ident**	**m**	**s**	π_o	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	202	100	-16,33	5,20	94,5	**D(25)**	30,0	25,4	20,4	99,3	**II, R1**
Axle of group	368	99	-13,12	8,28	94,9	**D+(20**	30,0	27,6	17,6	97,3	
Group of axles	166	99	-12,98	5,74	94,3	**D+(20**	23,0	23,0	20,0	94,3	**D(25)**
Gross weight	166	99	-14,06	4,58	94,3	**D(25)**	25,0	22,1	22,1	98,7	

OWC	**N**	**Ident**	**m**	**s**	π_o	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	101	50	-67,30	2,93	93,7	**E(60)**	75,7	72,4	67,4	99,5	**II , R1**
Axle of group	212	57	-59,40	5,98	94,5	**E(60)**	70,7	69,8	59,8	95,9	
Group of axles	97	58	-59,91	4,69	93,6	**E(65)**	70,2	68,1	65,1	97,5	**E(75)**
Gross weight	90	54	-63,04	4,41	93,5	**E(75)**	75,0	70,8	70,8	99,3	

Figure 67 shows the evolution of the accuracy (gross weight criterion) where each type of test vehicles is considered separately (extended repeatability – r2), C2 represents the two-axles rigid lorry, C3(12) represents the three-axles rigid lorry, S33 represents the six-axles semi-trailer with a tridem, at several speeds and loads.

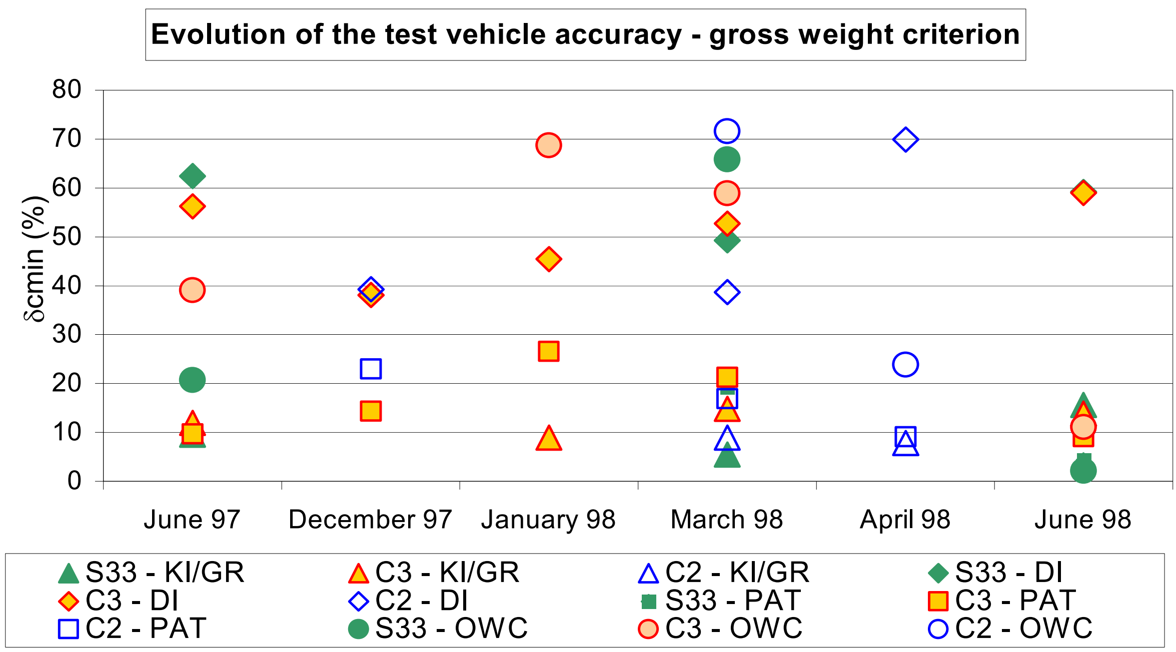


Figure 67. Gross weight criterion by system, period and type of test vehicle, (r2 - I)

9.1.4 Conclusions

The Kistler/Golden River system was stable throughout the year for both criteria and types of population. Month after month, Datainstrument lost its accuracy for the post-weighed population; about the test population, the curve of the variations is roughly sinusoidal through the year with a loss of accuracy after one year. The manufacturer explained that the automatic self-calibration procedure, in service all along the year, was affected by the trucks passing partially outside the traffic lane, even between the test periods. The Pietzsch system recovered its initial accuracy after one year, but was during the winter sensitive to subzero temperature, and its accuracy was affected in winter due to a lack of temperature compensation in the sensor installed in Lulea. Omni Weight Control proposed a prototype and was allowed to modify the software and to improve the system during the year. This was done several times during the winter, and the system gained approximately 20% in accuracy after one year. The poor results during the winter are due to the first modifications that were inadequate.

To resume, the Table 27 and Table 28 present the accuracy of each system for the four criteria (for both populations) in the case of a whole climatic year.

Table 27: Post-weighed vehicle population full climatic year (R2 - III)

** after elimination of 23 vehicles identified with an error code*

	Relative error statistics						**Accuracy calculation**				
KI/GR	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	750	90	0,29	10,25	92,0	**C(15)**	20,0	18,7	13,7	93,9	**III, R2**
Axle of group	1721	91	1,41	10,02	92,4	**B(10)**	20,0	18,5	9,3	94,6	
Group of axles	838	91	1,41	7,33	92,0	**C(15)**	18,0	13,6	10,6	98,1	**C(15)**
Gross weight	460	90	0,92	7,53	91,6	**C(15)**	15,0	13,9	13,9	94,0	

DI	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	765	92	-33,10	21,81	92,0	**E(55)**	70,0	65,3	60,3	94,6	**III, R2**
Axle of group	1642	87	-24,05	27,69	92,4	**E(60)**	70,7	65,2	55,2	94,8	
Group of axles	800	87	-24,30	26,84	92,0	**E(60)**	65,0	64,1	61,1	92,5	**E(60)**
Gross weight	458	90	-28,65	20,97	91,6	**E(60)**	60,0	59,6	59,6	91,9	

PAT	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	*804**	100	-8,83	10,88	92,0	**D+(20)**	25,0	25,0	20,0	92,0	**III, R2**
Axle of group	*1784**	100	-9,79	11,41	92,4	**D+(20)**	30,0	26,8	16,8	95,7	
Group of axles	*866**	100	-9,98	10,37	92,0	**D(25)**	28,0	25,3	22,3	95,3	**D(25)**
Gross weight	*486**	100	-9,35	9,61	91,7	**D(25)**	25,0	23,6	23,6	93,8	

OWC	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	398	48	-34,81	27,22	91,5	**E(60)**	75,7	75,0	70,0	91,9	**III, R2**
Axle of group	688	36	-26,50	33,27	91,9	**E(65)**	76,3	75,9	65,9	92,1	
Group of axles	338	37	-27,19	31,35	91,3	**E(70)**	75,4	73,6	70,6	92,3	**E(75)**
Gross weight	227	45	-31,93	28,18	90,9	**E(75)**	75,0	73,4	73,4	91,8	

Table 28. Test vehicle population full climatic year (R1 - III)

** after elimination of 1 vehicle identified with an error code*

	Relative error statistics						**Accuracy calculation**				
KI/GR	**N**	**Ident**	**m**	**s**	π_0	**Class**	δ	δ_{min}	δ_c	π	**Accepted**
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	383	84	2,68	5,39	93,7	**B(10)**	15,0	11,8	7,6	98,5	**III, R1**
Axle of group	922	96	5,18	9,98	94,2	**C(15)**	25,0	22,0	12,0	97,1	
Group of ax-	401	96	5,37	6,20	93,8	**C(15)**	18,0	15,6	12,6	97,3	**C(15)**
Gross weight	332	88	4,01	5,07	93,6	**C(15**	15,0	12,4	12,4	98,0	

DI	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	437	96	-42,78	13,90	93,8	**E(55)**	70,0	65,6	60,6	96,8	**III, R1**
Axle of group	905	96	-22,52	32,02	94,2	**E(65)**	76,3	75,4	65,4	94,5	
Group of ax-	396	96	-23,45	29,86	93,7	**E(70)**	75,4	72,6	69,6	94,9	**E(75)**
Gross weight	360	96	-33,00	22,71	93,7	**E(75)**	75,0	70,2	70,2	95,9	

PAT	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	*450**	99	-8,88	8,05	93,8	**D+(20)**	25,0	22,1	17,1	97,2	**III, R1**
Axle of group	*949**	100	-5,12	10,82	94,2	**C(15)**	25,0	23,4	13,4	95,8	
Group of axles	*415**	100	-5,12	7,83	93,8	**D+(20)**	23,0	18,1	15,1	98,5	**D+(20)**
Gross weight	*373**	99	-6,94	7,42	93,7	**D+(20)**	20,0	19,2	19,2	95,1	

OWC	N	Ident	m	s	π_0	Class	δ	δ_{min}	δ_c	π	Accepted
Entity		(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	**class**
Single axle	217	48	-39,90	25,94	93,2	**E(70)**	87,0	82,3	77,3	95,3	**III, R1**
Axle of group	379	40	-33,35	30,86	93,7	**E(75)**	87,7	83,9	73,9	95,1	
Group of axles	168	40	-35,19	30,09	93,0	**E(80)**	85,9	84,4	81,4	93,6	**E(85)**
Gross weight	171	45	-38,07	27,31	93,0	**E(85)**	85,0	82,7	82,7	94,1	

9.2 Research analysis

9.2.1 Principles of analysis

General

The main idea of all analysis was to find out how the WIM systems kept durability and performed in various climatic conditions. What were the reasons affecting durability and performance of systems?

The data used in analysis is based on two different data sets, (1) randomly selected post-weighed vehicles from the traffic flow and (2) test vehicles owned by SNRA.

Post-weighed vehicles data meets full reproducibility conditions (R2) according to the COST 323 European specification (draft 2.2, June 1997). Test vehicles data can be divided to meet full repeatability (r1), extended repeatability (r2) and limited reproducibility (R1) conditions. All test periods have been analysed separately.

The main analysis was made by using a spreadsheet program in order to visualise the data and calculate different indicators.

Post-weighed vehicles

Two most typical figures used in analysis are presented as examples in Figure 68 and Figure 69. Because there are about 100 figures like Figure 68 and more than 60 figures like Figure 69 only a small part of the figures can be presented in this report. There are as many figures of these kinds for the test vehicles.

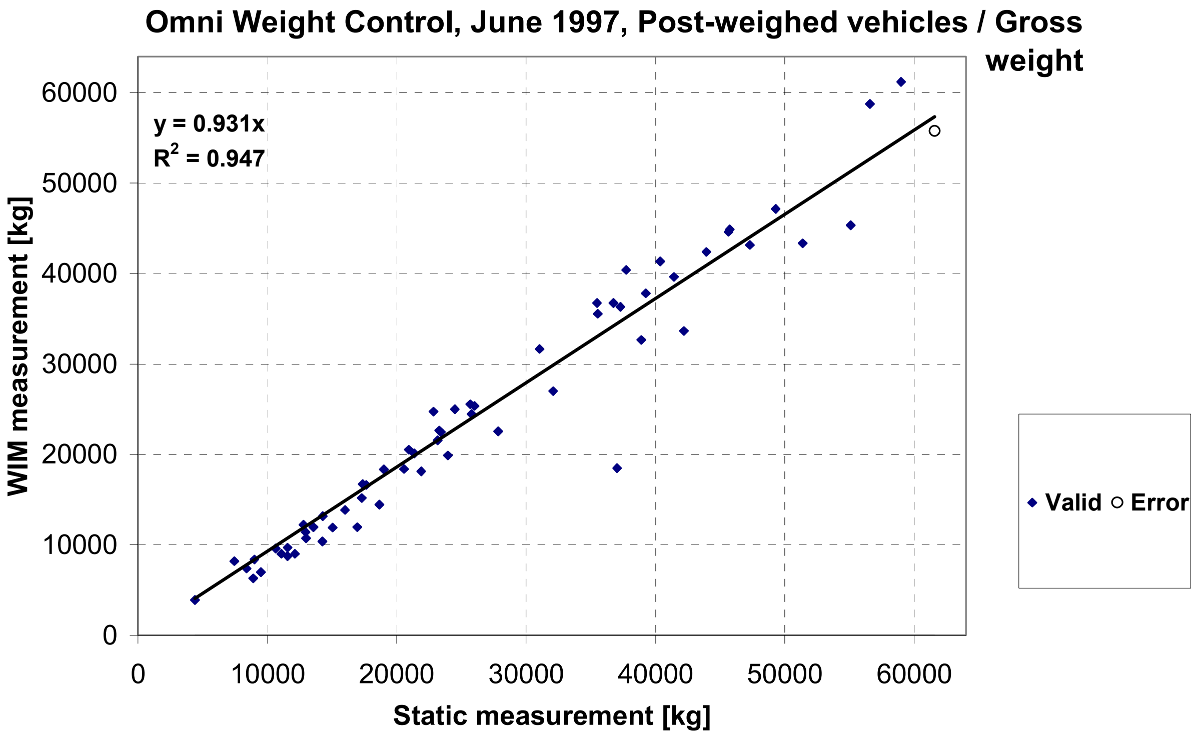


Figure 68. An example of a scattergram used in the analysis of post-weighed vehicles.

In Figure 68 the static weighed axle load ("true value") is on the abscissa and the axle load measured by a WIM-system is on the ordinate. The regression line is forced to the origin. Dots are valid points and circles are not taken into account as the regression line is calculated (see later in this chapter).

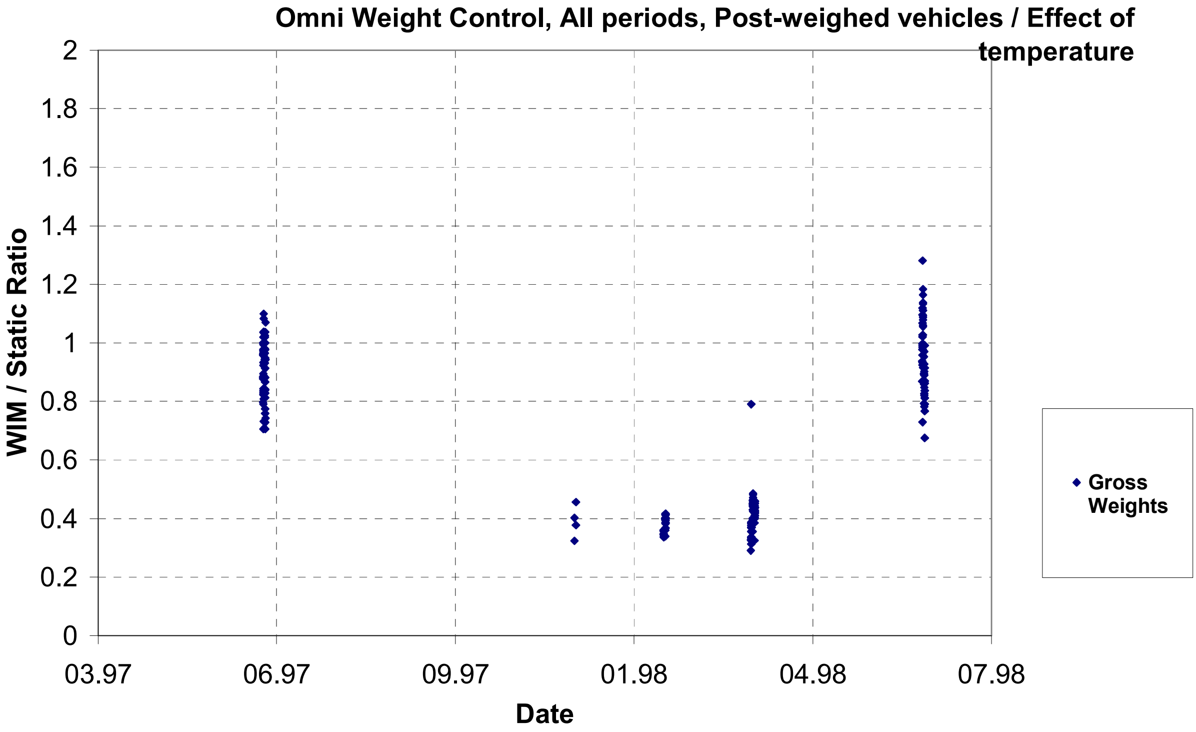


Figure 69. Effect of temperature on dynamic/static measurement ratio.

Another common type of figure is presented in Figure 69. Different factors (time, speed, temperature etc.) are on the abscissa and the ratio of axle load measured by a WIM-system and measured statically is on the ordinate.

Test vehicles

Test vehicles consist two types of vehicle, 3-axle rigid lorry (type 3 in Figure 37) and 6-axle semi-trailer (type 21).

Both test vehicle types were used as empty, half-loaded and full-loaded. Two speeds were also used, namely 50 and 80 km/h.

During December 1997 test only 3-axle lorry participated in the test. Empty and half-loaded 3-axle lorries were used accidentally as a 2-axle lorry as the 3rd axle (2nd tandem axle) was lifted up. These results are used only for single axle (front axle) and gross weight analysis. Also in April 1998 test only 2-axle rigid lorry (type 1) was used, no axle group was present.

The results are presented mainly in the following way (see Figure 70):

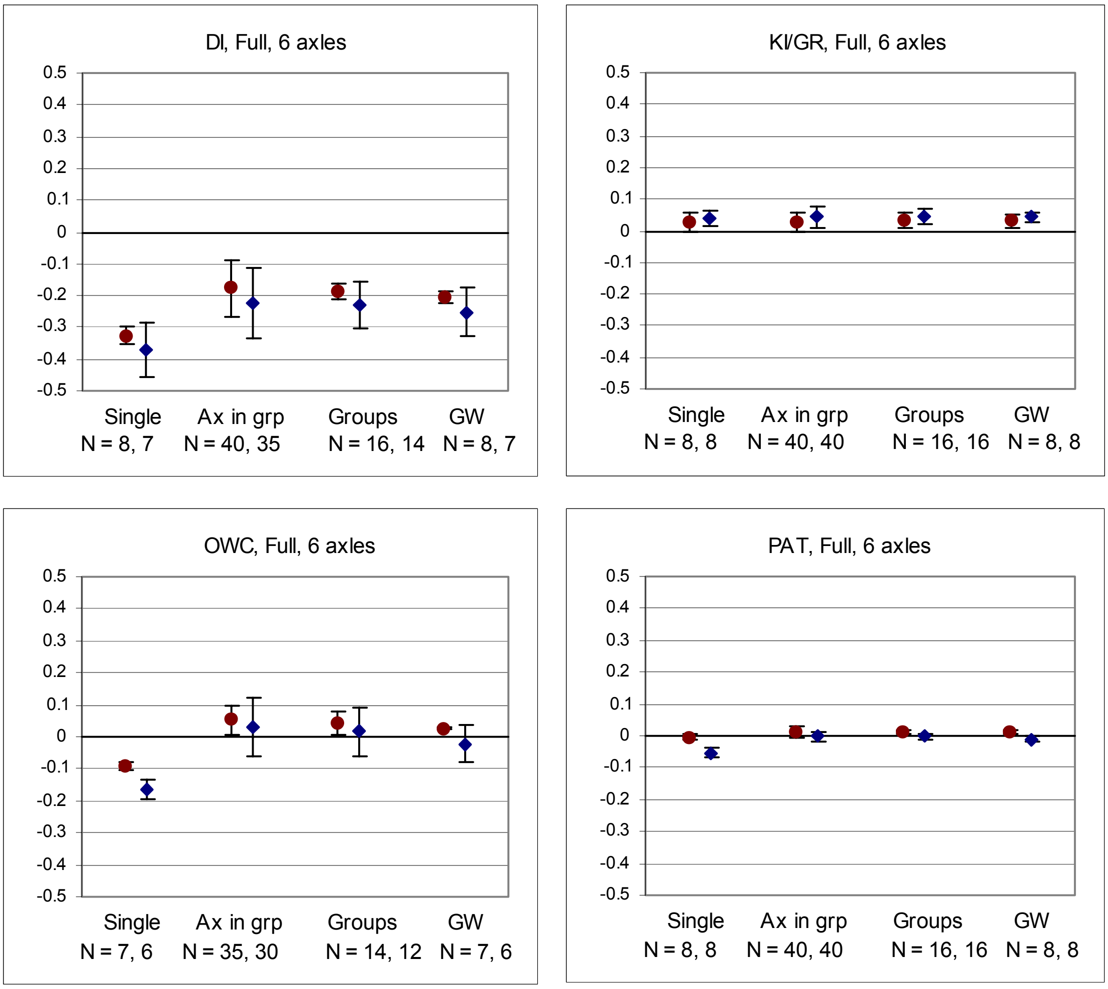


Figure 70. Examples of the figures used at the analysis of test vehicles.

The relative error was calculated as (measured weight – static weight)/static weight. The mean value is presented with a dot and +/- standard deviations with bars. The value at left is single axles, the following axles in groups, then axle groups (tandems and tridems) and the last one presents the gross weight. The left dot in each group is at speed 50 km/h and the right one at speed 80 km/h.

The numbers below the axle are the numbers of data in each case.

These figures were made separately for full-loaded, half-loaded and empty vehicles. Two vehicles were used, rigid one with three axles and semi-trailer with six axles.

The following analysis of test vehicles is based on these figures but only a part of the figures can be presented in this report because there are about 120 figures like in Figure 70. The corresponding values are available also in tables for more exact analysis.

9.2.2 Checking of data

After the data was matched i.e. post weighed vehicles were found from the WIM data, the data was cleaned by removing outliers. The removal of clearly erroneous data points was carried out using criteria, as follows:

1. Several WIM systems were showing odd results without any explicable reason. Perhaps the vehicle was braking or doing another unexpected manoeuvre.

2. An error of figures in data file. In some cases of Omni Weight Control's data the last figure of the measured axle load was missing. There was for instance 1114 kg instead of 11140 kg. Of course only this value was rejected.

3. Some vehicles have not correctly passed the WIM sensors. The nature of Swedish and Finnish heavy vehicles differs clearly to Central European. The maximum gross weight is 60 tons and 7-axle vehicle (4-axle trailer coupled to 3-axle rigid truck) having the length up to 25 metres is the most common post weighed-vehicle type in CET (see Table 13 above). It is normal that all axles of a long vehicle are not following the same wheel path but trailer is running a little bit skewed due to the inclination of the road. Thus WIM sensors covering only a part of the lane (for instance weighing pads) may not be able to measure the whole axle load.

4. Wide road shoulders are very common in Sweden and heavy vehicles drive often partly outside the driving lane in order to help passenger cars to bypass them. Even this kind of driving was tried to be prevented with temporary poles during the test some vehicles might be driven incorrectly over the WIM sensors.

5. Static weighing data is wrong. In a few cases measured axle load is clearly misrecorded into file.

If the mentioned criterion is met the data point is ignored in further analysis. It is, however, presented in the figures but it is marked by a circle (o) instead of a ball in scattergrams (see for instance Figure 71).

The number of vehicles, which were removed from the original data is presented in Table 29.

Table 29. Number of vehicles removed from the data (outliers).

WIM	9706	9712	9801	9803	9806
Datainstrument	3	1	6	10	6
Kistler/Golden River	3	0	4	11	5
Omni Weight Control	3	1	2	5	9
PAT	5	7	7	13	8

PAT system makes certain comparisons automatically within its data. That data is marked with violation codes, which also informs the reason for susceptible data. VTT learned about these violation codes very late and all figures etc. had already been done. A short comparison was made later between vehicles as considered outliers and those with violation codes. Most were the same as seen in Table 30.

Table 30. Number of vehicles removed from VTT data with PAT violation code and total number of vehicles with PAT violation code.

June 1997		December 1997		January 1998		March 1998		June 1998	
Outliers	Violation code	Outliers	Violation code	Outliers	Violation code	Outliers	Violation code	Outliers	Violation code
2	4	6	7	0	1	4	4	4	5

A great deal of data sits clearly on a regression line passing close to the origin in WIM vs. static measurement scattergrams. Calculated bias fits in most cases within +/- 300 kg, the only exception was the Datainstrument system where value sometimes exceeded 1000 kg. That will be discussed later. Thus a constant in linear regression analysis is forced to be zero in all further analysis.

An example of the importance of visualisation of data can be seen in Figure 71. Most data points are nicely on the regression line, which goes to the origin. Some points (circles) are clearly below the line. A further analysis showed that most of them were seven axle vehicles (type 30 in Figure 37), which have bypassed the weighing pads. The dotted line shows the regression line for the all data points having constant value ("bias") 1300 kg instead of 180 kg (regression line of valid data (dots)).

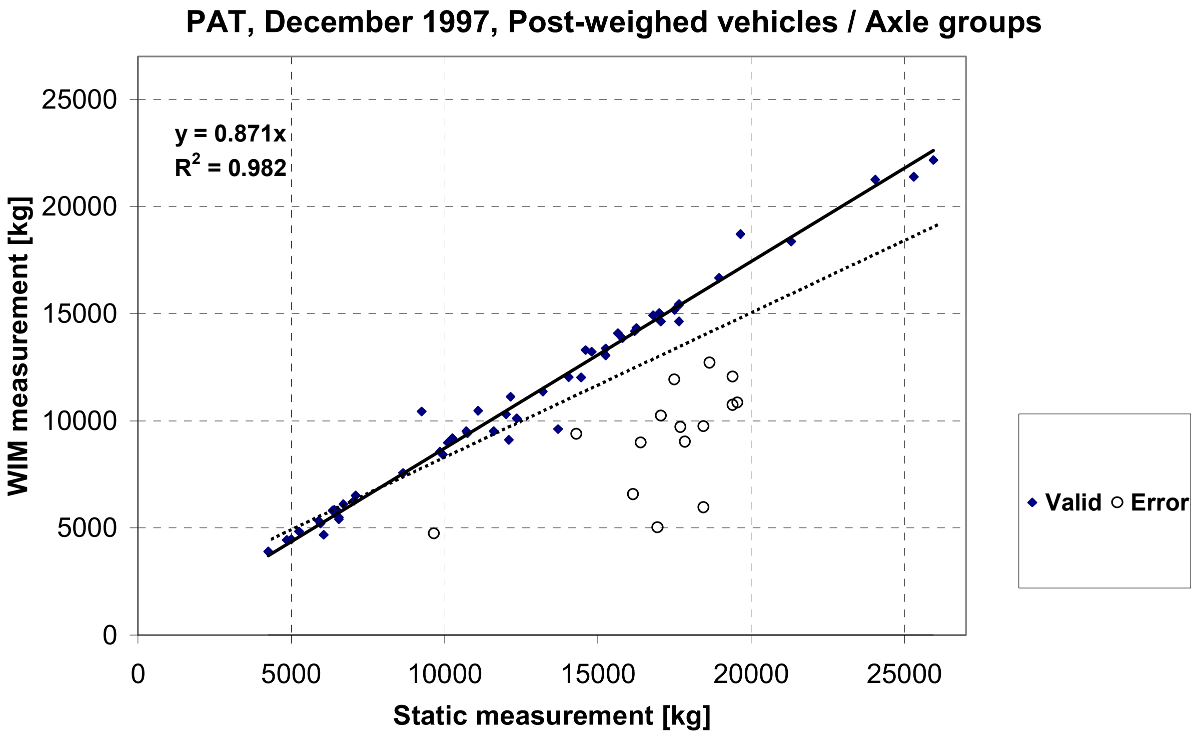


Figure 71. An example of misleading data points. Bypassed vehicles ignored.

Most of error points were corresponding to 7-axle vehicle (type 30, see Figure 37 above) having steering axle and three separate tandem axles. Results of each axle in a group were studied in order to be sure that the reason was really incorrectly passed vehicle but not the problem to measure tandem axle with a short axle spacing. That will be discussed later in chapter Axle groups.

Even with Datainstrument system the data does not seem to have any bias within half and full loaded vehicles as can be seen in Figure 72. Only empty vehicles seem to be measured systematically too heavy.

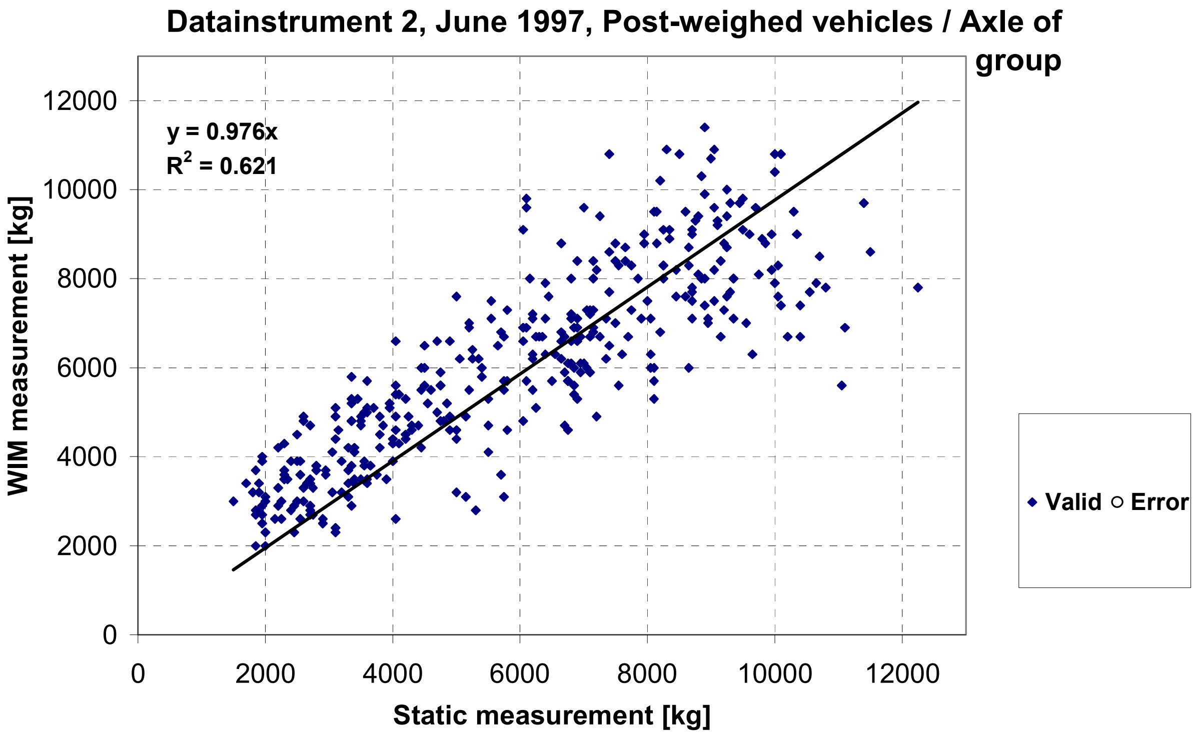


Figure 72. Light axle loads causing bias.

9.2.3 Results

Accuracy and performance

The accuracy analysis based on the draft WIM-specifications is presented in point 9.1. The accuracy here is on more general way and is based on figures and statistical values calculated from that data. The aim is not to classify WIM-systems but to describe the basic results and reasons to their behaviour and, hopefully help the manufacturers to develop their products.

The data is somewhat different which has been handled earlier in point 9.1.

The Figure 73 shows also how the accuracy can be presented.

As it was previously shown (for instance in Figure 71) there is no bias after clearly incorrect points were taken from the analysis (however, left in the figures shown as circles). There is no exact definition for bias but it can be described as the difference between the estimated value and true value in a statistic obtained by random sampling. In this case bias can be taken as the constant value in the regression equation or the difference between the origin and the point where the regression line meets the y-axis.

Bias is as presented earlier in most cases within +/- 300 kg which is simply due to statistical deviation with mean value very close to zero. Thus the regression line can be forced to zero and the results can be described with the slope of the regression line as done in Figure 73. This method is described in the European Specification on Weigh-in-motion of Road Vehicles drafted by a task group in COST-323 (draft 2.2, June 1997) as “1.c Calibration on the mean square error” and it is recommended there for most applications.

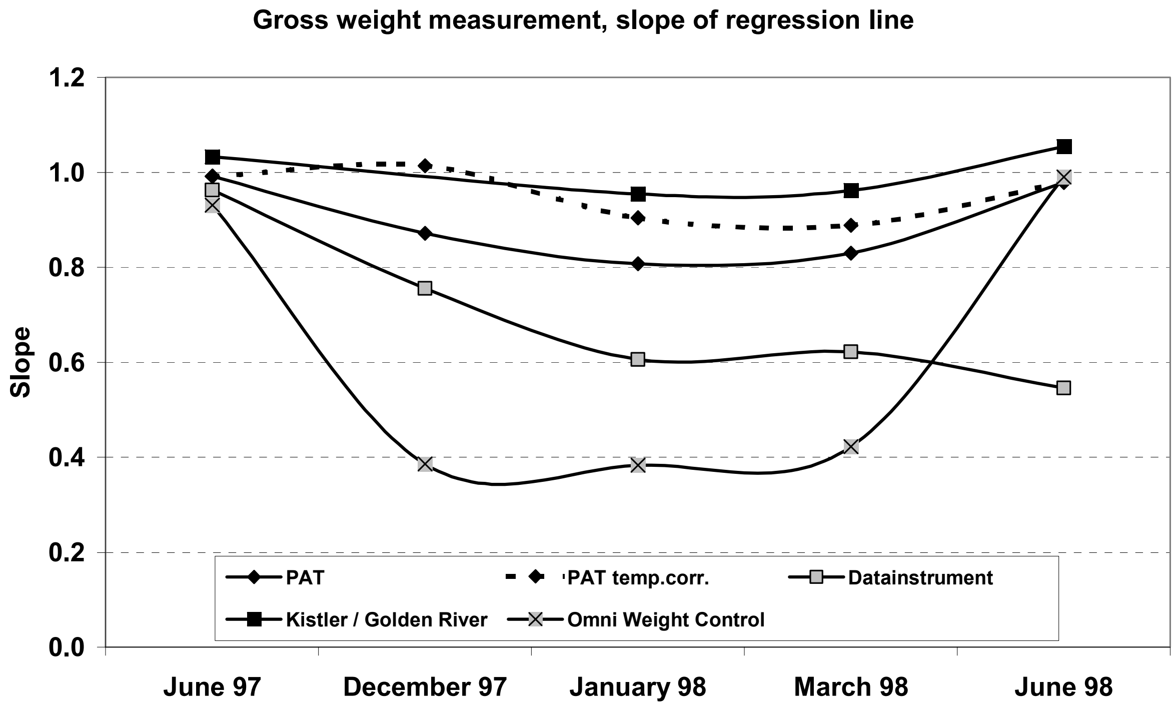


Figure 73. Accuracy of WIM measurements during all test periods.

The slope tells only if the results are systematically too small or too great or about accuracy (see Figure 1 in the report of Work Package 3.2) but nothing about the precision, which can be described as the variance or standard error.

In principle the error may be (1) independent of the variable and in this case the standard error of the predicted y-value for each x in the regression is justified or (2) it may be linearly dependent of the x-value and other approach must be selected. A careful study on the scatter-grams like Figure 68 was made and it was found that the error is not exactly independent but neither linearly dependent. However, it seemed to be in most cases closer to alternative 1.

If the precision is calculated using the alternative 1 and the truth is between 1 and 2 it means that the precision at greater axle loads is more prominent in the results. If the precision is calculated using the alternative 2 correspondingly the precision at smaller axle loads is more prominent. Because the precision at greater axle loads is more important in WIM-systems and the error behaved mostly like alternative 1 the use of standard error was more justified.

The standard error measured by each WIM-system at each measurement is presented in Figure 74. Both regression slopes and standard errors are presented in Table 31, Table 32, Table 33, Table 34, and in Table 35.

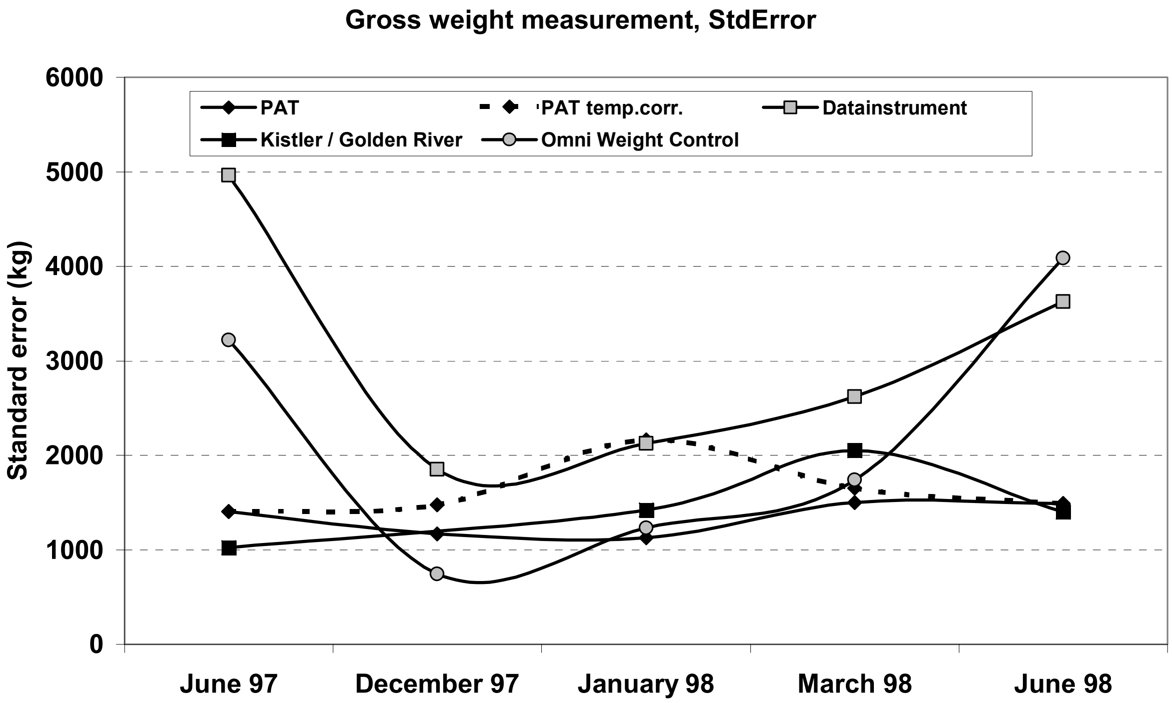


Figure 74. Data quality of WIM measurements during all test periods.

These two parameters are independent. The slope should be as close to 1 as possible and the deviation should be corrected by calibration. However, the slopes are often different for gross weight, single axles, axle groups and axles in groups.

The standard error describes the precision of the measurements. It is not, however, a perfect indicator because it does not yet take into account the number of measured vehicles.

These two indicators are mainly for research and development. No effort has been done to combine these two and to get an overall rating for the performance of WIM-systems.

Everyone should be very careful in comparing the test results from different tests. There are many factors which affect the results like

- Evenness of the road, even some manufacturers may have disadvantageous placement within a test
- Temperature, cold temperature (below zero) caused problems for temperature calibration for certain systems, three of five tests at Lulea were made at subzero temperatures which were never met in other European tests
- Snow and ice covers partly the road in wintertime at Lulea test which makes the road more uneven and makes vehicles to drive at different transverse position in wintertime than in summertime, it may change even from one test to another during the same winter
- Average daily traffic is small at Lulea which causes difficulties for self-calibrating systems and perhaps also for the system which uses neural networks
- There were 22 different types of vehicles (silhouettes) at Lulea test. The most prominent was seven axle 60 ton vehicle, 37 percent. The truck and semi-trailer with tridem had only 5 percent share which is very common for instance in France. The non-homogenous vehicle fleet causes problems especially for self-calibrating systems.
- Very special habit to drive in Sweden, outside the driving lane partly on the shoulder, causes some problems even the traffic was directed during the test measurements with temporary poles to drive on the driving lane.

Thus the test at Lulea was very harsh test but on the other hand very good for research and development. Because of the harshness of the test the results shall not be directly compared to other tests which have been done in good conditions.

Table 31. Results of PAT, no temperature compensation.

	Single axle			Axle group			Axle of group			Gross weight		
Period	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr
9706	214	0.990	401	186	0.991	661	383	0.990	391	121	0.992	1403
9712	71	0.873	440	54	0.871	634	116	0.869	335	38	0.872	1169
9801	125	0.795	398	119	0.811	597	244	0.811	353	64	0.808	1127
9803	215	0.829	376	260	0.831	754	538	0.831	579	133	0.830	1501
9806	227	0.985	383	271	0.975	786	552	0.973	464	137	0.979	1489

Table 32. Results of PAT, temperature compensation.

	Single axle			Axle group			Axle of group			Gross weight		
Period	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr
9706	214	0.990	401	186	0.991	661	383	0.990	391	121	0.992	1403
9712	71	1.016	527	54	1.012	763	116	1.011	401	38	1.014	1475
9801	125	0.893	522	119	0.909	878	244	0.910	480	64	0.904	2165
9803	215	0.885	413	260	0.889	818	538	0.890	628	133	0.888	1650
9806	227	0.985	383	271	0.975	786	552	0.973	464	137	0.979	1489

Table 33. Results of Datainstrument.

	Single axle			Axle group			Axle of group			Gross weight		
Period	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr
9706	209	0.878	1229	183	0.979	2232	377	0.976	1164	117	0.963	4962
9712	50	0.692	494	20	0.776	1065	41	0.745	911	22	0.756	1855
9801	107	0.591	564	83	0.606	789	170	0.609	507	51	0.606	2126
9803	206	0.590	568	250	0.628	1026	516	0.629	573	128	0.622	2622
9806	215	0.496	732	255	0.552	1331	523	0.550	706	130	0.546	3625

Table 34. Results of Kistler/Golden River.

	Single axle			Axle group			Axle of group			Gross weight		
Period	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr
9706	219	1.036	318	194	1.033	549	393	1.032	316	125	1.033	1021
9712	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
9801	126	0.951	394	123	0.960	693	252	0.961	425	66	0.955	1422
9803	215	0.955	544	262	0.964	916	542	0.967	712	134	0.962	2050
9806	240	1.057	392	283	1.054	625	576	1.053	386	144	1.055	1402

Table 35. Results of Omni Weight Control.

	Single axle			Axle group			Axle of group			Gross weight		
Period	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr	N	Slope	Stderr
9706	120	0.851	608	82	0.984	1506	171	0.979	831	62	0.931	3222
9712	7	0.376	492	5	0.397	873	11	0.378	549	5	0.386	745
9801	51	0.363	240	35	0.394	481	71	0.394	248	23	0.383	1233
9803	115	0.389	351	113	0.431	719	229	0.430	394	67	0.423	1741
9806	110	0.886	844	96	1.005	1771	202	0.997	965	56	0.990	4087

PAT

PAT uses bending plates, which are large enough to weigh the whole real wheel load as it is for a moment totally on the plate. Thus no integration of signal is needed and in principle only the greatest weight is recorded as the wheel load passes over the bending plate. In reality the measurements system is more complicated.

The PAT bending plate consists of a solid elastic steel metal plate with an integrated network of strain gauges. The bending plate sensor is installed in an independent metal frame and can be exchanged if necessary. The sensor is completely covered with hot vulcanised rubber for durable humidity and corrosion protection.

PAT uses two sensors, one for each wheel path and thus certain comparisons between the results from them can be made. Inconsistency between those two is expressed as violation codes and that data can be removed.

Slope of the regression lines can be seen in Figure 73 and in Table 31 and Table 32. Slopes are 0.990.. 0.992 in the first measurement in June 1997 and 0.975…0.9.85 in June 1998 or systematic error is 1…2% (Table 31). Results during the winter (freezing temperatures) were worse, even 0.8.

PAT has given the information that its temperature sensitivity is less than 0.05 %/ºC. Clearly PAT had no experience of freezing temperatures. As the plate bends under the wheel load it deforms protecting rubber which is temperature sensitive in cold temperatures. After December 1997 measurements PAT developed a temperature compensation formula which works well in June and December 1997 and June1998 measurements but not well in other measurements (will be handled later in chapter Seasonal effects).

The slopes are the same for single axles, single axles in groups, axle groups and gross weight.

Quality of data can be expressed by the standard error (Figure 74 and Table 31 and Table 32). Standard error is typically about 400 kg for single axle and 1200…1400 kg for gross weight. After temperature compensation the standard errors were slightly greater which points out that temperature compensation should be developed further.

The bending plate deflects about two millimetres as a wheel passes it. It causes a change in dynamic loading as seen in Figure 75. The lines are dynamic loadings measured by an instrumented vehicle. The bars show the place of the bending plate and their height corresponding reading from PAT. The speed and load of the vehicle have been same and there is relatively good spatial repeatability loading. However, exactly on the plate the phase is absolutely the same and the wheel force is smaller because of the plate deflection. The importance of this phenomenon to the accuracy is not known and should be studied further.

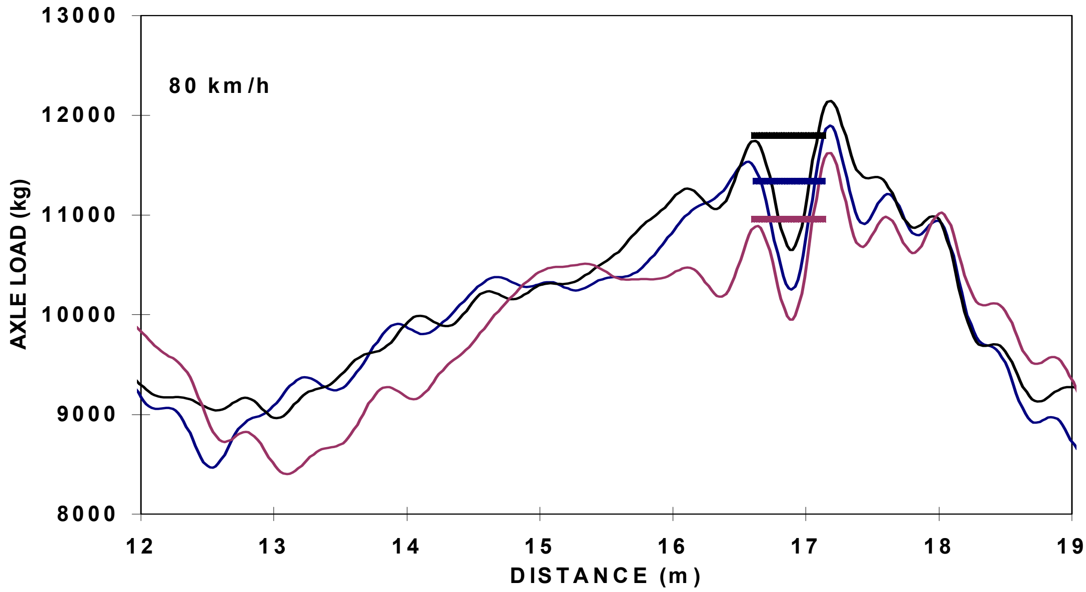


Figure 75. Dynamic axle loads of the driving axle over PAT WIM-system at Lulea, three vehicle passes.

DATAINSTRUMENT

Datainstrument uses in their system two sensors fabricated by Philips (Vibracoax), which are installed 3 metres apart. They are piezoelectric ceramic cables inside copper sheets and are installed grooves in the asphalt pavement. The grooves are filled with Sikadur up to the level of the pavement surface.

Datainstrument uses a self-calibration system.

The first results (Figure 72) show that the slope is nearly perfect but deviation of results is poor. Some bias can be seen; points presenting values smaller than 5000 kg are measured greater than static values. The results from later measurements deviated more from 1 (see Figure 73 and Table 33) but the deviation is better (Figure 74 and Figure 76).

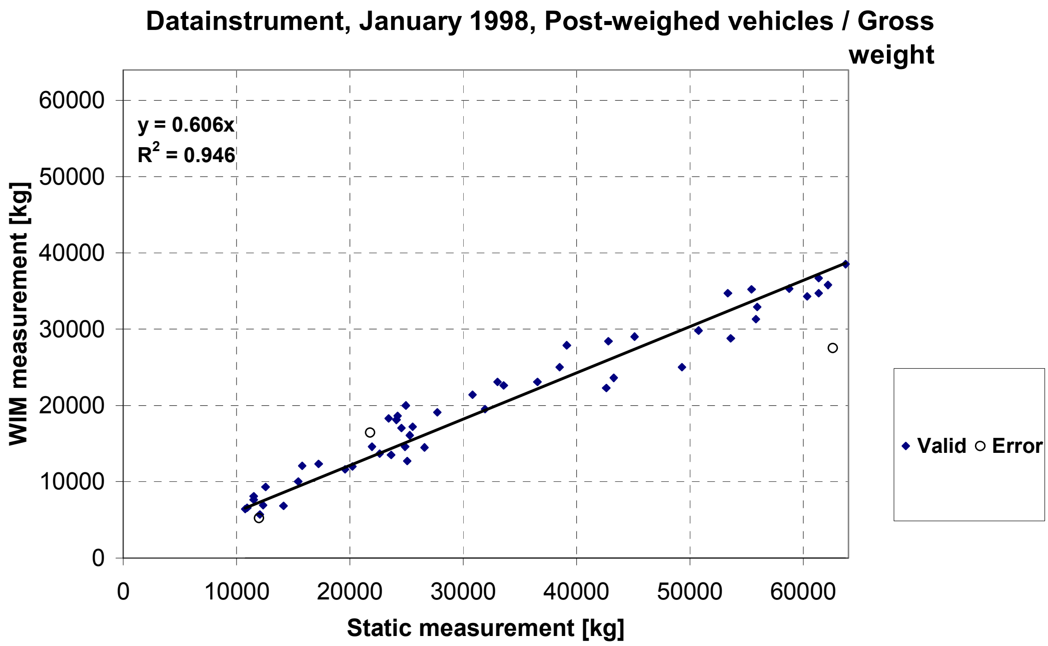


Figure 76. An example of improved accuracy during the test.

The reason for the results is due to the self-calibration system, which did not work well in those circumstances. The basic properties of the self-calibration system used by Datainstrument are described below:

The sensors are sensitive for temperature, speed and moisture. They do not necessarily affect only directly to the properties of the sensor but also indirectly; bituminous materials are stiffer at colder temperature and moisture may affect on the properties of underlying unbound road materials.

The low end of the scale is calibrated with personal cars. Cars are divided into three categories, small, medium-small and medium. The front axles of personal car of the group medium-small are used for calibration. It is defined as cars with axle spacing between 2.4 and 2.9 meters. The moving average of last 100 vehicles is used for calibration.

The high end of the calibration scale is made by using single axles of heavy vehicles, not, however, the front axles. The characteristic value is taken as the 95% of the cumulative distribution calculated from 100 vehicles.

The first axle of the latest 25 to 100 private cars is used to determine the cable signal strength and variation. These reference values is thus updated relatively quickly and is independent of heavier vehicles. When a heavy vehicle passes, axle weight is calculated as a function of the strength of the actual reference signal. The reference signal strength changes continuously during a day as a response to changes in temperature, humidity and asphalt viscosity. If the reference signal level is high, a high signal strength is required to calculate a heavy load. A low reference signal level accordingly requires lower signal strength.

Selected 'heavy' axles is used in a feedback and connected to actual signal strength. This means that the system continuously is building a set of reference values for light and heavy axles belonging together. This way the system adapts to a measuring site and changing levels of signal strength as a response to changes in temperature, humidity, and asphalt stiffness. This requires most of the vehicles to pass a site with all wheels of an axle directly over a detecting cable. A complete build of reference values to adapt to a site can take several days.

At first start-up the set of reference values is filled with values based on averaged earlier measurements.

In Sweden the road shoulder is often used by vehicles, almost as a lane number two. Before every test and calibration a set of cones is installed to lead the traffic correctly into the desired lanes. At the end of a test the cones are removed.

At system start-up in June 1997 the Datainstrument system was set up with reference values based on earlier general experience. At test time experienced reference values for heavy axles was used at start-up, while reference values for light axles determined signal strength. In this test results are within +10 to –10 percent. Variation was high, but this was expected to improve as our system was supposed to adapt to the site.

At the end of the initial test the cones leading the vehicles correctly into the lane was removed. Without the cones the vehicles tended to drive closer to the shoulder, and even at the shoulder. The result was that a lot of vehicles passed the cables with only the left wheels of axles at the measuring cables. It is assumed that heavy vehicles and slow light vehicles tend to use the shoulder more than private cars. The system decided that this was a site with low and varying signal strengths, and the automatic calibration system made a reference set of values based on this driving pattern.

At the following tests the cones again was installed to lead vehicles correctly into the lane. The reference signal strength (based on private cars) rapidly changed as now both wheels of axles was within the cable range. This in turn required high signal strength from heavy axles. All weights were underestimated due to the erroneous set of reference values made on the base of the atypical driving pattern. The resulted in mean values calculated 20 to 30% too low.

KISTLER/GOLDEN RIVER

Kistler/Golden River uses two strip sensors, which are installed at the distance of 4 metres apart. The system is using four WIM sensor channels, each containing two Lineas sensors (of 1 meter length). The signals of a Lineas pair are added onto one amplifier channel.

Thus every axle is weighed by four sensor pairs:

- Channel 1: First sensor , right wheel-track
- Channel 2: First sensor , left wheel-track
- Channel 3: second sensor , right wheel-track

- Channel 4: second sensor , left wheel-track

The Kistler LINEAS Quartz sensors used in the Golden River Traffic WIM system are linear in their output (charge output against force applied) and have little temperature sensitivity (less than 1% per 50 ºC, from –50 ºC to +80 ºC).

All GRT WIM sensors are tested during manufacture to ensure that all are within a sensitivity band. Each sensor is also individually tested to ensure the linearity of this sensitivity along it's length. This linearity allows the Golden River System to use a very simple calibration technique with a single number, or 'calibration factor' representing the site's affect on each sensor.

During calibration the WIM System compares each test vehicle which passes over the site with the known weight and calculates 'calibration factors' for each sensor (for each wheel impact). These calibration factors are noted and, at the end of the calibration these factors are simply averaged to give a single calibration factor for each sensor.

At the Lulea test site three test trucks were provided and were run through at different speeds and with different loads.

The slope of the regression line is very close to 1 (Figure 73 and Table 34). There is probably a very small sensitivity to temperature. Single axles, axles in axle group, tandem axles and gross weight have the same slope.

Standard error (Figure 74 and Table 34) is relatively small.

OMNI WEIGHT CONTROL

The sensor of the OWC system is a steel frame, which is installed on a prefabricated concrete bed. The sensor is horizontal and covered by asphalt mixture of about 70 mm at the shoulder side of the road and about 200 mm in the centreline. The asphalt mix is compacted in a net against the steel box in order to ensure good bond between the asphalt and the sensor.

The whole sensor is inside the road and nothing but the new asphalt can be seen. The advantage is that there will be no problems because of winter maintenance (ploughs etc) or studded tyres. If it is necessary to repave the road because of rutting, it can be done over the sensor; only new calibration is needed.

In the current installation the steel structure is roughly 350 cm x 180 cm x 18 cm and inside it there are ten active strain gages. Every strain gage has a passive duplicate glued near it. This reserve gage is activated automatically if there are problems with the primary gage.

The strain information is sent to a box by the roadside where the computer linearizes the data with a neural network to kilograms. This weight information is combined with time information and passed to a different neural network that detects vehicles from the stream and classifies them in their proper groups.

Neural network is a name for a very wide variety of different mathematical methods that are used for linearization, classification and control purposes just to name a few areas. OWC uses two different neural networks on two places in the system. The first one linearizes the strain data to simple kilograms. This network could be replaced with a simple mathematical function, but a neural network gives more space for later modifications than a simple function. The second network classifies the passing vehicles into different groups depending on the country's specifications. OWC used neural networks mainly to be able to tailor the system to different conditions without resorting to modifying the underlying software.

The final data is placed into a database from which it can be retrieved either directly by modem or if desired through the internet. From the internet side the scale would look like a normal www-page that the scale automatically updates.

The system must be calibrated (or taught) by loading it with passing vehicles. At least four weights and three speeds are needed. Calibration must be done at different circumstances, especially at different temperatures.

OWC system is a prototype and this model has never been installed in a real road before, only at a gate of a paper and pulp factory in order to measure incoming timber etc at the courtyard.

The slope in Figure 73 and Table 35 is smaller than 1 but relatively close to it in the first measurements. During the winter slopes are around 0.4. After the winter the results were once again close to 1.

The reason seems to be temperature effect. That will be discussed briefly later in chapter Seasonal effects. OWC had no temperature compensation during the test.

OWC tends to underestimate single axles.

The results from OWC are very linear even neural network system has been used. During the summer deviation in results is important (Figure 74 and Table 35.)

Seasonal effects

The seasonal variation is very large in the Nordic countries. During the summertime temperature of pavement may reach +50 ºC and wintertime –30 ºC is not rare. Snow and ice cause difficulties for traffic and WIM systems.

Dependencies on temperature of each WIM-systems are shown in Figure 77, Figure 78, Figure 79, and in Figure 80. During the second summer test June 1998 pavement surface temperature was not available. Missing temperatures were chosen to be +20 ºC.

PAT

Temperature compensation

It was informed before the test that no temperature compensation is needed. However, later preliminary results from December 1997 showed that temperature compensation is needed. It was decided that all PAT results would be analysed also with the temperature compensation developed by the manufacturer. Temperature compensation is based on results of the December 1997 test and is formulated, as follows:

temperature above +5 ºC: no compensation

below +5 ºC: factor = 1 + ((5 - temperature) / 5) x 0.03

Temperature compensation is needed during the cold period. Thus compensation was made only for the data received from tests of December 1997, January and March 1998.

The temperature of the pavement surface varied between –18 ºC and –24 ºC during the test in December 1997. Temperature compensation works properly under very cold temperature. Under cold temperatures, above –20 ºC but below +5 ºC, more efficient compensation is needed as can be seen in Figure 77.

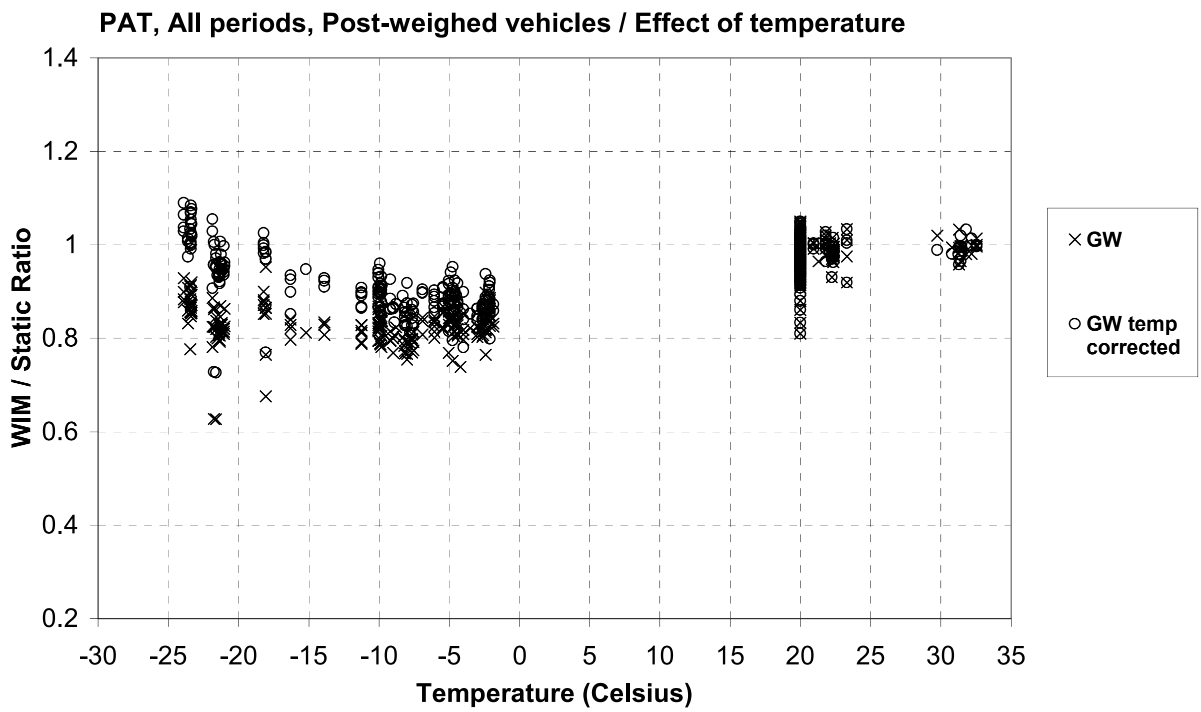


Figure 77. Effect of the temperature compensation.

DATAINSTRUMENT

As Datainstument uses a self-calibration, temperature variations can be taken into account. Due to special way to drive on road shoulders in Sweden, which was prevented during the tests by poles, self-calibration may be affected by those vehicles, which were passing sensors incorrectly before the start of tests. All results from winter tests and second summer test are under-estimated as can be seen in Figure 73 and Figure 78 (points vertically at 20 ºC from 2nd summer test as the real temperatures were not known). However, this under-estimation is almost independent on temperature (WIM/static measurement ratio varies between 0.55…0.62)

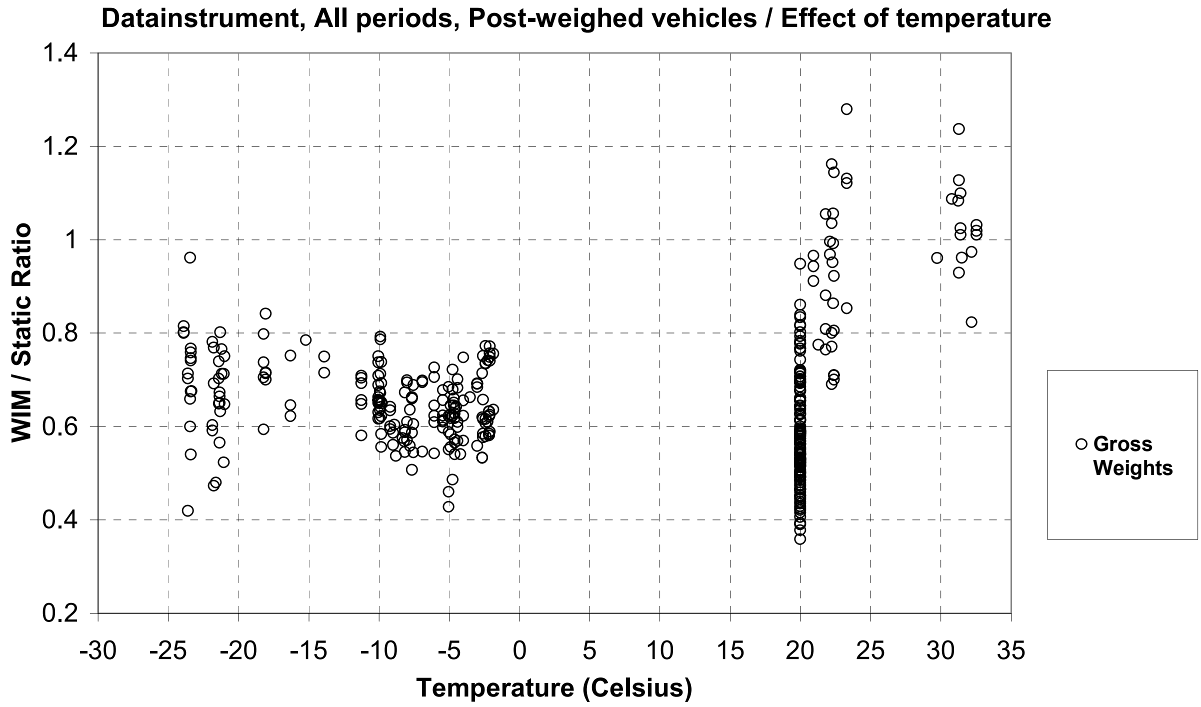


Figure 78. Dependence on temperature (Datainstrument).

KISTLER/GOLDEN RIVER

Kistler/Golden River system is insensitive to climatic variations. During the winter test periods this system maintains correct sensitivity. Results of the first and second summer tests show slight increase in WIM/static measurement ratio (1.04 vs. 1.09). Figure 79 presents Kistler/Golden River's dependence on temperature.

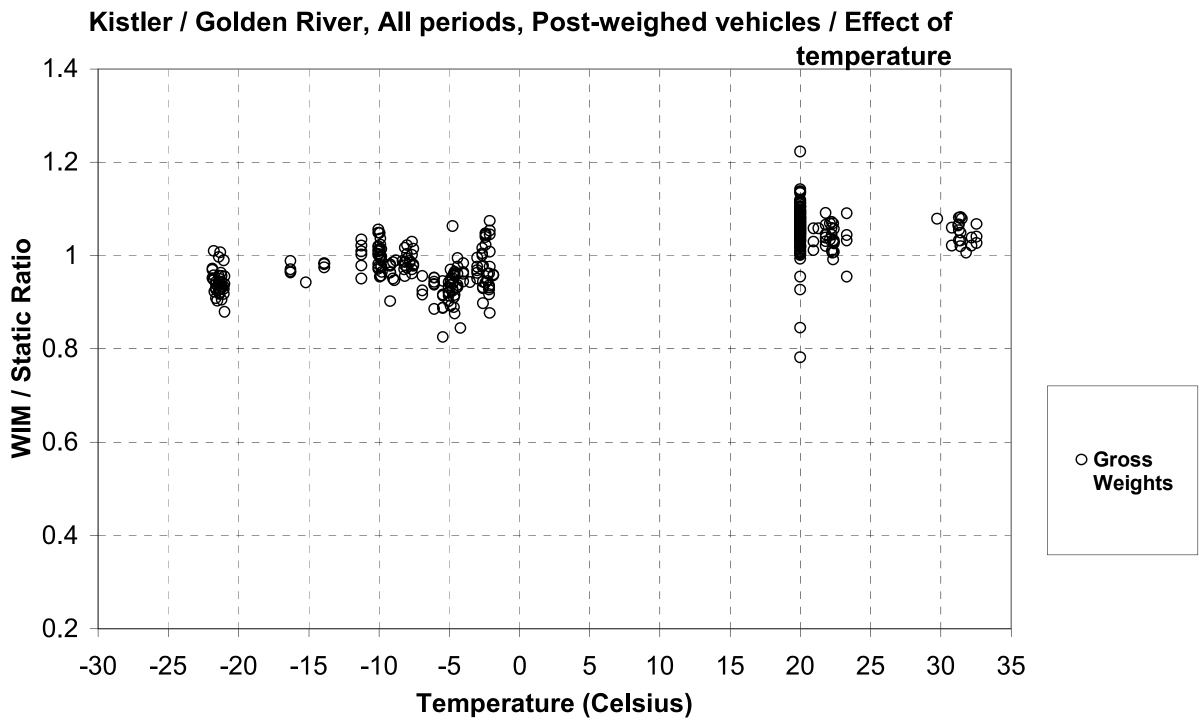


Figure 79. Dependence on temperature (Kistler/Golden River).

OMNI WEIGHT CONTROL

OWC system is clearly affected by temperature variation (Figure 80). Under cold temperature the relative error can be more than 50 %. The stiffness of asphalt is very sensitive to temperature and the modulus is easily more than ten times greater during the winter than during the summer. After wintertime, during the second summer test, OWC could provide data on correct level again. There is a clear need for temperature compensation.

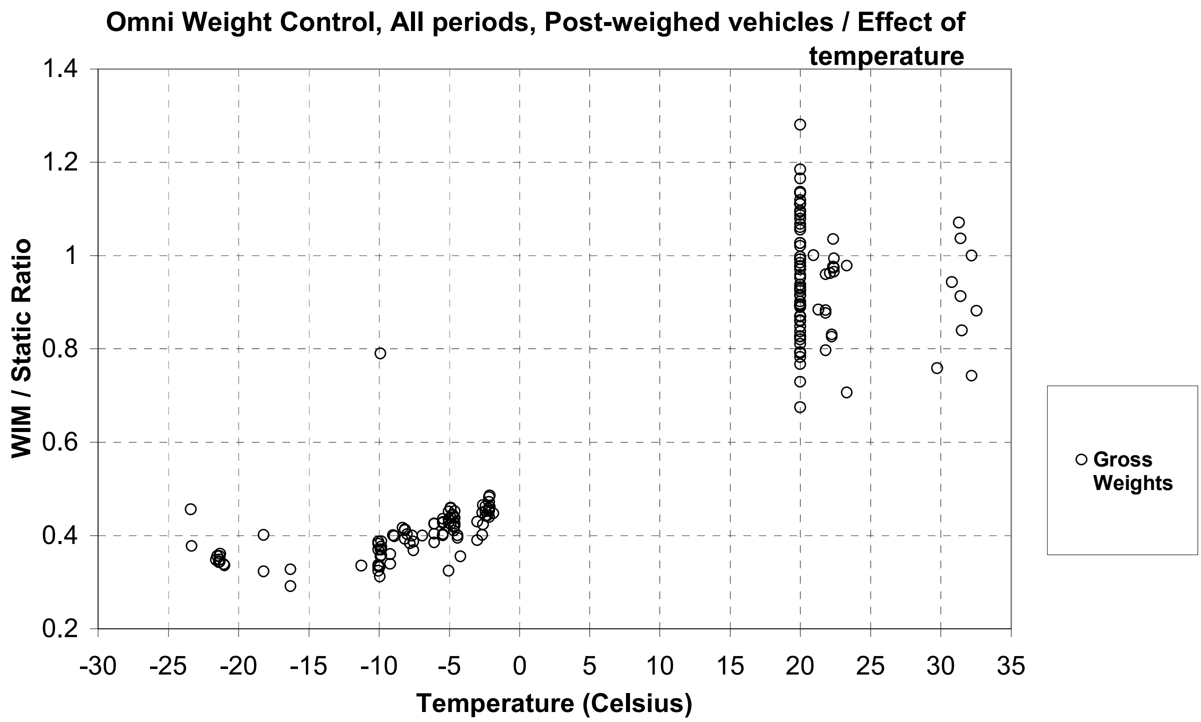


Figure 80. Dependence on temperature (Omni Weight Control).

Effect of load and speed

Used load of vehicle affects the precision of WIM system. Empty vehicles cause more variation to results as can be seen in Figure 81. The phenomenon is not due to self-calibration as can be seen in Figure 82 where self-calibration was not used. Results are getting better as the load increases and the behaviour of the vehicles is more steady.

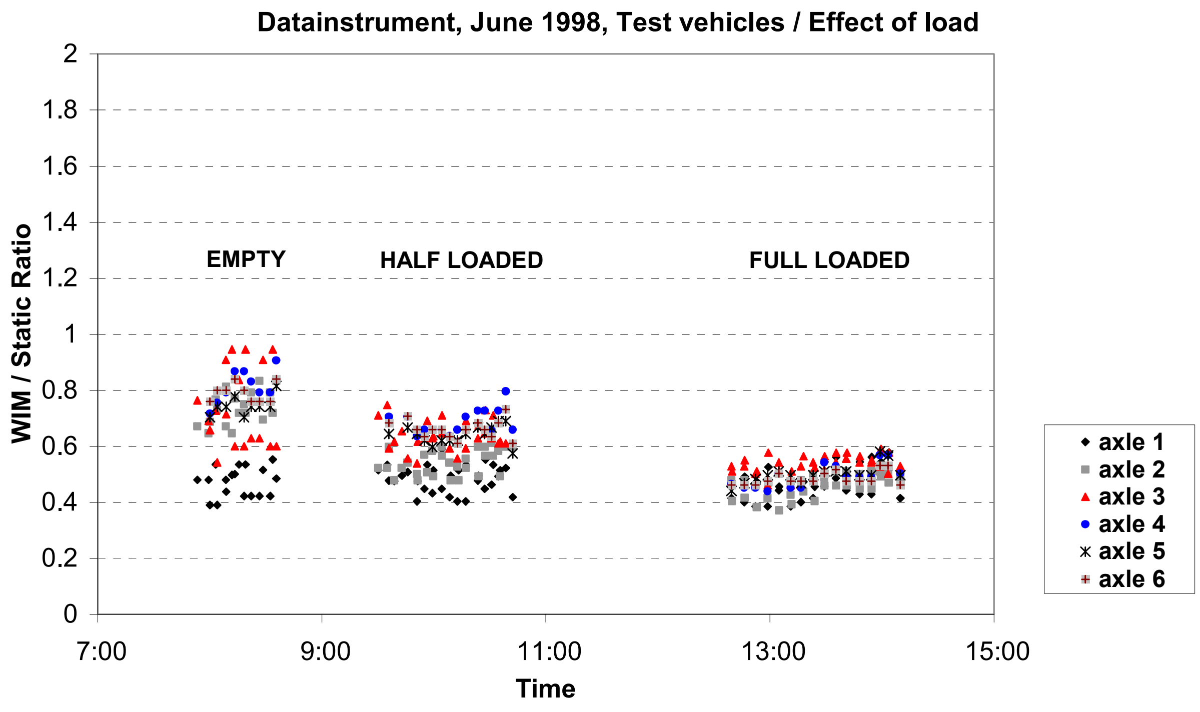


Figure 81. Effect of load on WIM measurements (self-calibration).

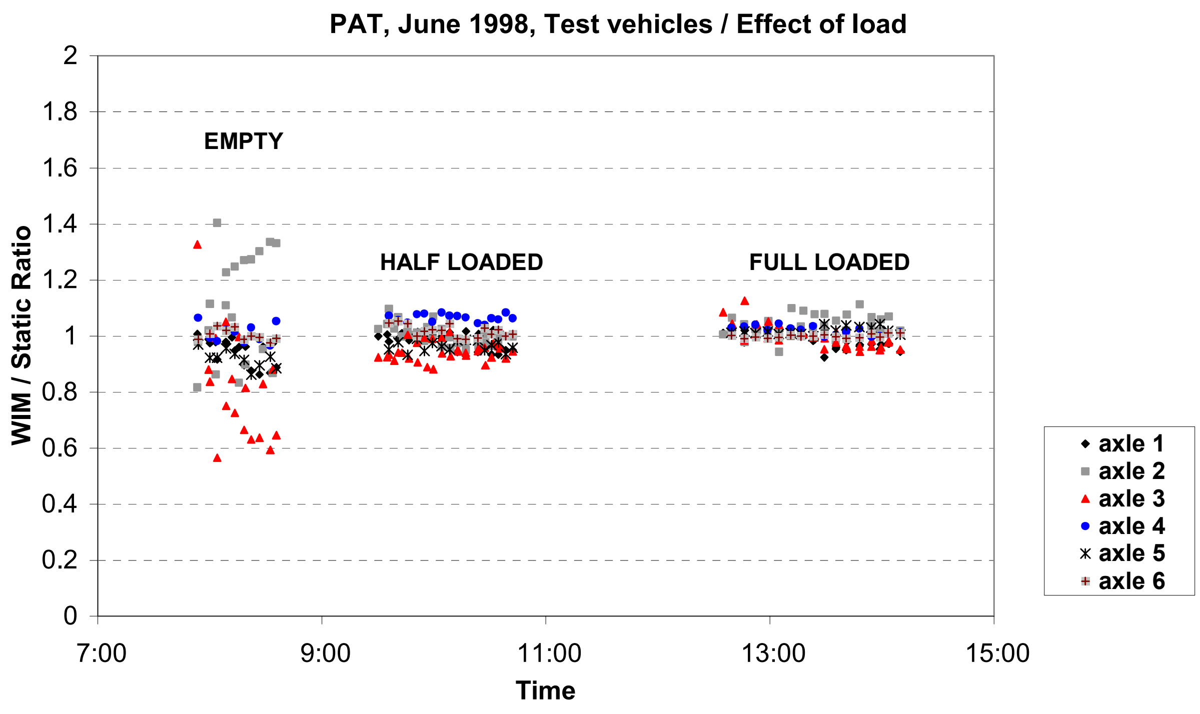


Figure 82. Effect of load on WIM measurements (no self-calibration).

During the tests test vehicles were running at different speeds. Speed had a very small effect on the results. Examples are shown in Figure 83 and in Figure 84. Nearly all other systems behaved like these examples. The figures presented here are only examples.

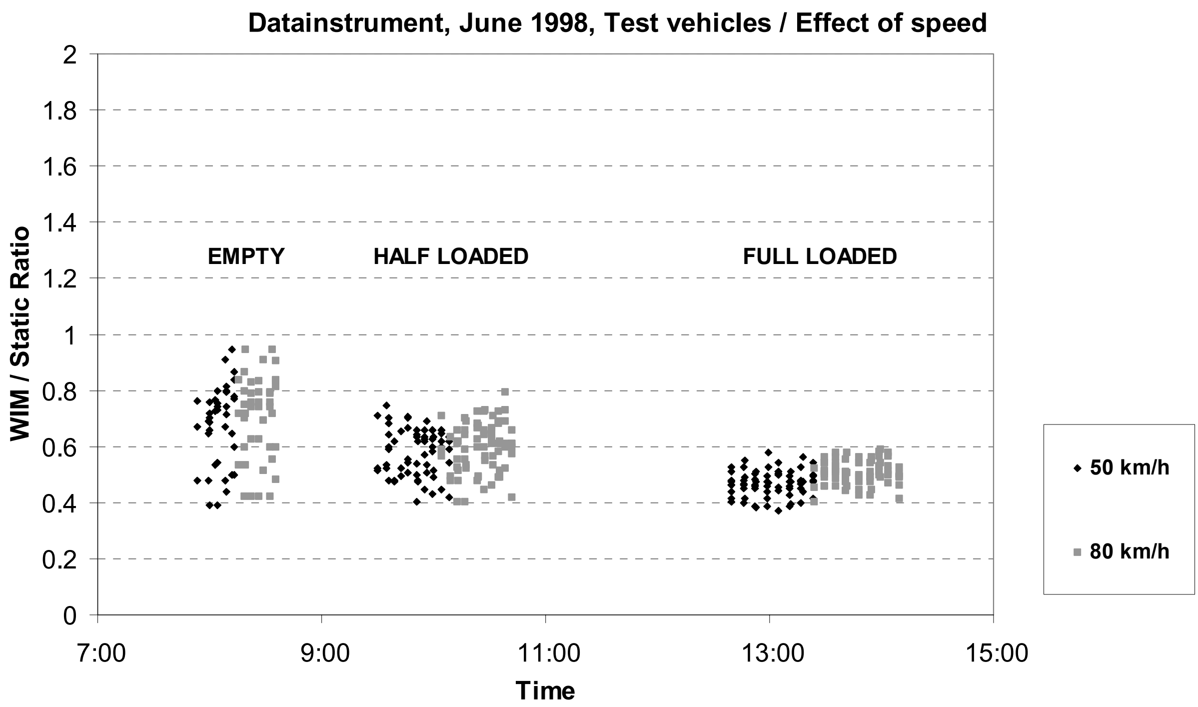


Figure 83. Effect of speed on WIM measurements (self-calibration).

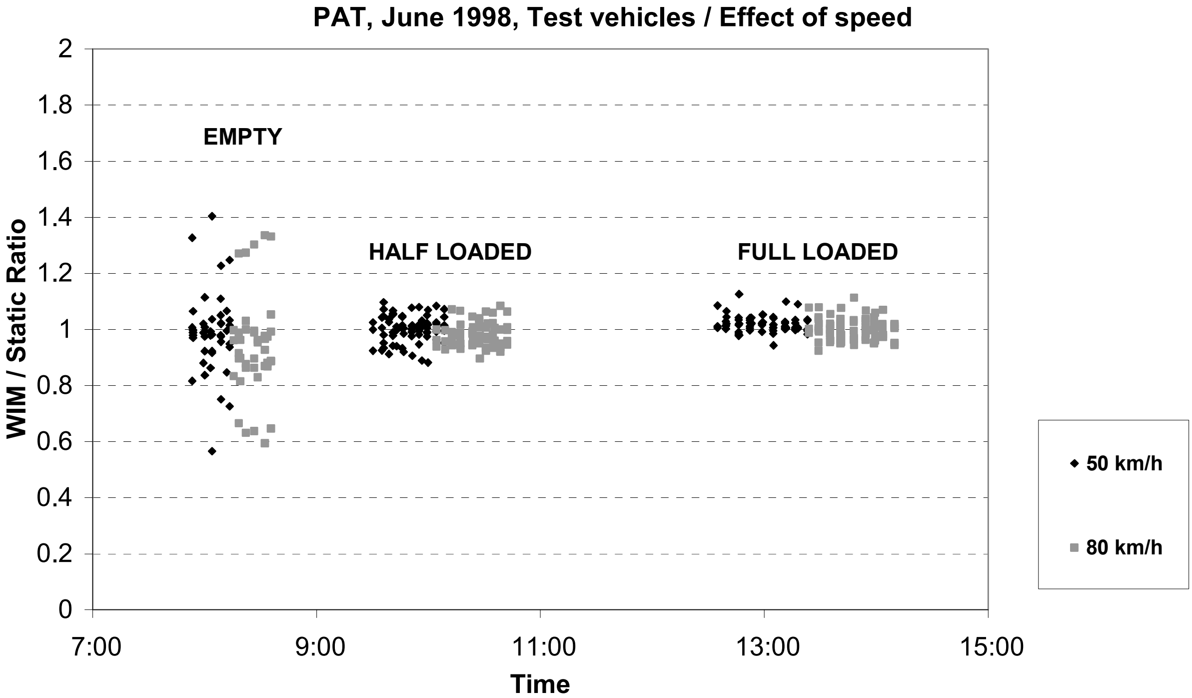
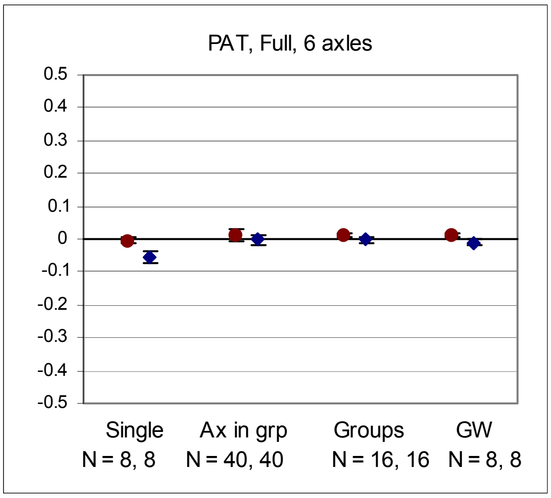


Figure 84. Effect of speed on WIM measurements (no self-calibration).

PAT

The same dynamic behaviour of the tandem axle of empty test vehicles, which was seen on the other systems, was also noticed on the PAT results. During the winter test results were systematically underestimated, relative error varied between -13 and -22 per cent. Results of full-loaded, six-axle test vehicle can be seen in Figure 85.

There is need for the temperature compensation. A small difference was noticed between single (front axle) and dual tyres (rear/trailer axles).



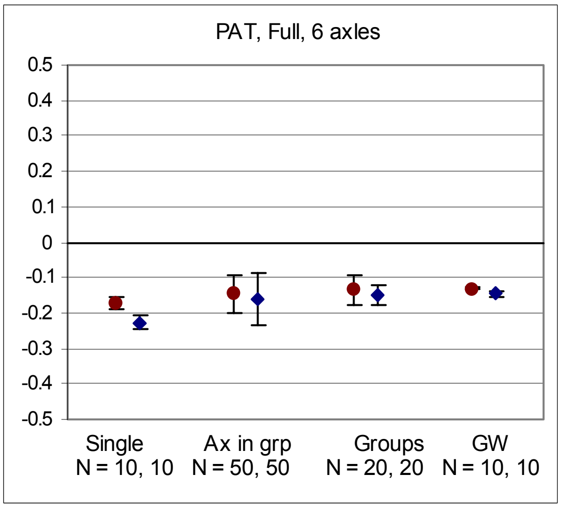


Figure 85. Full-loaded, six-axle test vehicle. First summer test on the left and first winter test on the right.

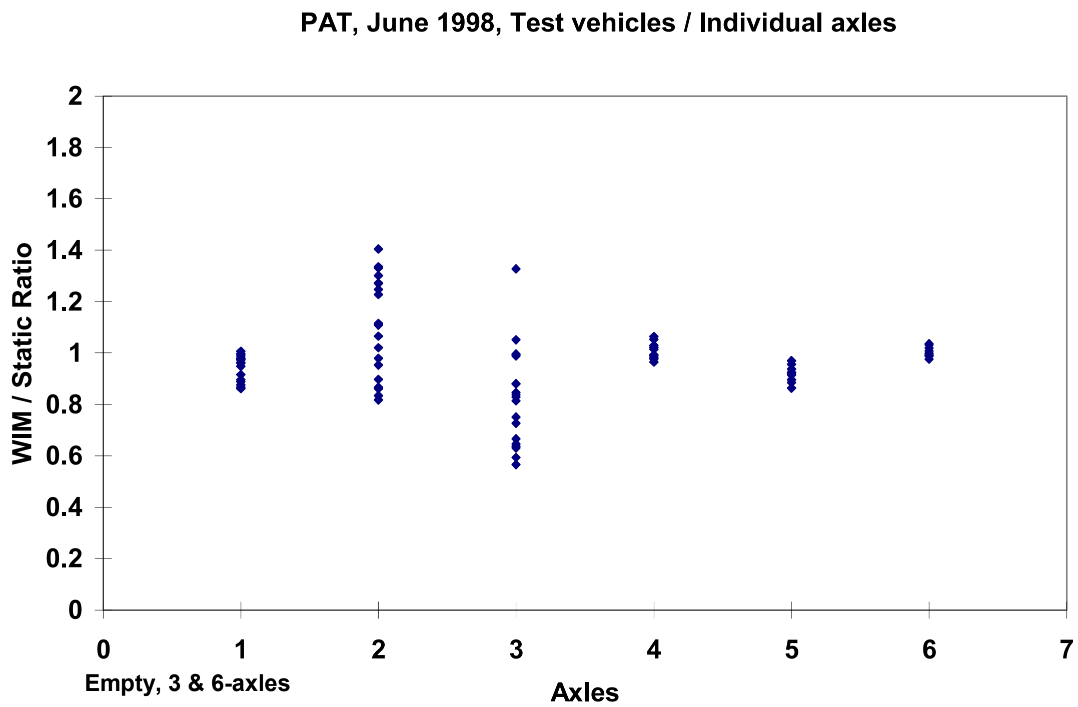


Figure 86. An example of tandem axle behaviour, empty test vehicles.

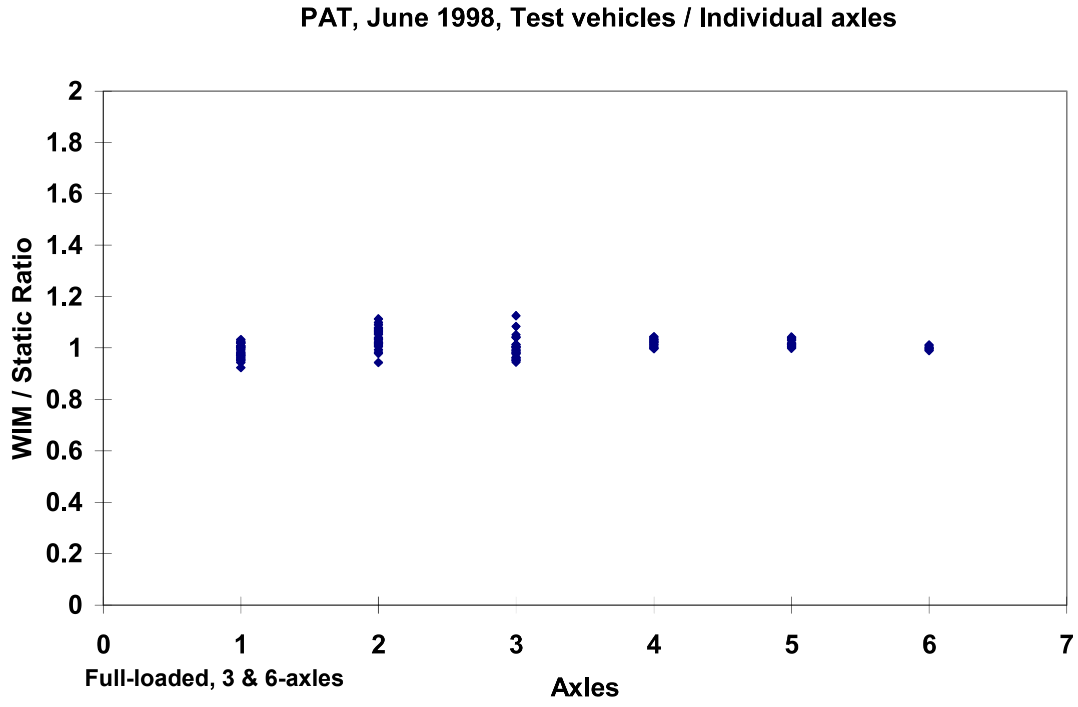


Figure 87. An example of tandem axle behaviour, full-loaded test vehicles.

DATAINSTRUMENT

During the first summer test (June 1997) test vehicle results were highly dependent on axle loads. Results of empty and half-loaded test vehicles showed even 100 per cent overestimated values. It can be seen especially on the results of drive axle or axle in axle groups.

Reason may be self-calibration and/or that the size of tyre imprints was varying in a larger scale with the dual tyres than with the single tyre. That will be discussed later in chapter Tyre imprint.

During the winter tests or second summer test the phenomenon could not be seen anymore but results were underestimated systematically having only value of about 50 per cent of the correct one.

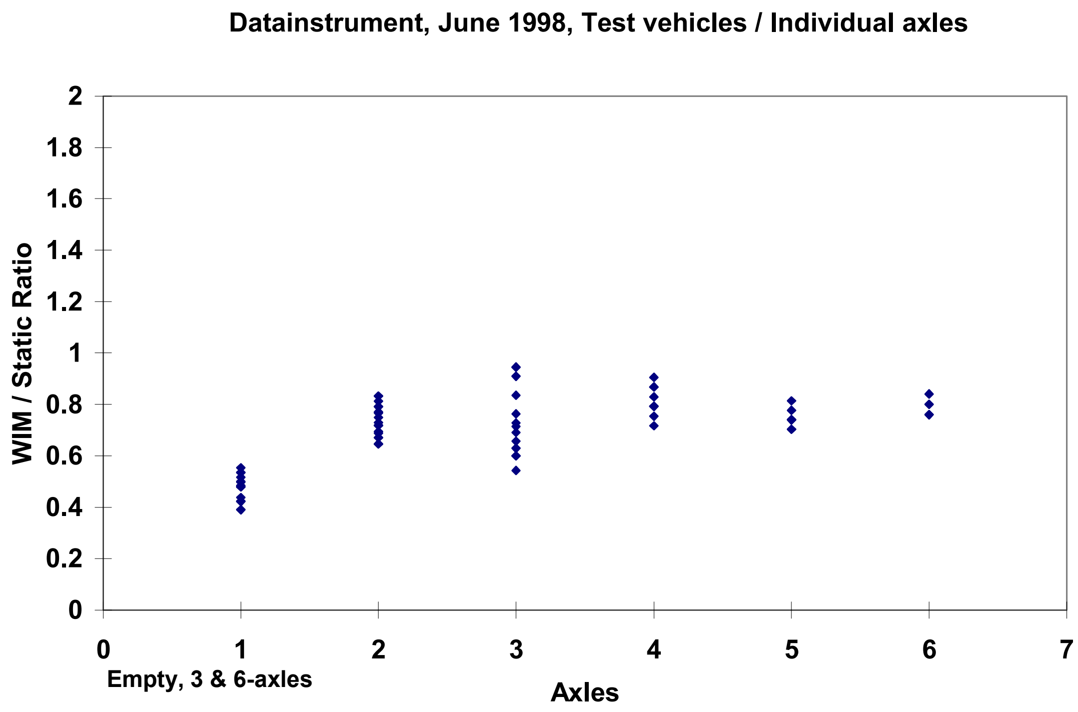


Figure 88. An example of tandem axle behaviour, empty test vehicles.

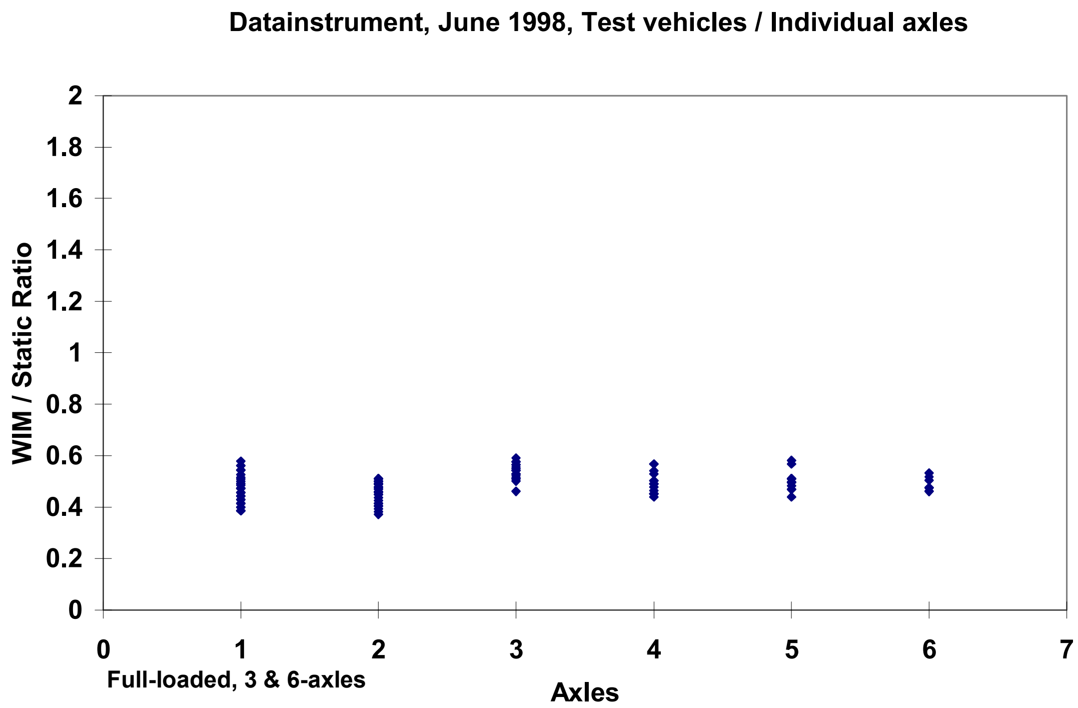


Figure 89. An example of tandem axle behaviour, full-loaded test vehicles.

KISTLER/GOLDEN RIVER

Vehicle dynamics causes bigger deviation to results of the tandem axle of empty test vehicles. An example can be seen in Figure 90, 2nd and 3rd axles as a tandem axle. With full-loaded vehicles dynamic effects have clearly decreased, as can be seen in Figure 91.

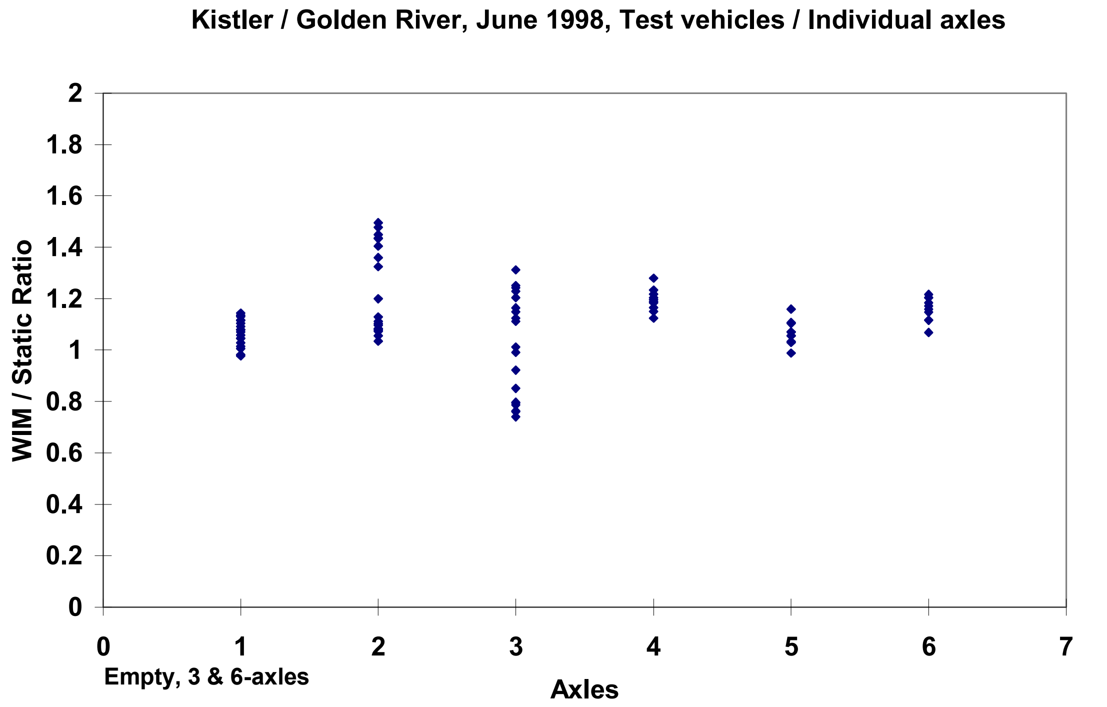


Figure 90. An example of tandem axle behaviour, empty test vehicles.

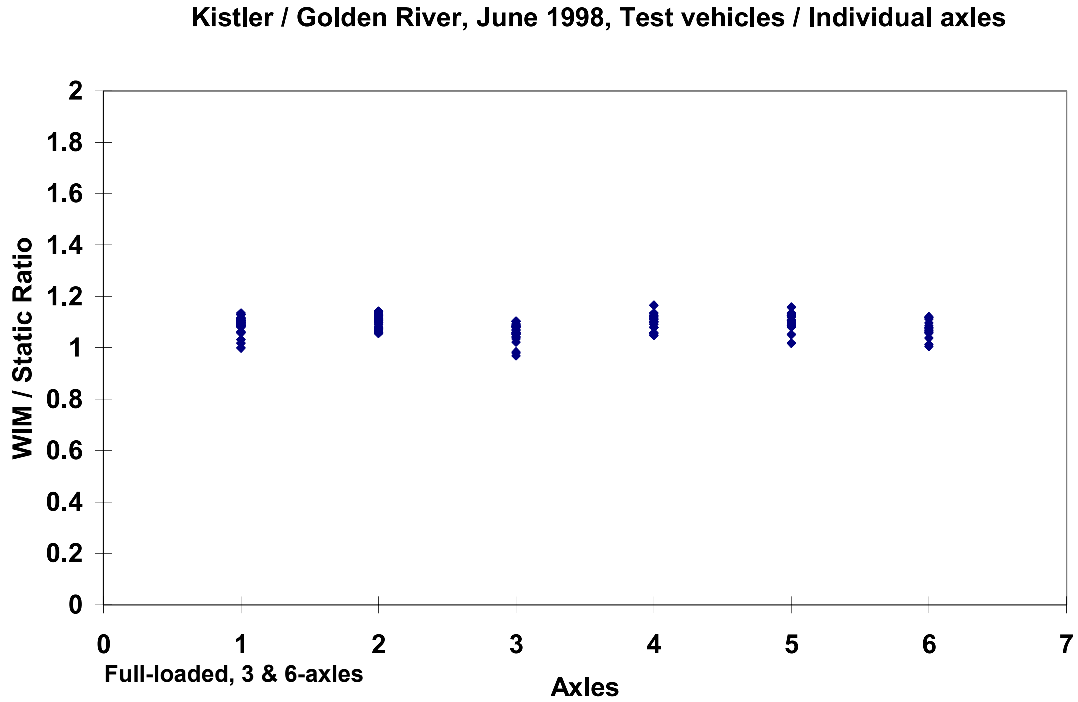


Figure 91. An example of tandem axle behaviour, full-loaded test vehicles.

With empty test vehicles a small difference was noticed between single and dual tyres. It may be related to the size of tyre imprint as well as in Datainstrument system.

OMNI WEIGHT CONTROL

In the beginning of the first summer test Omni Weight Control could not provide data. Thus empty and half-loaded test vehicles were missing. However, data of full-loaded test vehicle is available. Between 50 and 80 km/h measurements there is noticeable difference on results. Being a prototype clear improvement can be seen on the second summer test results. Results of full-loaded, three-axle test vehicle can be seen in Figure 92. WIM/static measurement ratios are rather similar with empty and full-loaded test vehicles as can be seen in Figure 93 and Figure 94.

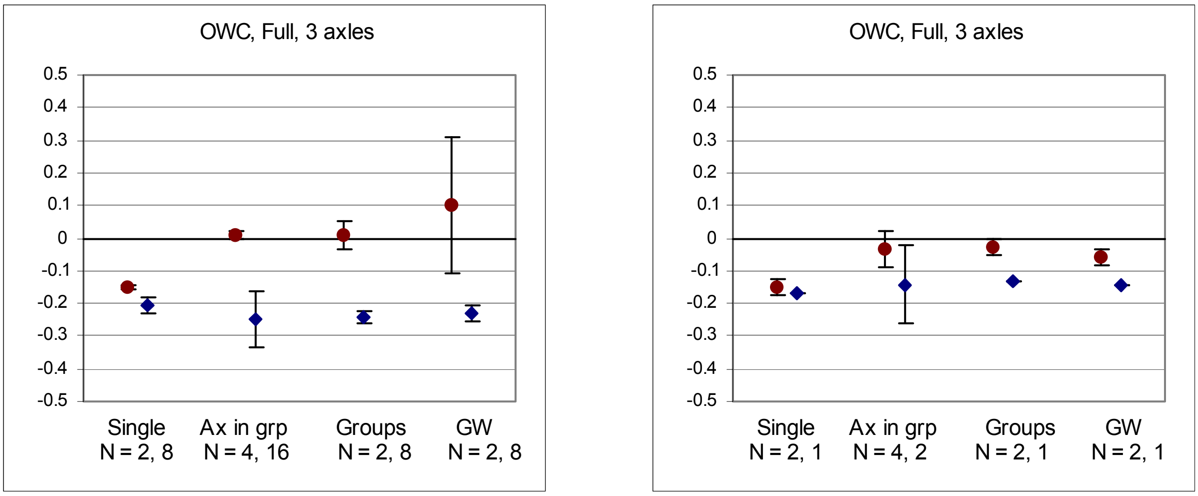


Figure 92. Full-loaded, three-axle test vehicle. First summer test on the left and second summer test on the right.

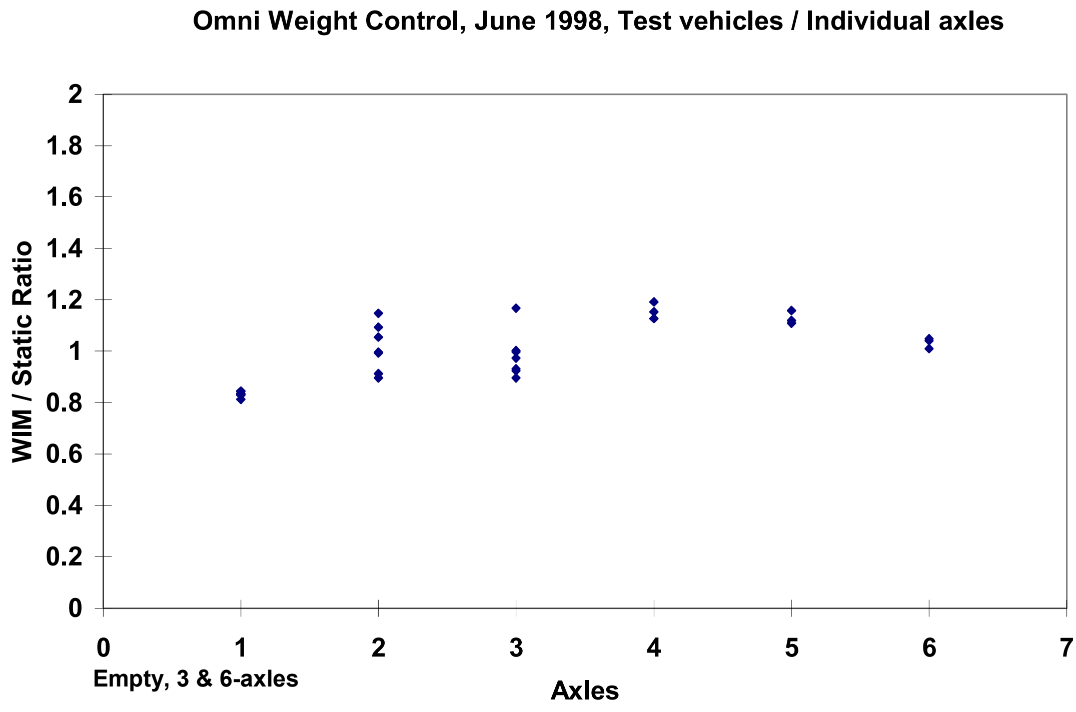


Figure 93. An example of tandem axle behaviour, empty test vehicles.

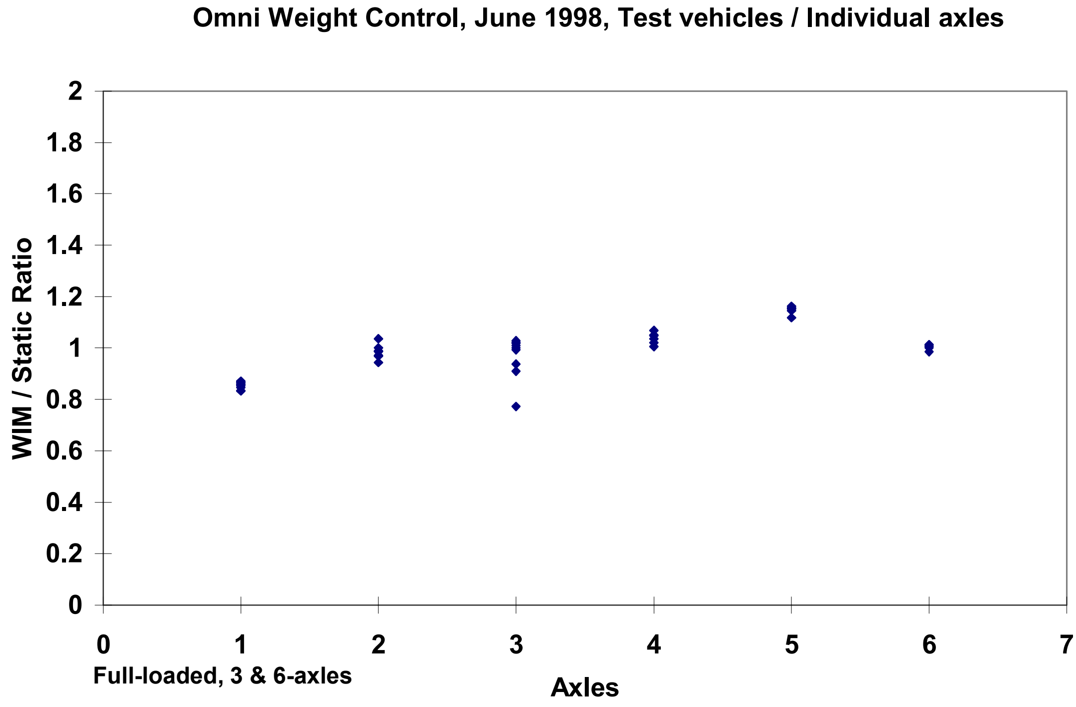


Figure 94. An example of tandem axle behaviour, full-loaded test vehicles.

Axle groups

Axle groups can be divided to two different categories, two axle group (tandem) and three axle group (tridem). In the analysis no difference as a group could be found between these two categories. An example can be seen in Figure 95.

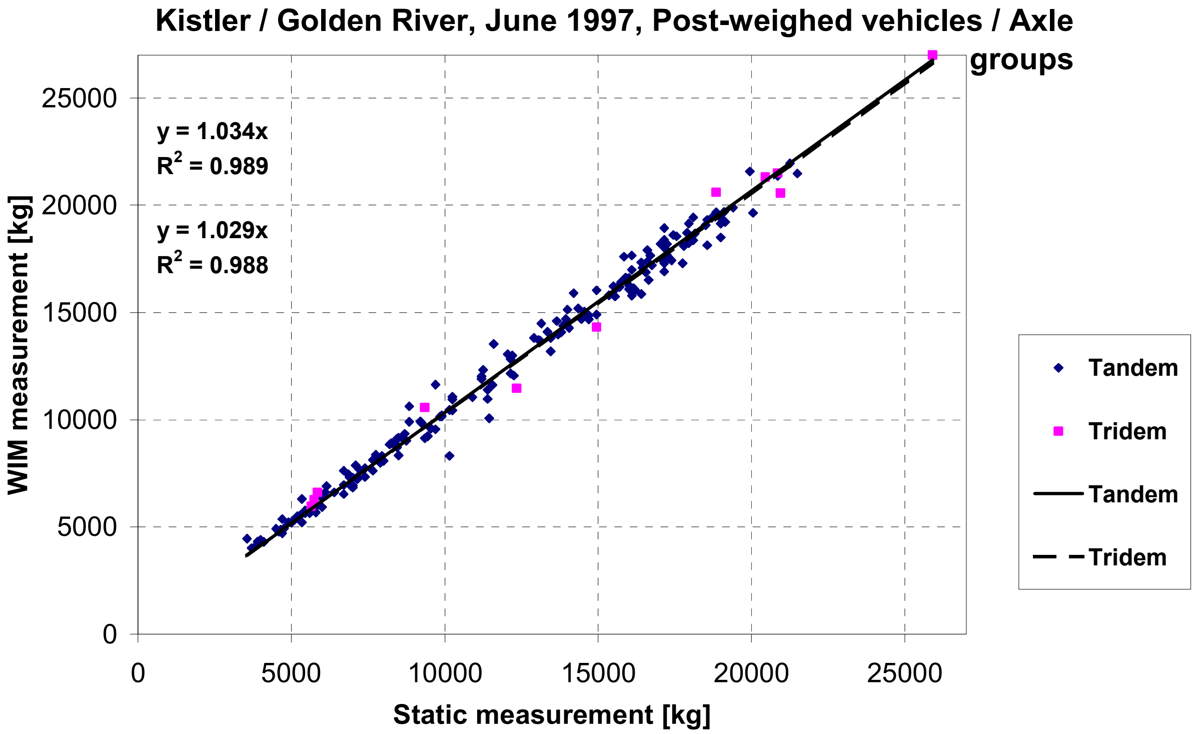


Figure 95. Tandem and tridem axle groups.

However, behaviour of separate axles in a group is depending more on the number of axles. Typically in Finland and in Sweden tandem of lorries have a drive axle and a liftable bogie axle. In case of steel spring they are normally coupled together i.e. impact force on one axle is affecting on other axle. Normal load distribution between drive and bogie axles is about 55%/45% in order to maintain reasonable traction properties also on icy roads. Load distribution of axle groups in trailers is usually equal. That may vary due to different tyres in axles.

In Figure 96 another tandem axle has a very high measured value and another axle has a low value, respectively. This is common especially with empty lorries, because the suspension is designed to bear payload and does not work optimally as the vehicle is empty. One case is marked with boxes and another with ovals. Note, results of single axles in a group are typically more deviated (Figure 96) than results of axle groups (Figure 95). That will be discussed more in chapter Axle rank.

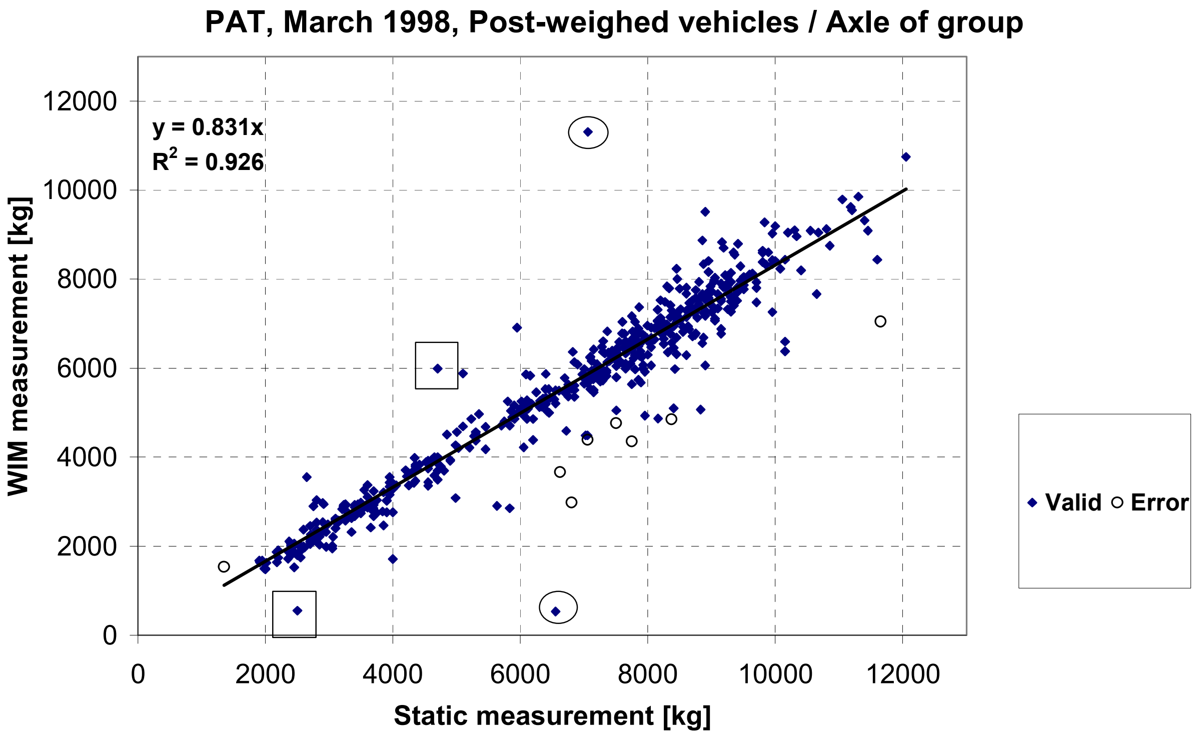


Figure 96. Influence of tandem axle hop on results.

Because of short axle spacing in axle groups a WIM sensor has very little time to relax for the next measurement. Type 30 vehicle (see Figure 37 above) was used to study if there is a problem with relaxation among axle group weighing. The average of WIM/static measurement ratio of individual axles for the vehicle type 30 is presented in Table 36 (first winter test) and Table 37 (second summer test). Axle number on the column corresponds to the axle of vehicle (1 to steering axle, 2 and 4 to 1st tandem axle, 3 and 5 to 2nd tandem axle etc).

Table 36. Average of WIM/static measurement ratio of individual axles (vehicle type 30, January 1998).

WIM	Axle number						
	1	2	3	4	5	6	7
PAT	0.792	0.830	0.803	0.805	0.827	0.803	0.807
DI	0.545	0.641	0.575	0.716	0.643	0.719	0.646
KI/GR	0.923	1.000	0.952	0.923	0.976	0.953	0.946
OWC	0.349	0.397	0.405	0.390	0.398	0.391	0.398

Table 37. Average of WIM/static measurement ratio of individual axles (vehicle type 30, June 1998).

WIM	Axle number						
	1	2	3	4	5	6	7
PAT	1.000	0.979	0.988	1.002	0.947	0.979	0.993
DI	0.462	0.508	0.596	0.655	0.630	0.577	0.609
KI/GR	1.052	1.069	1.041	1.049	1.025	1.065	1.062
OWC	0.906	1.030	0.993	1.115	0.981	1.005	1.018

PAT uses bending plates for the axle load measurement. That kind of technique does not lead to incorrect weighing result even the plate yet remains bent when the next axle reaches the plate. It can be seen in Figure 97 and Figure 98 that WIM/static measurement ratio has only rather small difference between individual axles or tandems. Averages for tandem axles are between 0.80 and 0.83 during the first winter test and between 0.95 and 1.00 during the second summer test, respectively.

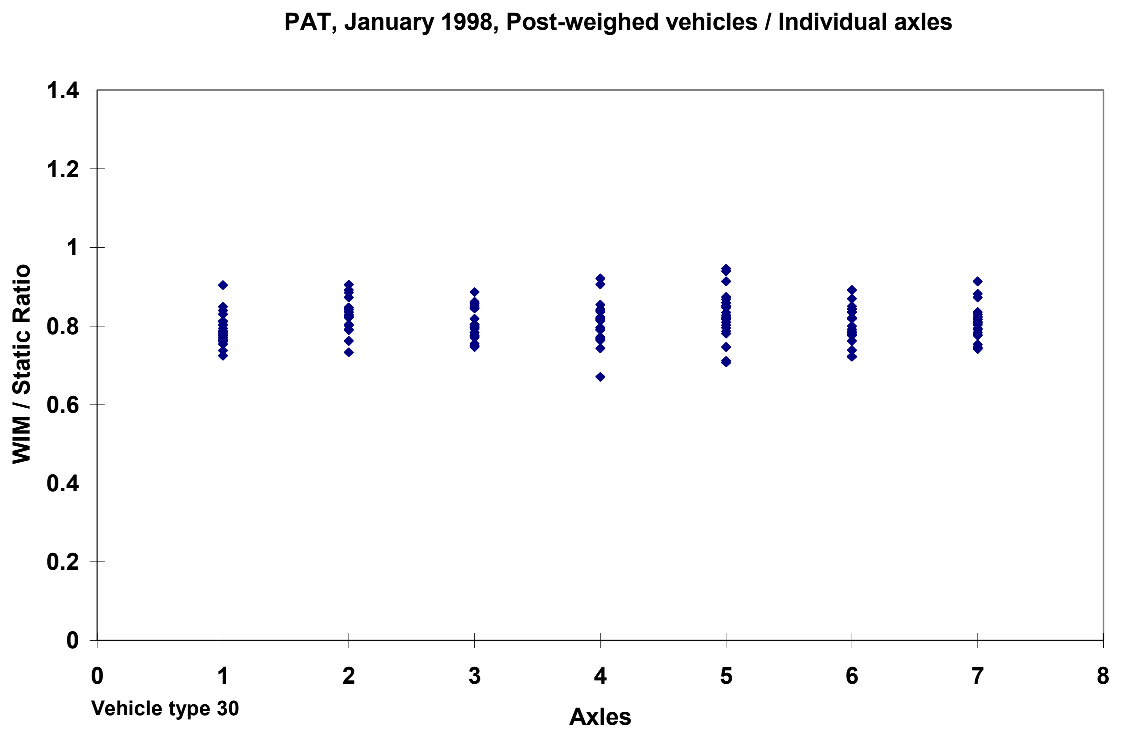


Figure 97. WIM/static measurement ratio for each axle during the first winter test (PAT).

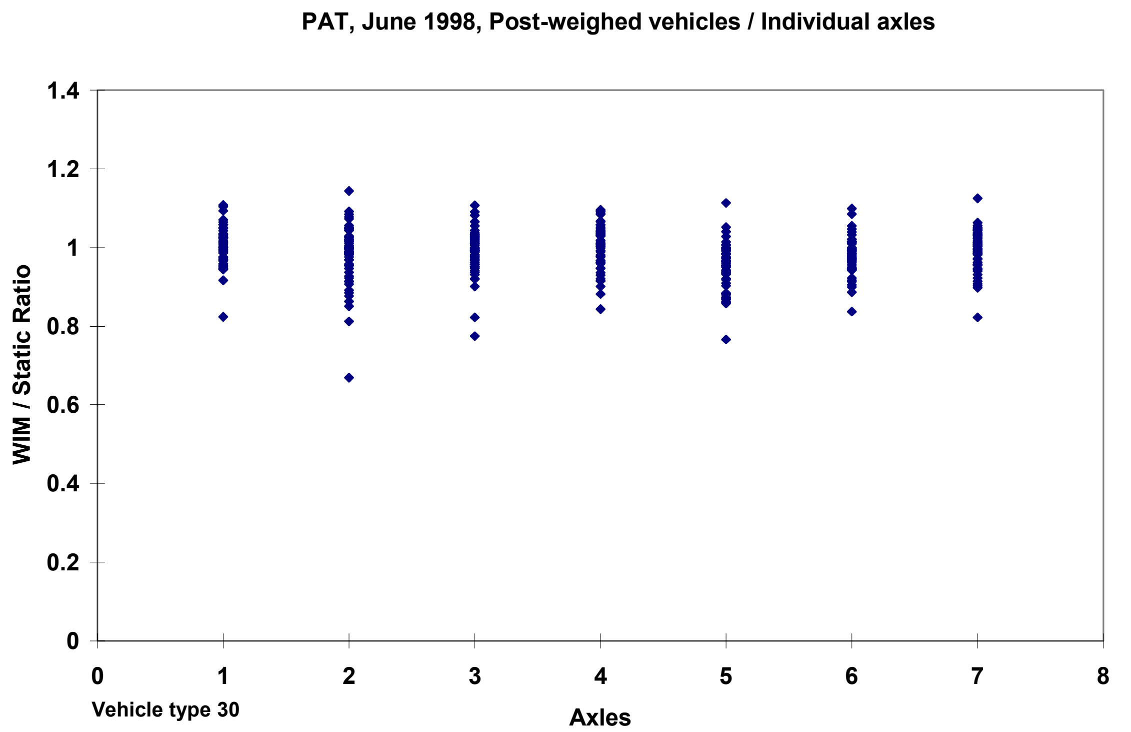


Figure 98. WIM/static measurement ratio for each axle during the second summer test (PAT).

Datainstrument has piezoelectric sensors. Bending plates can measure continuous (static) loads. Piezoelectric sensors cannot do that but measuring principle is more complicated, thus a relaxation problem may occur. Especially during wintertime second tandem axle gives systematically smaller results (see Figure 99), averages for first tandem axles are between 0.64 and 0.72 but only between 0.58 and 0.65 on second tandem axles. During the second summer test the phenomenon is not clear due to large deviation on the individual axle results (see Figure 100).

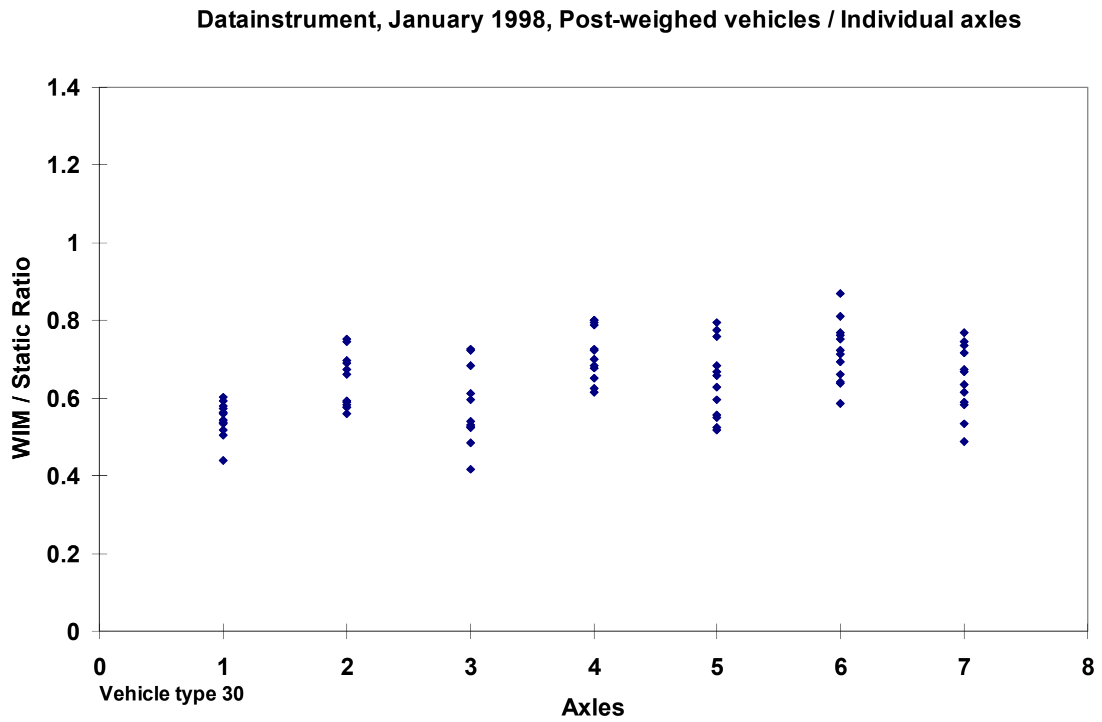


Figure 99. WIM/static measurement ratio for each axle during the first winter test (DI).

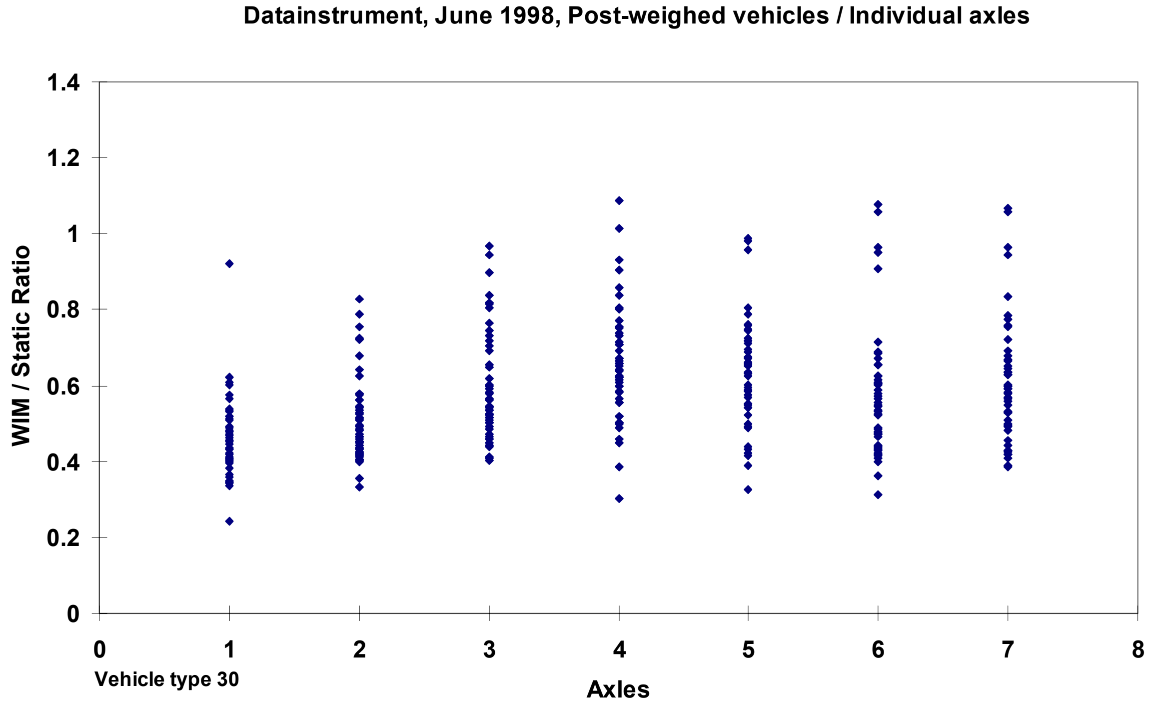


Figure 100. WIM/static measurement ratio for each axle during the second summer test (DI).

Kistler/Golden River's sensors are based on quartz sensor technique, which is sensitive to vertical force only. They have not problem with the relaxation as can be seen in Figure 101 and Figure 102. Under the first winter test the averages are kept between 0.92 and 1.00 and between 1.03 and 1.07 during the second summer test, respectively.

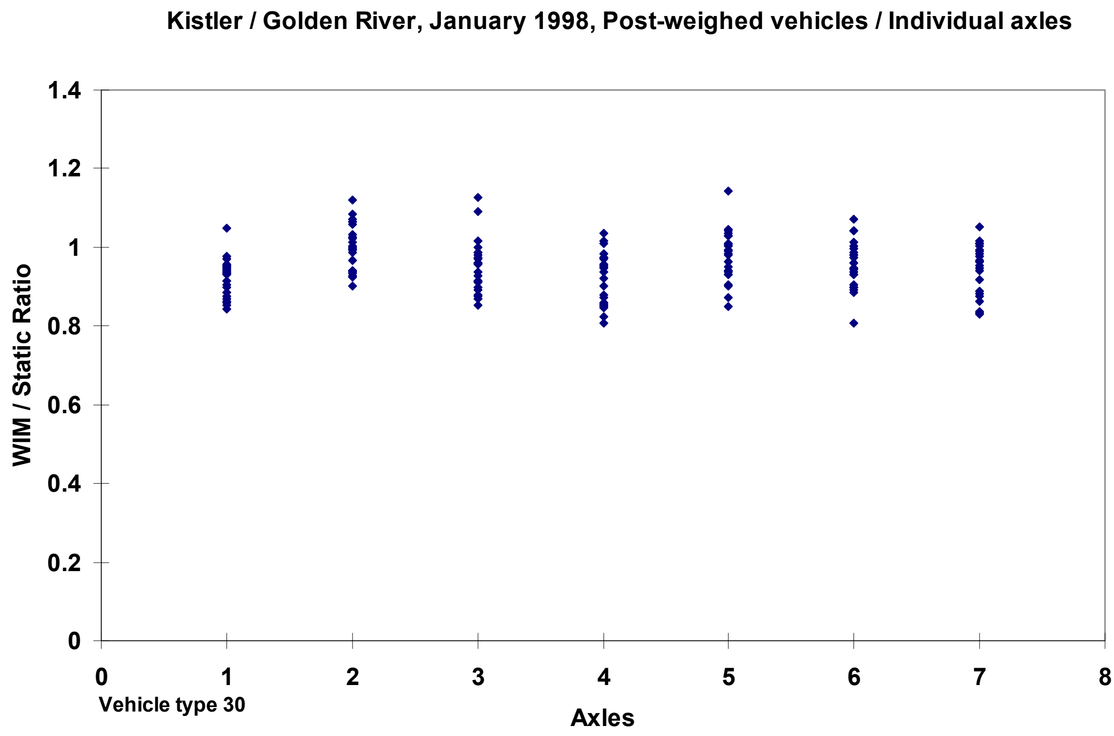


Figure 101. WIM/static measurement ratio for each axle during the first winter test (KI/GR).

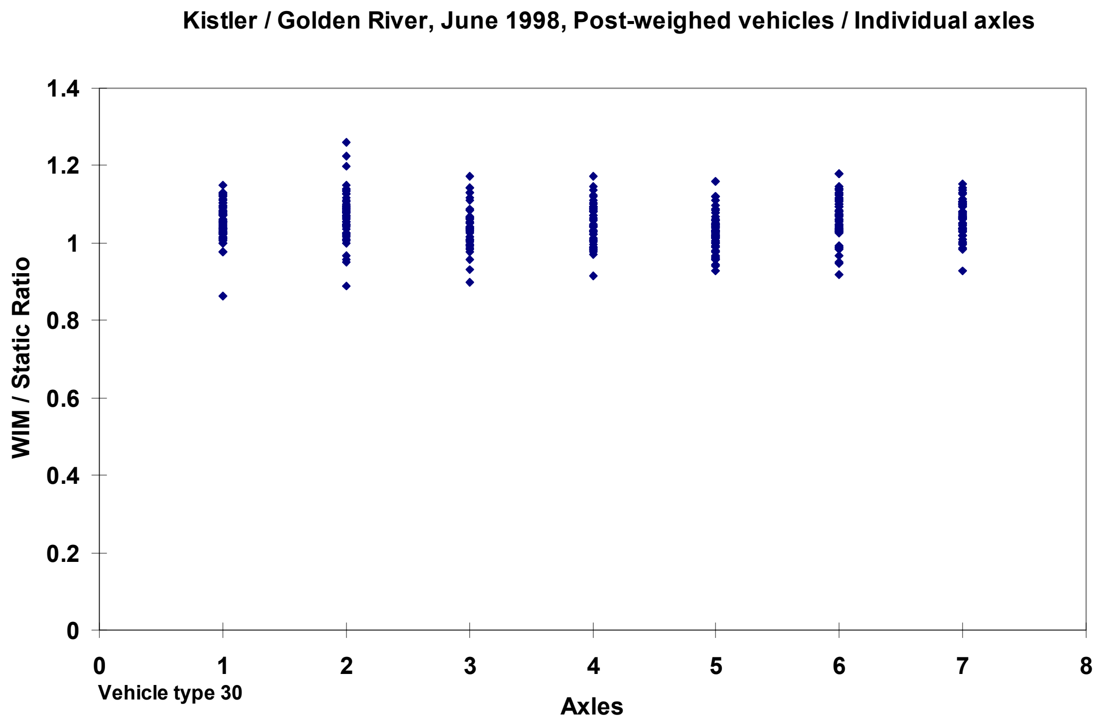


Figure 102. WIM/static measurement ratio for each axle during the second summer test (KI/GR).

Omni Weight Control has clearly problem to measure axle groups having very short axle spacing under warm temperatures as can be seen in Figure 104. Because of too long steel frame sensor (length of 1,80 m) two axles may pass the sensor simultaneously and cause this problem. That is the case especially with the second tandem axle (axles 4 and 5 in Figure 104), the first tandem axle of a trailer, which has shortest possible axle spacing in existing vehicle types. Mainly that is due to smaller diameter tyres used and the steering nature of that particular tandem axle. Differences of the WIM/static measurement ratio between these two tandem axles are about 12 % but only 3.5 % or less with tandem axles having longer axle spacing. Wintertime when asphalt surface is much stiffer and more elastic (not visco-elastic like the summer), the problem does not occur. WIM/static measurement ratio is very even over all tandem axles; averages are between 0.39 and 0.41.

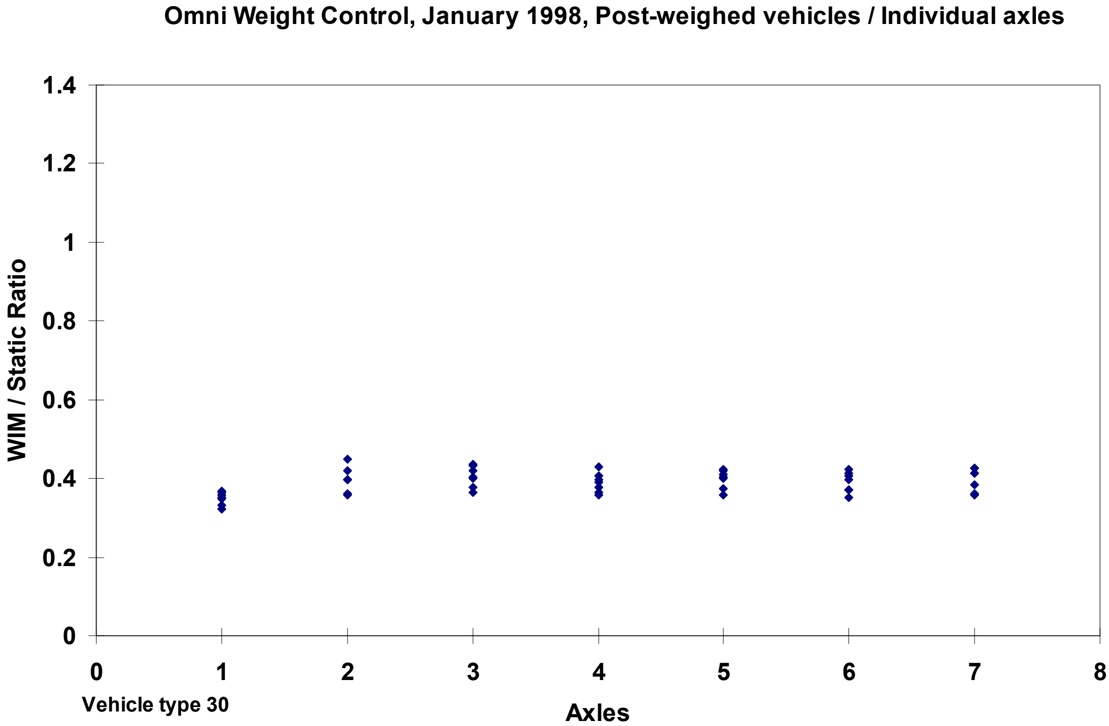


Figure 103. WIM/static measurement ratio for each axle during the first winter test (OWC).

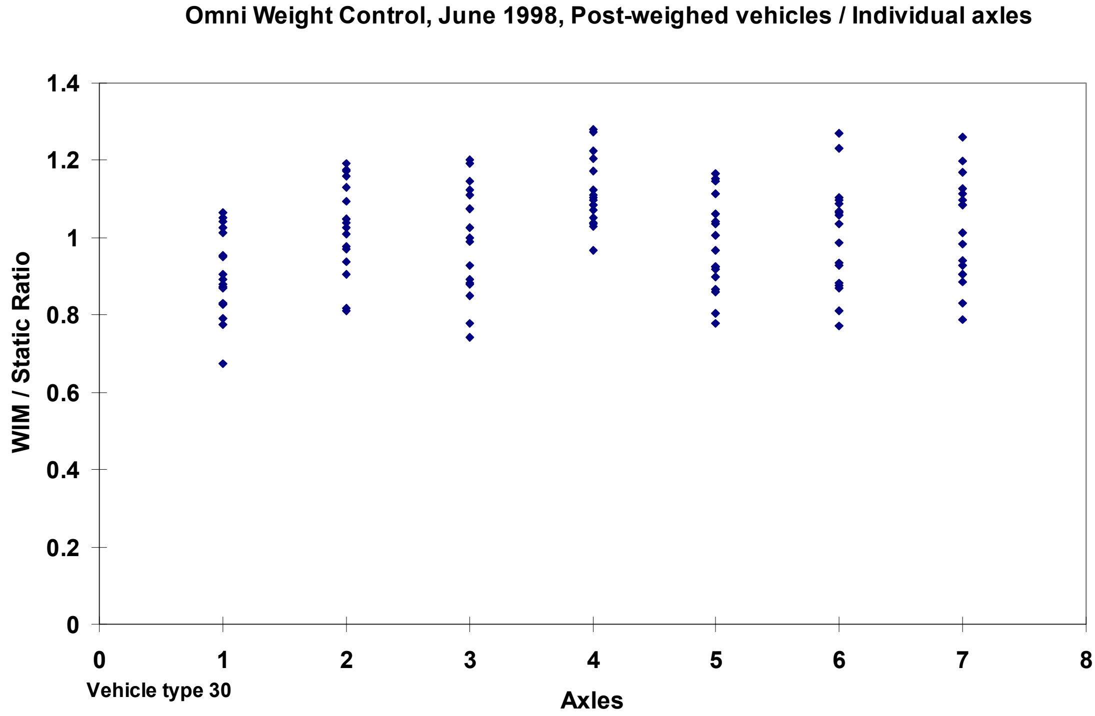


Figure 104. WIM/static measurement ratio for each axle during the second summer test (OWC).

Tyre imprint

Both 3- and 6-axle test vehicles have similar axle construction on the first three axles. Front axle has an ordinary single tyre, drive and bogie axles have dual tyres and in semitrailer there is wide base tyre assembly. Range of axle loads between empty and full-loaded vehicles varied much more on axle groups than on single (front) axle, namely 2500 – 11000 kg on an axle in axle groups but only 5000 – 7300 kg on front axle. Thus the shape of contact area between tyre and pavement is very different in these two cases. With a single tyre it is narrow and long but wide and short with a dual tyre, respectively.

The comparison was made on individual axles in order to study whether the width of tyre has an influence on the results or not. The ratio of dynamic/static measurements on individual axles of full-loaded test vehicles can be seen in Table 38 (June 1997) and Table 39 (June 1998). The ratio of dynamic/static measurements on individual axles of empty test vehicles can be seen in Table 40 (June 1997) and Table 41 (June 1998).

PAT is insensitive regarding the width of the tyre. With a full load Kistler/Golden River maintains also same level through the different type of tyres. With empty test vehicles a small difference can be seen between single and dual tyres. Datainstrument shows smaller values for single tyres especially with the empty test vehicles. In case of OWC, especially on warm temperature there is a clear difference between single (front axle) and dual tyres (rear/trailer axles). Results of full-loaded, six-axle test vehicle can be seen in Figure 105.

Table 38. WIM/static ratio of individual axles, full-loaded test vehicles June 1997.

WIM	Single	Tandem		Tridem			TOTAL
	1	2	3	4	5	6	
PAT	0.967	0.998	0.976	1.016	0.992	1.008	0.989
Datainstrument	0.615	0.683	0.868	0.849	0.728	0.834	0.749
Kistler/Golden River	1.047	1.057	1.022	1.047	1.008	1.019	1.036
OWC	0.845	0.919	0.890	1.087	1.101	1.053	0.955

Table 39. WIM/static ratio of individual axles, full-loaded test vehicles June 1998.

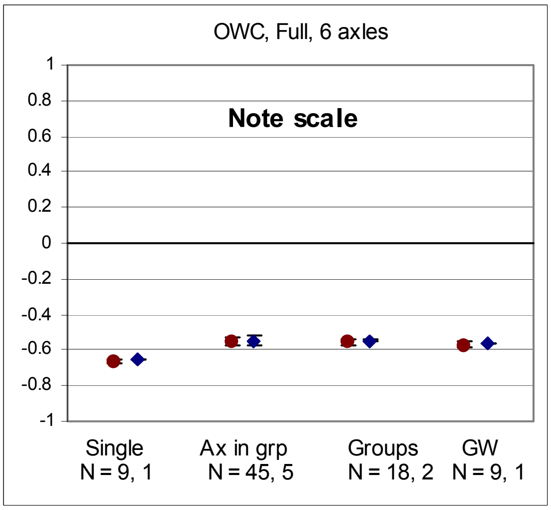
WIM	Single	Tandem		Tridem			TOTAL
	1	2	3	4	5	6	
PAT	0.989	1.037	0.997	1.020	1.019	1.000	1.009
Datainstrument	0.470	0.460	0.536	0.492	0.502	0.485	0.490
Kistler/Golden River	1.090	1.103	1.063	1.098	1.104	1.074	1.087
OWC	0.855	0.985	0.966	1.038	1.149	1.005	0.987

Table 40. WIM/static ratio of individual axles, empty test vehicles June 1997.

WIM	Single	Tandem		Tridem			TOTAL
	1	2	3	4	5	6	
PAT	0.958	1.107	0.905	1.030	0.982	1.035	0.999
Datainstrument	0.908	1.447	1.599	1.696	1.492	1.706	1.426
Kistler/Golden River	1.022	1.218	0.938	1.034	1.019	1.046	1.050
OWC	no data	no data	no data	no data	no data	no data	no data

Table 41. WIM/static ratio of individual axles, empty test vehicles June 1998.

WIM	Single	Tandem		Tridem			TOTAL
	1	2	3	4	5	6	
PAT	0.948	1.101	0.824	1.009	0.919	1.004	0.964
Datainstrument	0.472	0.736	0.736	0.813	0.745	0.791	0.693
Kistler/Golden River	1.069	1.233	1.011	1.195	1.067	1.159	1.117
OWC	0.833	1.013	0.984	1.158	1.129	1.034	0.992



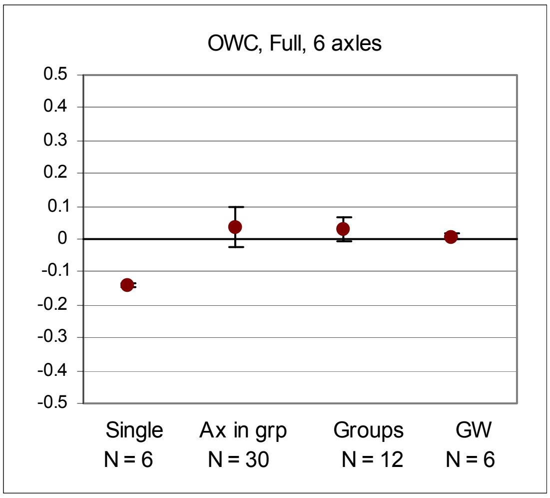


Figure 105. Full-loaded, six-axle test vehicle. First winter test on the left and second summer test on the right.

Axle rank

Analysis has been done separately for single axles, group of axles, axles of groups and gross weight. Each test periods are handled also separately. Measuring a single axle is easiest task to perform. An example of results of single axle is shown in Figure 106.

Measuring an axle of group is most demanding task to perform. Because of a short axle spacing, even less than 1.3 meter, a WIM system has only 50 ms or less to recover for the next axle measurement. An example of results of an axle in group is shown in Figure 107. Results of axle group and gross weight are the sums of individual axles or groups and are therefore better. Dynamic axle loads are spread randomly and a variation as a mean is smaller. Examples of the results of axle group and gross weight are shown in Figure 108 and in Figure 109.

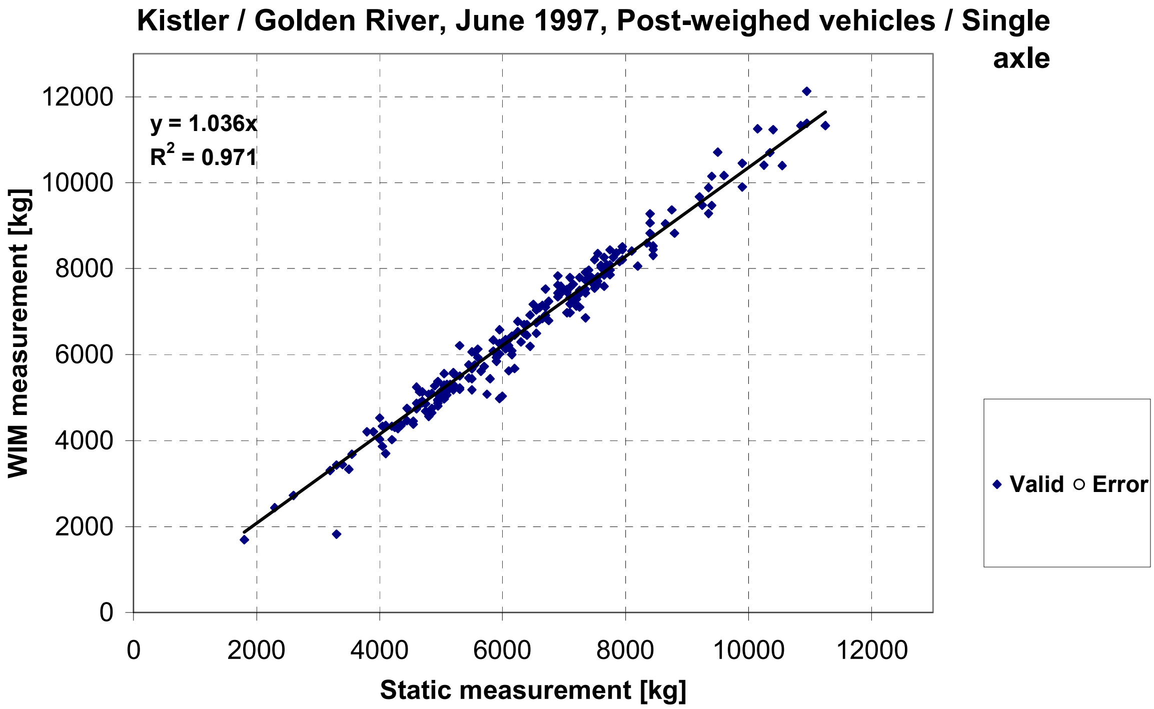


Figure 106. An example of single axle data.

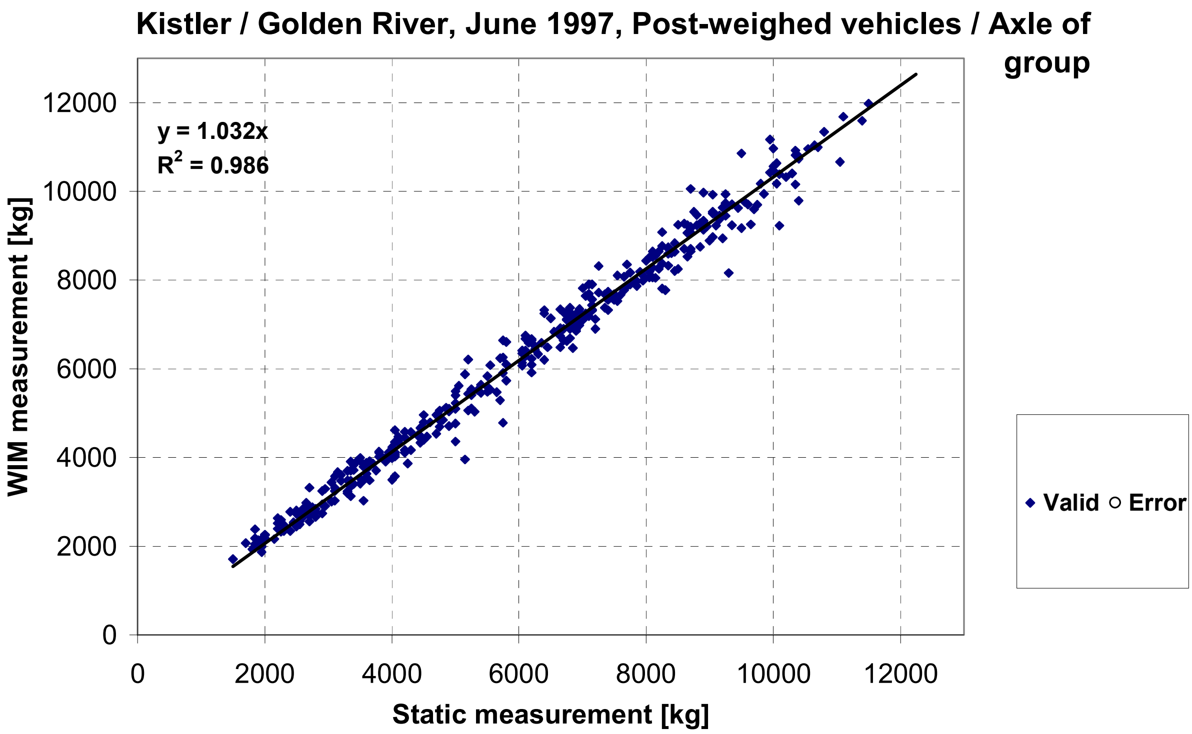


Figure 107. An example of axle in group data.

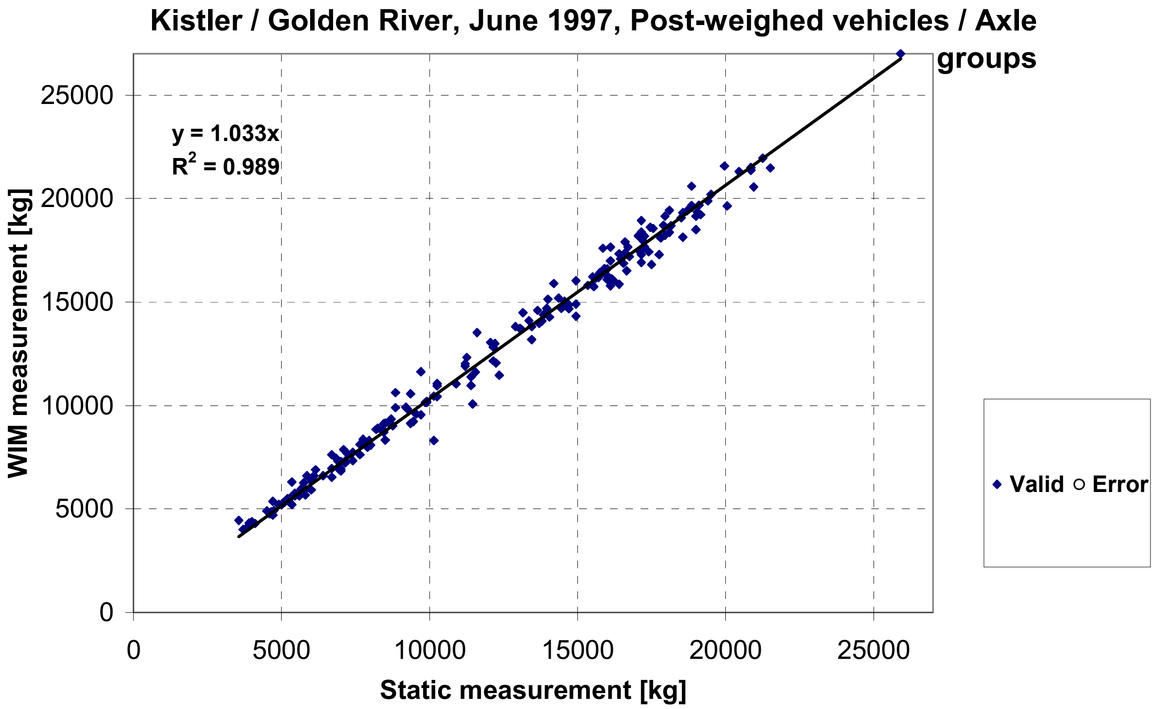


Figure 108. An example of axle group data.

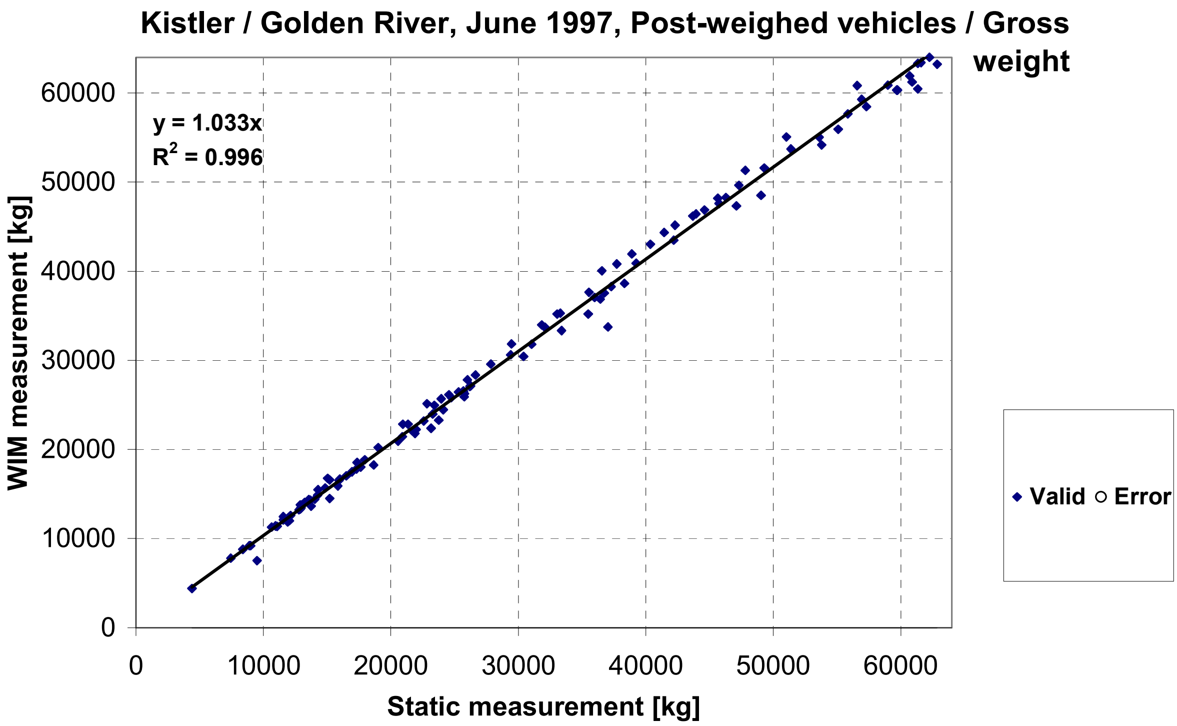


Figure 109. An example of gross weight data.

9.2.4 Conclusions

All WIM systems survived over the winter despite very harsh climatic conditions (cold temperature, winter maintenance etc). Datainstrument, Omni Weight Control and PAT were providing data during all tests. Kistler/Golden River could not provide data during the test of December 1997 due to faulty software settings.

This test lasted for one year. To be sure about long term performance, longer monitoring would be essential.

Kistler/Golden River and PAT showed the best results. The first one did not need temperature compensation. PAT showed also good performance during the wintertime but lack of the temperature compensation caused general under-estimation to results. PAT delivered later a formula for temperature compensation based on only December 1997 test, which improved results especially under very cold temperatures (colder than -20 ºC) but not under cold temperature (-20…+5 ºC).

Local traffic condition in Lulea differs clearly from Central European one. Type of heavy vehicles is more inhomogeneous, number of axles and gross weights are bigger and vehicles are longer. Because of wide road shoulders, which are commonly used for driving, heavy vehicles may partly bypass WIM sensors. Snow and ice will also lead drivers to use different wheel paths than during the summer time. Having relatively narrow weighing pads PAT was penalised due to partially measured vehicles.

One explanation may be that in winter either the pavement's stiffness differs from summer stiffness or the WIM-equipment doesn't work properly i.e. measured loads are temperature dependent. The road profile may change due to frost heave. Or the cars and trucks that drove over the WIM systems are different in Central European that the automatic calibration did not work properly.

Datainstrument system has a self-calibration system. Because of specific traffic conditions light vehicles were systematically over estimated and results were biased. Deviation is relatively large. Also Datainstrument's self-calibration could not take into account correctly heavy vehicles partly bypassing WIM sensors. Longer usage of poles in advance to steer the traffic to correct line might have been helpful.

Omni Weight Control is a prototype system, which did not have temperature compensation. Because the sensor are installed under the asphalt layer it has a high temperature dependency. Therefore results from winter period are clearly under estimated. Omni Weight Control had also problem to identify vehicles during winter tests. After cold season the results were reasonable again. Software was improved during the tests and results were promising. A proper temperature compensation would improve the performance considerably.

Analysis carried out at VTT showed clearly that it is essential to examine what are the reasons to outliers. In this study, good reasons to remove outliers was often found.

Practically all data went to origin (no bias), except data of Datainstrument system. If results are biased, the reason for that should be studied.

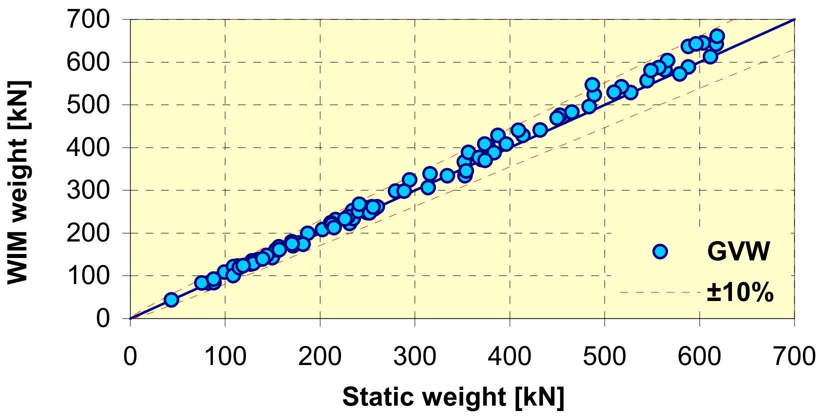
Matching and qualifying the data took much more effort what was thought.

Vehicle classification system (recording vehicle silhouettes) is essential especially when heavy vehicle silhouettes in traffic flow are very inhomogeneous. That is not perhaps so important in Central Europe where vehicles have less axles, are smaller and more similar. Detailed knowledge of vehicle properties improves the research quality and it is quite easy to arrange. In future studies recorded data should be enlarged to consist also technical properties of heavy vehicles like information of tyres, suspensions etc.

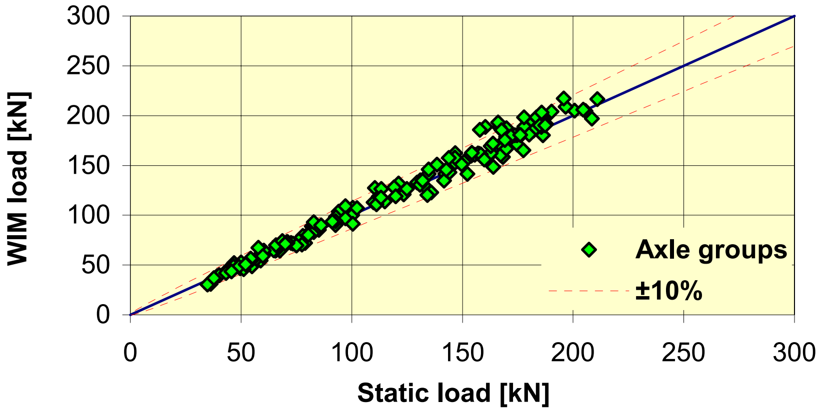
9.3 Bridge WIM results

9.3.1 TCD/UCD Results (DuWIM)

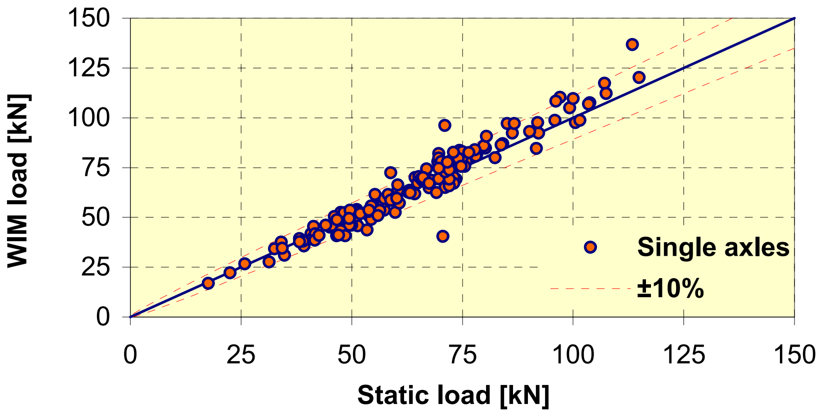
Graphical results from the Bridge WIM system and the DuWIM algorithm for the 1st Summer test are presented in Figure 110. The data was analysed in accordance with the COST323 draft specification and the results are presented in Table 42. An accuracy class of C(15) was returned.



(a) Gross Vehicles Weights



(b) Axle Groups



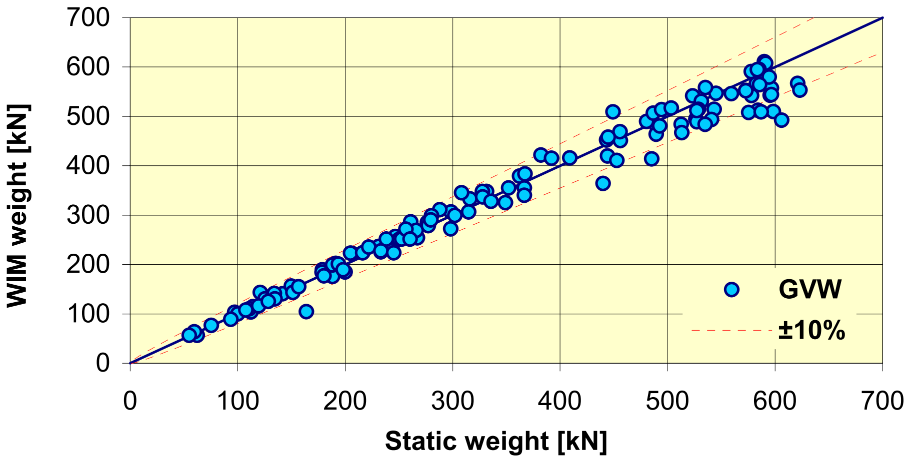
(c) Single Axles

Figure 110. Graphs of Dynamic versus Static Weights for the 1st Summer Test; (a) Gross Vehicle Weights, (b) Axle Groups, (c) Single Axles

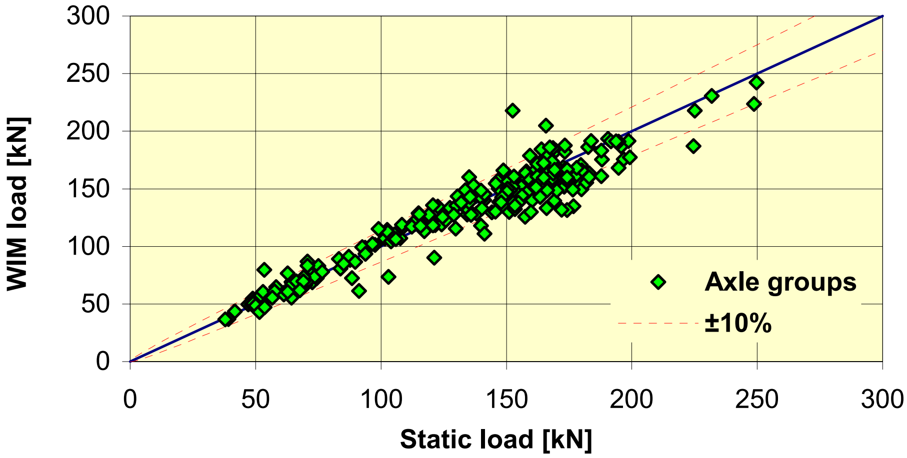
Table 42. Results for 1st Summer Test

Criterion	Number	Mean (%)	St.dev. (%)	π_0 (%)	Class	δ (%)	δ_{min} (%)	π (%)	Class retained
Single axle	156	-0,25	8,43	93,5	**C(15)**	20	17,0	97,2	**C(15)**
Group of axles	162	2,09	5,93	93,5	**B(10)**	13	12,6	94,4	
Gross weight	95	1,49	4,01	92,8	**B(10)**	10	8,6	96,6	

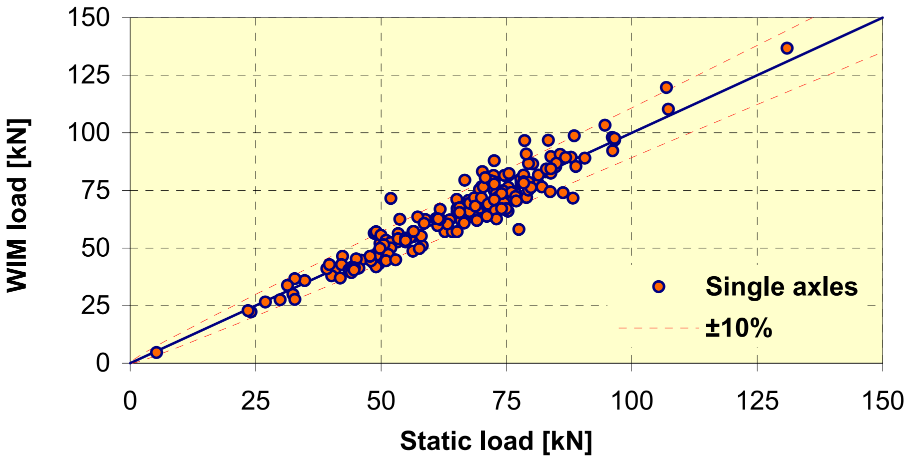
Graphical results from the Winter test are presented in Figure 111. The accuracy classification in accordance with the COST323 draft specification are presented in Table 43. As for the 1st Summer test, an accuracy class of C(15) was returned.



(a) Gross vehicle weights



(b) Axle groups



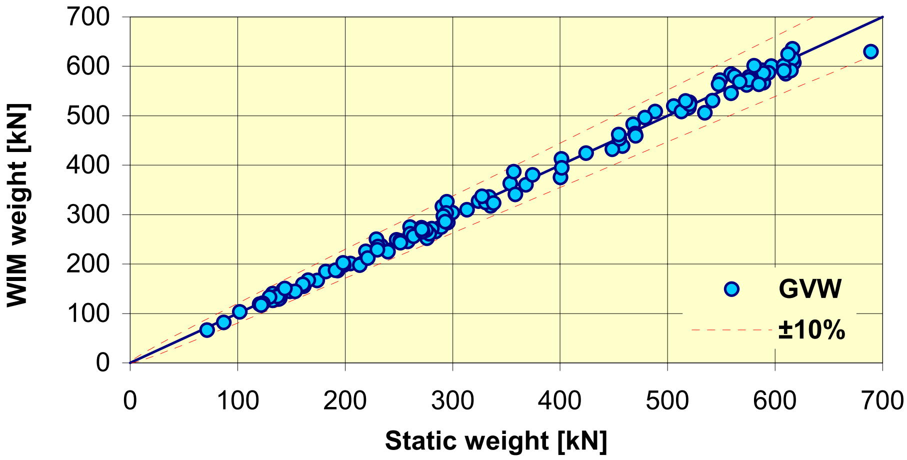
(c) Single axles

Figure 111. Graphs of Dynamic versus Static Weights for Winter Test; (a) Gross Vehicle Weights, (b) Axle groups, (c) Single axles

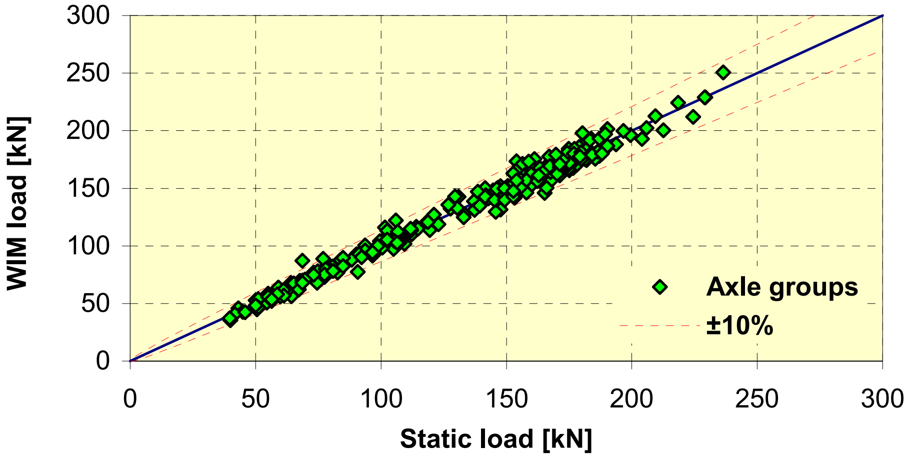
Table 43. Results of the Winter Test

Criterion	Number	Mean (%)	St.dev. (%)	π_0 (%)	Class	δ (%)	δ_{min} (%)	π (%)	Class retained
Single axle	164	-0,64	8,45	93,5	**C(15)**	20	17,1	97,1	**C(15)**
Group of axles	220	-1,77	8,40	93,8	**C(15)**	18	17,2	95,0	
Gross weight	116	-1,49	7,20	93,1	**C(15)**	15	14,8	93,5	

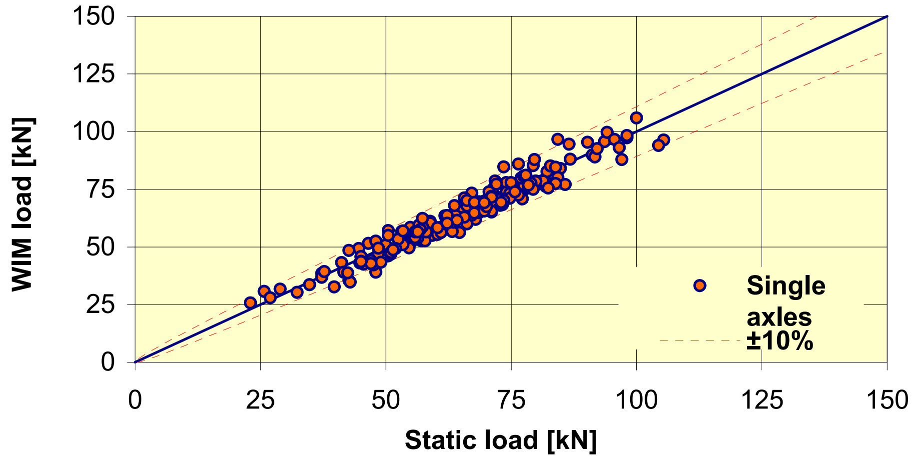
Graphical results from the 2nd Summer test are presented in Figure 112. The accuracy classification in accordance with the COST323 draft specification is presented in Table 44. This time, without filtering, an accuracy class of B(10) was returned.



(a) Gross vehicle weights



(b) Axle groups



(c) Single axles

Figure 112. Dynamic versus static weight for 2nd Summer test; (a) Gross vehicle weight, (b) Group of axle weights, (c) Single axle weights

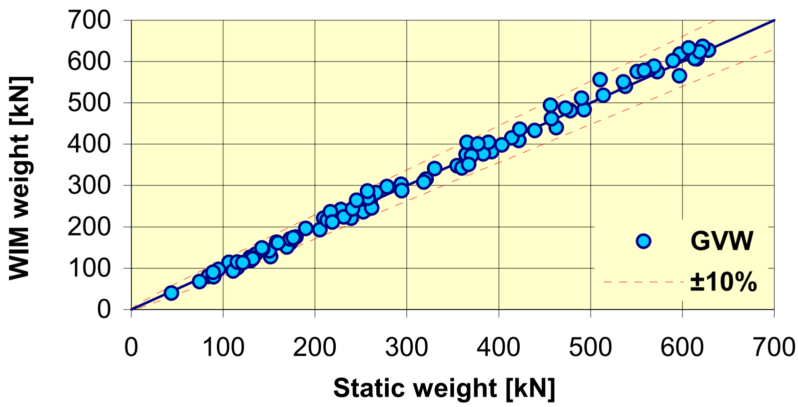
Table 44. Accuracy classification for 2nd Summer Test

Criterion	Number	Mean (%)	St.dev. (%)	π_0 (%)	Class	δ (%)	δ_{min} (%)	π (%)	Class retained
Single axle	188	-1,31	7,27	93,7	**B(10)**	15	14,8	94,0	**B(10)**
Group of axles	239	-0,18	5,26	93,9	**B(10)**	13	10,6	98,0	
Gross weight	122	-0,88	3,72	93,1	**B(10)**	10	7,7	98,4	

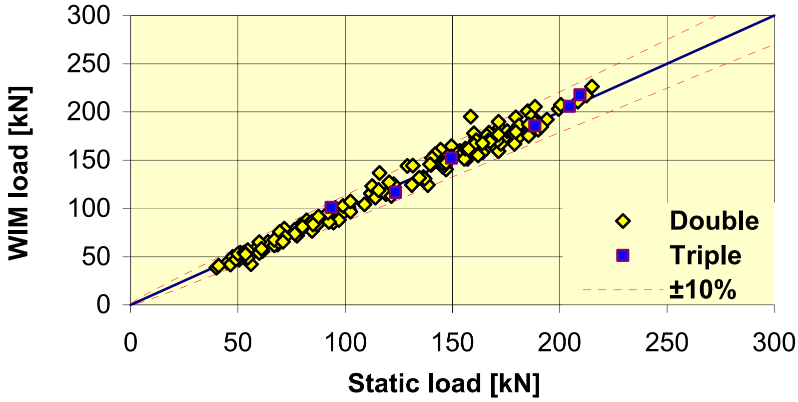
9.3.2 ZAG Results (SiWIM)

The following section presents the most important SiWIM results from the June 1997, March 1998 and June 1998 measurements. The first summer test results are presented in

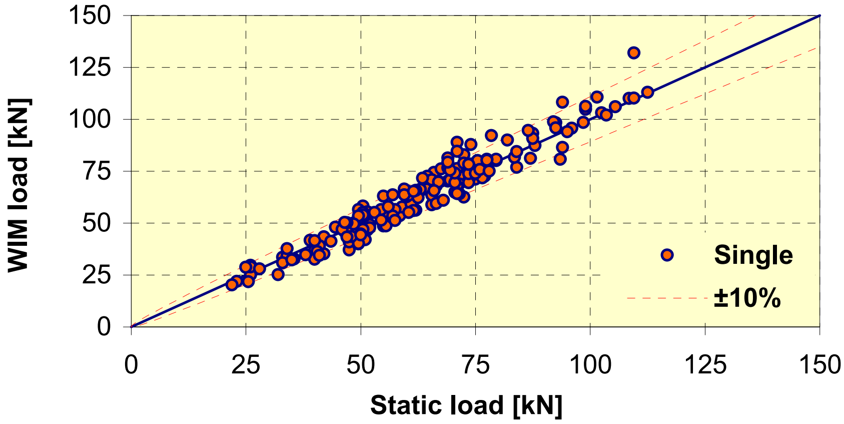
Figure 114 and Table 46.



(a) Gross vehicle weights



(b) Axle group loads



(c) Single axles

Figure 114. SiWIM results for Luleå – 1st Summer Test

Table 46: SiWIM results Luleå – 1st Summer Test – Accuracy of the CET bridge WIM measurements

Type	Criterion	Number	Mean (%)	St.dev. (%)	π_0 (%)	Class	δ (%)	δ_{min} (%)	π (%)	Class retained
Calibration	Single axle	29	0,56	3,63	92,40	**B+(7)**	8,7	8,1	94,5	**B(10)**
	Group of axles	43	0,67	4,63	93,53	**B(10)**	10,4	10,3	93,8	
	Gross weight	29	0,00	3,48	92,40	**B(10)**	8,0	7,7	93,5	
Random traffic	Single axle	177	0,22	8,97	95,26	**C(15)**	20	18,1	96,1	**C(15)**
	Group of axles	150	0,35	6,24	95,23	**B(10)**	13	12,6	94,3	
	Gross weight	95	-0,60	5,49	92,80	**C(15)**	15	11,2	98,6	

When analysing the March 1998 results (Figure 116), the following interesting conclusions have been observed.

- As the strain transducers used did not comprise temperature compensation, the winter results were highly influenced by the temperature fluctuations which, during the days of measurement, exceeded 30° (Figure 115). When linear temperature correction was applied (marked as "Temp" in Table 47), the accuracy class improved from D(20) to C(15).
- In winter the soil was deeply frozen which influenced unexpectedly the bridge behaviour. Possibly due to the very thick ice under the bridge, a different influence line had to be applied which corresponded more to a single span rather than a two-span bridge.

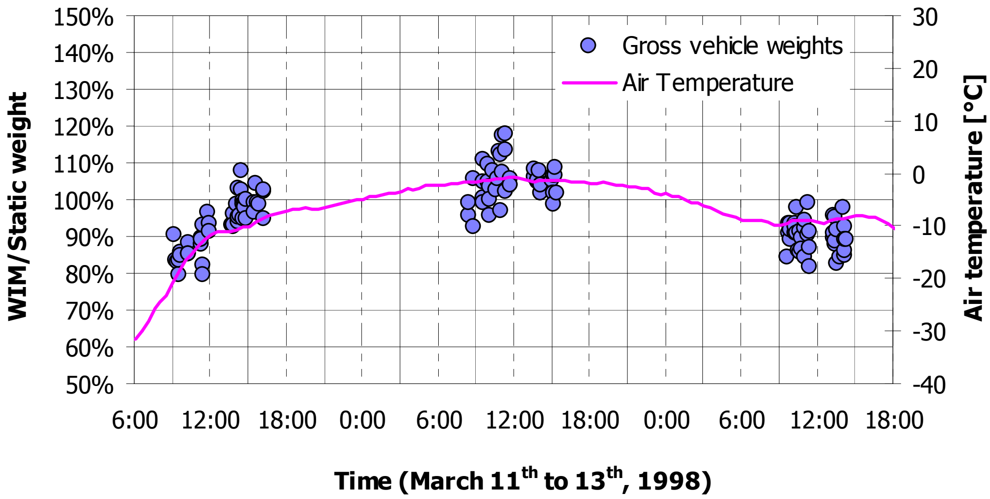
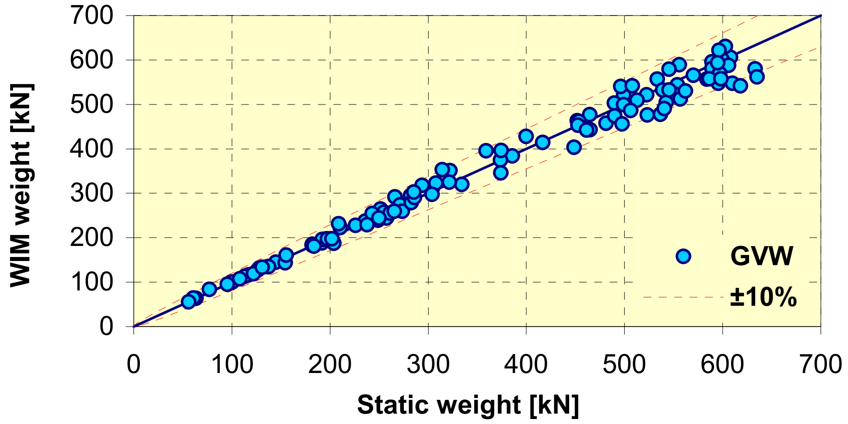
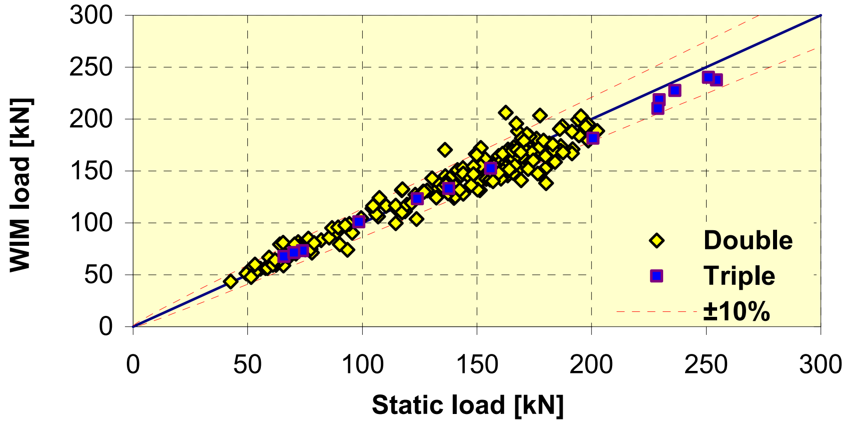


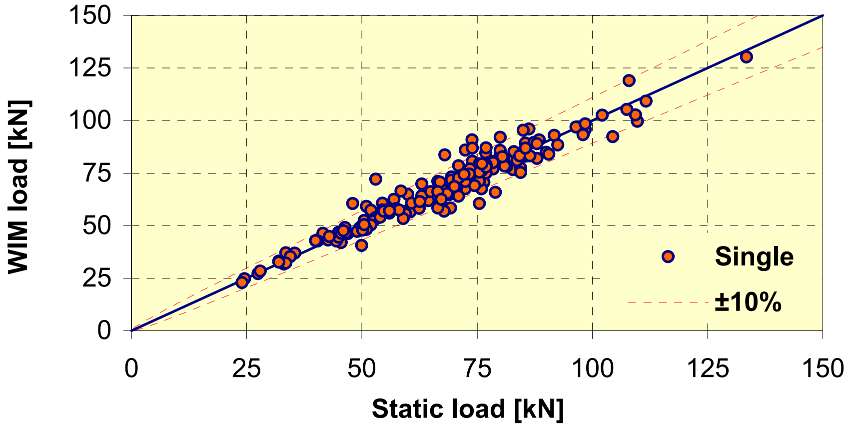
Figure 115: Temperature dependency of Luleå B-WIM measurements



(a) Gross vehicle weights



(b) Axle groups



(c) Single axles

Figure 116: SiWIM results Luleå - Winter Test

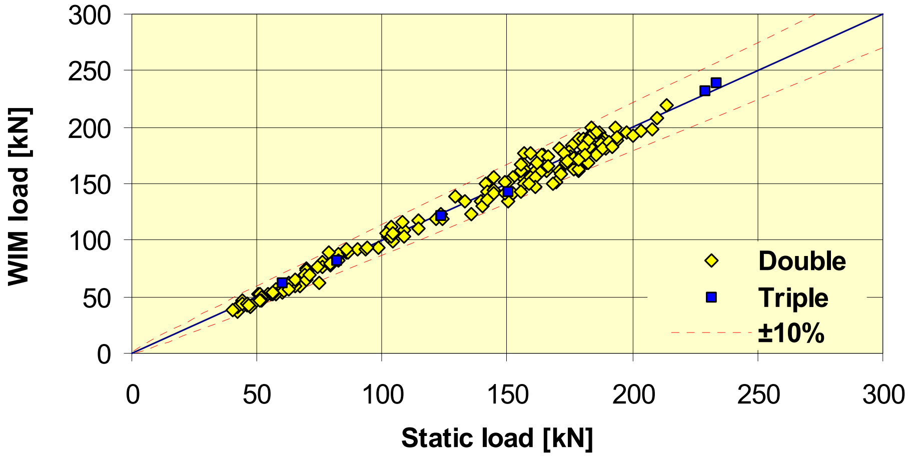
Table 47: SiWIM results Luleå - Winter Test – Accuracy of the CET bridge WIM measurements (with and without temperature compensation)

Type	Criterion	Num-ber	Mean (%)	St.dev. (%)	π_0 (%)	Class	δ (%)	δ_{min} (%)	π (%)	Class retained
Calibra-tion	Single axle	43	-1,29	4,51	93,40	**B(10)**	15	12,79	97,16	**C(15)**
	Group of axles	50	1,48	3,43	93,80	**B(10)**	13	10,08	98,63	
	Gross weight	38	-0,09	4,23	93,10	**C(15)**	15	11,65	98,33	
Random traffic R2	Single axle	174	1,46	7,95	93,6	**C(15)**	20	16,2	97,9	**C(15)**
	Group of axles	214	-0,41	8,51	93,8	**C(15)**	18	17,1	95,1	
	Gross weight	114	0,11	5,75	93,0	**C(15)**	15	11,6	98,3	
Random traffic **Temp**.	Single axle	174	0,67	7,69	93,6	**C(15)**	20	15,5	98,4	**C(15)**
	Group of axles	214	-1,13	7,90	93,8	**C(15)**	18	16,0	96,5	
	Gross weight	114	-0,61	5,11	93,0	**C(15)**	15	10,4	99,3	

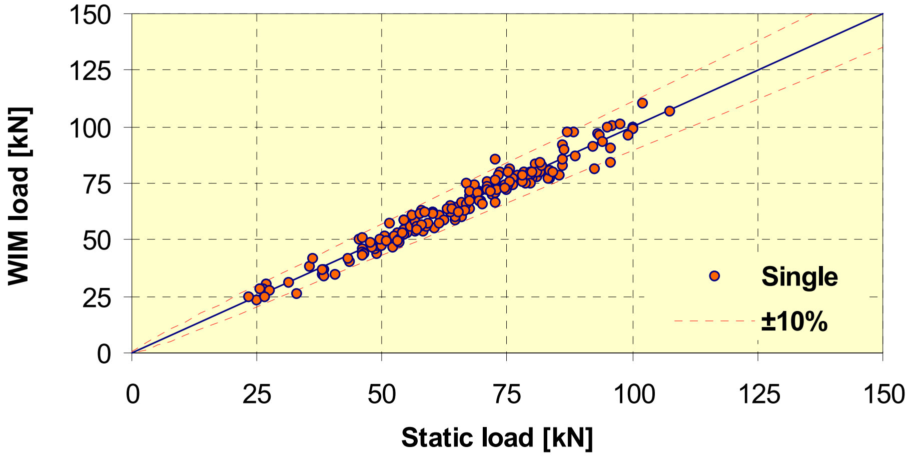
Based on results from June 1997 and March 1998, some changes in the data acquisition setup were proposed which in June 1998 resulted in better, less filtered strain signals and provided one accuracy class better calibration results. The results of the random traffic however did not give satisfactory results. Further analysis identified the following reasons:

- The crossing times in some cases did not precisely define some of the test vehicles in the free traffic flow, which resulted in some clear outliers in the results due to miss-matches of the trucks weighed on B-WIM system and on the static scales. Results of two types of analysis are presented in Table 6. First, all trucks were considered and only class D(25) was retained. Then, all these outliers, defined as the values outside the 3 standard deviation interval from the mean value, were skipped out (in Table 6 marked as “No Outl.”). Results improved to class C(15), with 2 criteria in class B(10) and the third one very close to it.
- The results with and without outliers had considerable bias, which was most likely caused by absence of temperature compensation and some difficulties in static weighing of the test trucks where some substantial differences were observed when comparing weights of the same axles obtained on a static weigh bridge and on portable axle weighers.
- Although the temperature effects were less obvious than during the winter measurements they still existed (Figure 117). However, as temperature data for this period was not available, a simple linear temperature correction was applied to fine-tune the results and to assess the effect of temperature on the accuracy of the results (the last set of data in Table 48).

(a) The final results are presented in Gross vehicle weights



(b) Axle groups



(c) Single axles

Figure 118.

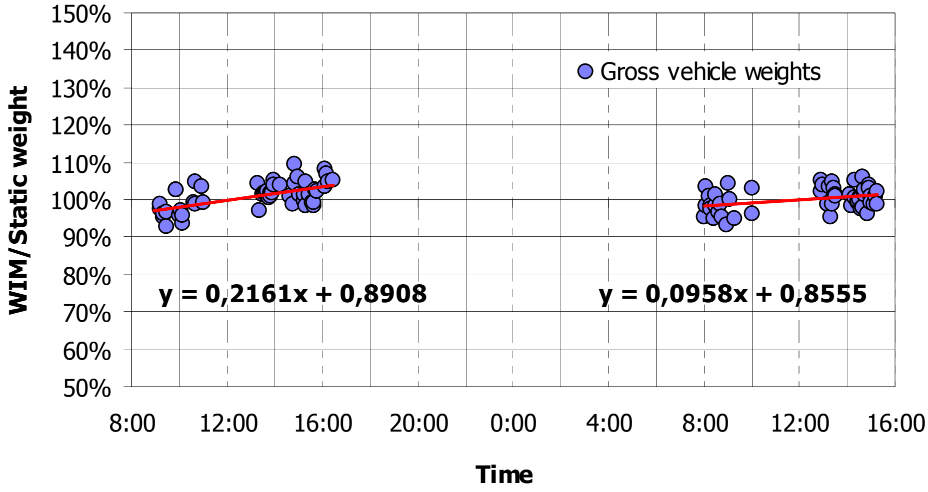
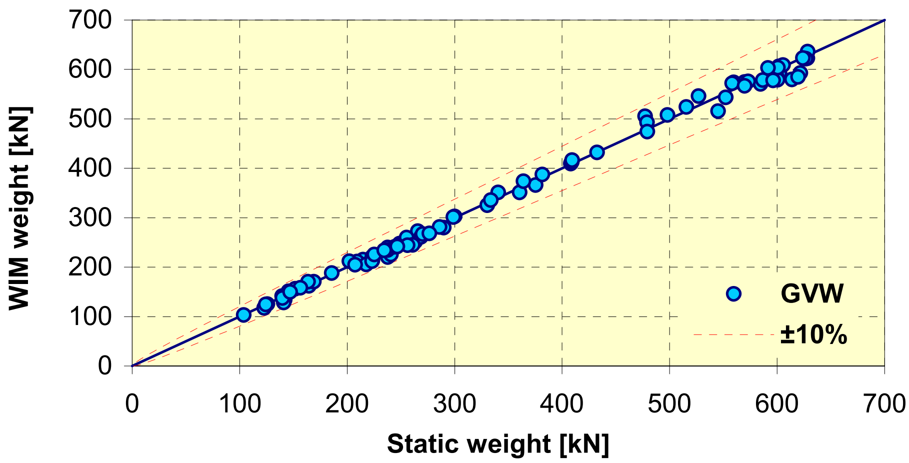
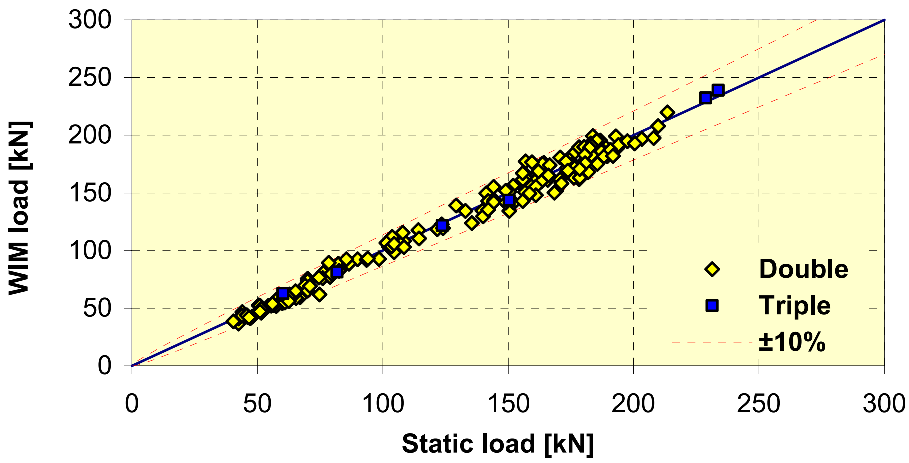


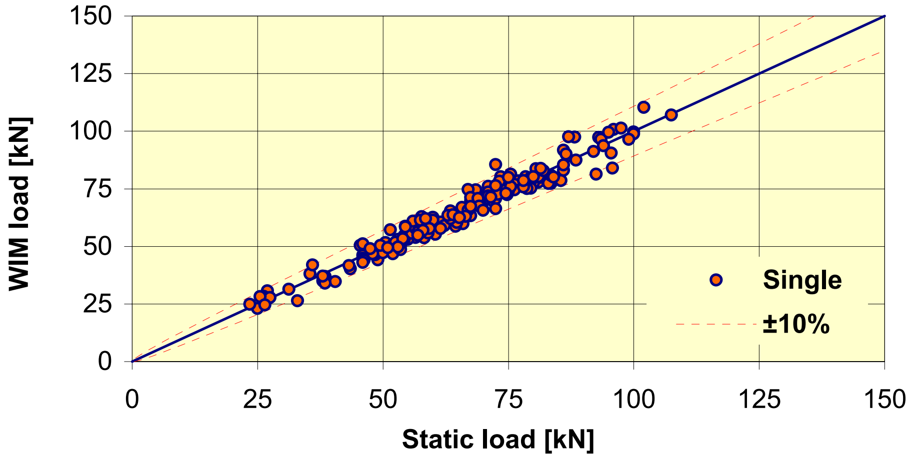
Figure 117: Temperature dependency of Luleå B-WIM measurements and simple linear temperature corrections used to fine-tune the results



(d) Gross vehicle weights



(e) Axle groups



(f) Single axles

Figure 118: SiWIM results Luleå - 2nd Summer Test

Table 48: SiWIM results Luleå - 2nd Summer Test – Accuracy of the CET bridge WIM measurements

Type	Criterion	Number	Mean (%)	St.dev. (%)	π_0 (%)	Class	δ (%)	δ_{min} (%)	π (%)	Class retained
Calibration	Single axle	34	0,32	4,27	95,5	**B(10)**	15	13,0	98,1	**B(10)**
	Group of axles	54	0,01	2,57	96,2	**B+(7)**	10	7,7	99,4	
	Gross weight	34	0,00	2,30	95,5	**B+(7)**	7	7,0	95,5	
Random traffic	Single axle	225	-1,48	13,50	95,3	**D(25)**	30	28,9	96,1	**D(25)**
	Group of axles	232	-3,05	11,73	95,3	**D(25)**	28	25,7	97,0	
	Gross weight	125	-2,26	8,76	95,2	**D+(20)**	20	19,6	95,7	
Random traffic **No outl.**	Single axle	186	-2,16	6,31	95,3	**B(10)**	15	14,2	96,4	**C(15)**
	Group of axles	195	-3,20	5,96	95,3	**C(15)**	18	14,2	99,0	
	Gross weight	103	-2,62	3,15	92,9	**B(10)**	10	7,9	98,3	
Random Traffic **Adj.**	Single axle	187	0,75	6,42	93,7	**B(10)**	15	13,0	96,9	**B(10)**
	Group of axles	191	-0,86	5,75	93,7	**B(10)**	13	11,7	96,2	
	Gross weight	104	-0,03	2,83	92,9	**B+(7)**	7	5,7	97,5	

10. TEST RESULTS FROM SWITZERLAND

10.1 Test Plan

Static measurements

At the different test sites special places near the WIM sites were chosen to weigh and measure statically the selected vehicles. For these actions enough staff (about ten persons), the appropriate equipment as well as enough area for several vehicles was required.

Selection of trucks

In each direction at each site and measuring period, about 40 to 70 vehicles were selected out of the traffic. Most of them are trucks with a gross weight above 3.5 t. A smaller part of them are cars with a trailer, delivery van and camper vans. The police organised the stopping and the allocation of the trucks and the detour of the rest of the traffic. On every truck a number is fixed on the right backside. The complete measurement lasts about three hours.

Video registration

The trucks were recorded by a video system when they are driving towards the WIM station after they have been weighted (preweighed or postweighed). The trucks are filmed a second time while passing the WIM sensors. This allows finding the measured trucks out of thousands of other traffic vehicles in the WIM report coming from the data logger.

Software for the identification of the statically weighed trucks was written as a Excel Makro.

Geometry

Beginning in the front, all spans between the axles and the allover lenght are measured with a precision measuring tape. The results are registrated in a form. An example of such a form can be found below.

Axle weight

The measurement was done with the static scale as described in chapter 3. One person has to guide the truck-driver to stop exactly when the wheel is on the plate, the second person has to operate the data logger and to adjust the plates in the lateral position if necessary.

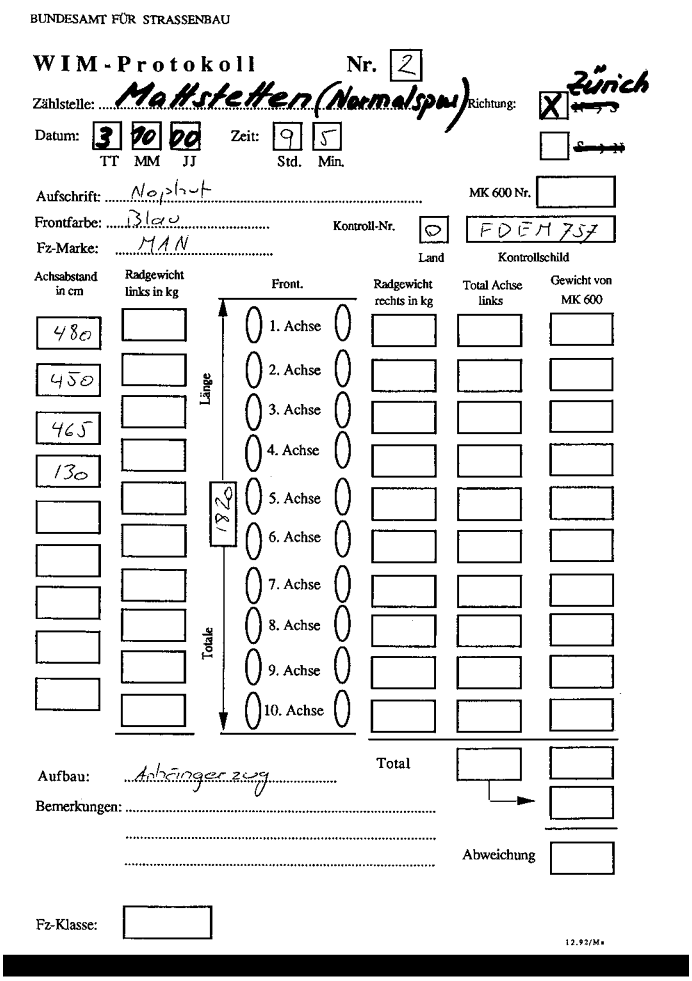
Gross weight

The gross weights are calculated using the wheel-by-wheel weight figures. A few numbers of trucks –within each measuring period between 3 and 4 trucks- was weighted on a large bridge scale because of the enforcement by the police. These data are not considered in this report.

Classification

On the base of the number of axles, the distance between the axles, the existence of tandem and triple axles and the gross weight; the WIM system can distinguish with certain accuracy the category of the vehicle. The classification is marked in the form in addition to the other static measurements. The classification can also be checked with the video recorder.

Figure 119


BUNDESAMT FÜR STRASSENBAU

WIM-Protokoll Nr. 2

Zählstelle: Mattstetten (Normalspur) Richtung: [X] Zürich

Datum: 3 10 00 (TT MM JJ) Zeit: 9 5 (Std. Min.)

Aufschrift: ...

Frontfarbe: Blau

Fz-Marke: MAN

MK 600 Nr.

Kontroll-Nr. (Land, Kontrollschild)

Achsabstand in cm	Radgewicht links in kg	Front.	Radgewicht rechts in kg	Total Achse links	Gewicht von MK 600
480		1. Achse			
450		2. Achse			
465		3. Achse			
130		4. Achse			
		5. Achse			
		6. Achse			
		7. Achse			
		8. Achse			
		9. Achse			
		10. Achse			

Länge / Totale: 1820

Total

Aufbau: Anhängerzug

Bemerkungen:

Abweichung

Fz-Klasse:

12.92/Ms

10.2 Short description of the procedure according to COST 323 WIM Specifications

The checking procedure is summarised in this paper. For more detailed information the draft 2.2, WIM specification [2] has to be consulted.

The aim is to classify the WIM-systems into accuracy classes, Table 49 shows the accuracy classes. The numbers indicate the maximum relative deviation a certain percentage of the measurement of the whole sample (confidence interval π), must fulfil to be classified in a certain class. The relative deviation is calculated by comparing the static measurement with the dynamic measurement, as shown in equation 1.

$$r = [(W_{dyn}/W_{stat})-1]*100 \qquad \text{equation 1}$$

where:

W_{dyn} dynamic axle weight

W_{stat} static axle weight

r relative deviation in %

The confidence interval π depends on the number of tests and on the environmental condition Table 50 and on the reproducibility conditions Table 49. The confidence intervals π are indicated in Table 53: Minimum levels of confidence π. Minimum levels of confidence π. Of the cenered confidence intervals (in %) depending on the reproducibility conditions (shown in Table 51) and the environmental conditions (shown in Table 50) depending on the environmental conditions.

Example of a WIM classification:

120 single axles over 20 kN were measured in full reproducibility condition and at environmental condition I. This means, in 92% of the measurements, the relative deviation has to be lower than 15% to fulfil the class B(10).

Table 49. Tolerance of the accuracy classes (δ in %)

Criteria (type of measurement)	**Accuracy Classes: Confidence interval width δ [%]**					
	A(5)	B+(7)	B(10)	C(15)	D+(20)	E
Gross weight	5	7	10	15	20	>25
single axle	8	11	15	20	25	>30

Table 50. Environmental condition

Environmental condition classes	Description
I	The test time period is limited to a couple of hours within a day or spread over a few consecutive days, such that the temperature, climatic and environmental conditions do not vary significantly during the measurement.
II	The test time period extends at least over a full week or several days spread over a month, such that the temperature, climatic and environmental conditions vary during the measurements, but not seasonal effect has to be considered.
III	The test time period extends over a whole year or more, or at least over several days spread over a year, such that the temperature, climatic and environmental conditions vary during the measurements and all the site seasonal conditions are encountered.

Table 51. Reproducibility conditions

Reproducibility condition classes	Description
r1; full repeatability condition	if only one vehicle passes several times at the same speed, the same load and the same lateral position
r2; extended repeatability condition	if only one vehicle passes several times at different speeds(according to the traffic lane conditions), different loads(e.g. fully loaded, half loaded and empty), and with small lateral positions variations (according to the real traffic paths)
R1; limited reproducibility condition	if small set of vehicles (typically 2 to 10), representative of the whole traffic composition expected on the site (silhouettes and gross weights), is used, each of them passing several times, at different speeds, different loads, and with small lateral positions variations
R2; full reproducibility condition	if a large sample of vehicles (i.e. some tens to a few hundred) taken from the traffic flow and representative of it, pass on the WIM system and are statically weighed before or after it.

Table 53: Minimum levels of confidence $\pi$of the centred confidence intervals (in %) depending on the reproducibility conditions shown in Table 51. Reproducibility conditions and the environmental conditions shown in Table 50. Environmental condition

Table 53: Minimum levels of confidence π

	Sample size	**10**	**20**	**30**	**60**	**120**	**∞**
Reproducibility Condition	**Environmental Condition**						
r1	I	95.0	97.2	97.9	98.4	98.7	99.2
r2	I	90.0	94.1	95.3	96.4	97.1	98.2
R1	I	85.0	90.8	92.5	94.2	95.2	97.0
R2	I	80.0	87.4	89.6	91.8	93.1	95.4
r1	II	93.3	96.2	97.0	97.8	98.2	98.9
r2	II	87.5	92.5	93.9	95.3	96.1	97.5
R1	II	81.9	88.7	90.7	92.7	93.9	96.0
R2	II	76.6	84.9	87.4	90.0	91.5	94.3
r1	III	91.4	95.0	96.0	97.0	97.6	98.5
r2	III	84.7	90.7	92.4	94.1	95.1	96.8
R1	III	78.6	86.4	88.7	91.1	92.5	95.0
R2	III	73.0	82.3	85.1	88.1	89.8	93.1

10.3 Implementation of the Checking Procedure

We checked the WIM Systems at the San Bernadino and at the Gotthard site every year for a day in each direction. About 60 lorries and other vehicles were taken from the traffic flow and were measured statically (see 10.1) and have passed the WIM site afterwards. This corresponds with a full reproducibility condition R2 and with an environmental condition I. The minimum value π_0 of the required level of confidence is shown in Table 53: Minimum levels of confidence π. δmax is the maximum relative deviation within the required confidence interval. The accepted accuracy class has to be estimated for each direction. The accuracy test according the WIM specification is only done for axle loads and gross weights. The accuracy of the recordings of the geometry, span between the axles and the total length, of the trucks is shown in chapter 10.6.

Table 54. Results of in service verification (in bold, the accepted levels of confidence) for the San Bernardino 1996

R2/I condition				δ	δ	δ	δ	π_0	accura-cyclass	maximum δ_{max} within the con-fidence
Unit/class	m	s	n	B+(7)	B(10)	C(15)	D+(20)	(%)		interval
Direction: south						Accepted class			**C(15)**	
Single axles,	+0.6	6.5	88	11	15	20	25	92.6	**B(10)**	13.2
Sin. axl. out of a group	- 2.7	9.9	38	15	20	25	30	90.5	**C(15)**	20.8
Group of axles	- 2.7	8.2	20	10	13	18	23	87.4	**C(15)**	17.6
Gross weight,	+0.1	4.7	48	7	10	15	20	91.3	**B(10)**	9.6
Direction : north						Accepted class			**C(15)***	
Single axles,	- 6.7	4.6	86	11	15	20	25	92.6	**B(10) ***	14.4
Sin. axl. out of a group	- 3.3	6.0	48	15	20	25	30	91.3	**B+(7)**	13.6
Group of axles	- 3.9	5.7	24	10	13	18	23	88.5	**C(15)**	13.6
Gross weight,	- 5.1	3.8	50	7	10	15	20	91.4	**C(15)***	11.4

* The mean value deviation is higher then the standard deviation, this causes a lower accuracy class

Table 55. Results of in service verification (in bold, the accepted levels of confidence) for the San Bernardino 1997

R2/I condition				δ	δ	δ	δ	π_0	Accuracyclass	Maximum δ_{max} within the confidence
Unit/class	m	s	n	B+(7)	B(10)	C(15)	D+(20)	(%)		Interval
Direction: south						Accepted class			**C(15)**	
Single axles,	+2.2	6.9	118	11	15	20	25	93.1	**B(10)**	14.5
Sin. axl. out of a group	+0.6	7.4	58	15	20	25	30	91.8	**B(10)**	15.1
Group of axles	+6.5	6.6	27	10	13	18	23	89.1	**C(15)**	17.5
Gross weight,	+2.7	4.6	61	7	10	15	20	91.9	**C(15)**	10.6
Direction : north						Accepted class			**B(10) ***	
Single axles,	- 2.5	6.3	94	11	15	20	25	92.7	**B(10)**	13.6
Sin. axl. out of a group	- 1.7	7.3	32	15	20	25	30	89.9	**B(10)**	15.3
Group of axles	- 1.0	5.7	18	10	13	18	23	86.7	**B(10)**	12.0
Gross weight,	- 2.3	4.3	45	7	10	15	20	91.1	**B(10) ***	9.7

Judgement of the test results compared with those of 1996:

- The standard deviation differs only by statistical uncertainty

- The maximum δmax tend to be slightly lower than 1996
- The mean value deviation differs in some cases more as it can be expected by statistical uncertainty

Table 56. Results of in service verification (in bold, the accepted levels of confidence) for the San Bernardino 1998

R2/I condition				δ	δ	δ	δ	π_0	accura-cyclass	maximum δ_{max} within the confidence
Unit/class	m	s	n	B+(7)	B(10)	C(15)	D+(20)	(%)		interval
Direction: south						Accepted class			**C(15)**	
Single axles,	+0.8	6.9	123	11	15	20	25	93.1	**B(10)**	14.0
Sin. axl. out of a group	+3.7	8.2	51	15	20	25	30	91.4	**B(10)**	18.0
Group of axles	+2.9	5.9	30	10	13	18	23	89.6	**C(15)**	13.2
Gross weight,	+1.9	4.1	61	7	10	15	20	91.9	**B(10)**	9.0
Direction: north						Accepted class			**B(10)**	
Single axles,	- 0.7	5.8	130	11	15	20	25	93.2	**B(10)**	11.8
Sin. axl. out of a group	+1.2	6.3	83	15	20	25	30	92.5	**B+(7)**	12.9
Group of axles	+1.5	5.1	41	10	13	18	23	90.8	**B(10)**	10.8
Gross weight,	+0.6	3.2	69	7	10	15	20	92.2	**B+(7)**	6.6

Judgement of the test results compared with those of 1997:

- The standard deviation differs only by statistical uncertainty

- The maximum δ_{max} differs only by statistical uncertainty
- The mean value deviation differs in some cases more as it can be expected by statistical uncertainty

Table 57. Results of in service verification (in bold, the accepted levels of confidence) for the Gotthard 1996

R2/I condition				δ	δ	δ	δ	π_0	accura-cyclass	maximum δ_{max} within the con-fidence
Unit/clas	m	s	n	B(10)	C(15)	D+(20)	D(25)	(%)		interval
Direction: south						Accepted class			**E(30)**	
Single axles,	+3.1	11.9	101	15	20	25	30	92.9	**D+(20)**	24.7
Sin. axl. out of a group	+2.6	18.6	75	20	25	30	35	92.3	**E(30)**	38.0
Group of axles	- 0.2*	9.0*	30	13	18	23	28	89.6	**D+(20)**	18.5
Gross weight,	+3.2	9.5	46	10	15	20	25	91.1	**D(25)**	20.2
Direction : north						Accepted class			**C(15)**	
Single axles,	+1.3	8.5	102	15	20	25	30	92.9	**C(15)**	17.3
Sin. axl. out of a group	- 0.7	9.4	76	20	25	30	35	92.4	**B(10)**	19.1
Group of axles	-1.1	6.9	30	13	18	23	28	89.6	**C(15)**	14.3
Gross weight,	-0.6	5.4	48	10	15	20	25	91.3	**C(15)**	11.1

* without a measurement with a relative error of +70%

From the calibration test at the Gotthard site in 1997, the data of length measures failed this is why it was not anymore possible to distinguish between single axles and group of axles hence no accuracy test according the WIM-Specification was done. The results of the axle-loads and of the gross weights is illustrated in chapter 10.6

Table 58. Results of in service verification (in bold, the accepted levels of confidence) for the Gotthard 1998

R2/I condition				δ	δ	δ	δ	π_0	Accura-cyclass	Maximum δ_{max} within the con-fidence
Unit/class	m	s	n	B(10)	C(15)	D+(20)	D(25)	(%)		Interval
Direction: south						Accepted class			**D+(20)**	
Single axles,	+7.2	7.0	77	15	20	25	30	92.4	**C(15)**	18.9
Sin. axl. out of a group	+6.2	6.8	74	20	25	30	35	92.3	**B(10)**	17.6
Group of axles	+7.6	7.2	36	13	18	23	28	90.3	**D+(20)**	19.6
Gross weight,	+7.3	3.6	39	10	15	20	25	90.6	**C(15)**	13.3
Direction: north						Accepted class			**C(15)**	
Single axles,	-2.4	7.8	126	15	20	25	30	93.2	**C(15)**	16.4
Sin. axl. out of a group	-1.8	10.1	97	20	25	30	35	92.8	**C(15)**	20.7
Group of axles	-2.7	7.6	44	13	18	23	28	91.0	**C(15)**	16.3
Gross weight,	-2.6	6.4	62	10	15	20	25	91.9	**C(15)**	13.9

Judgement of the test results compared with those of 1996:

- The standard deviation differs more than it can be expected by statistical uncertainty in the test to the direction north
- In the southern direction the mean value deviation differs far more than it can be expected by statistical uncertainty. The standard deviation is up to 64 % lower

10.4 Analysis of the test results

The change of the mean value deviation m (bias) can be explained by the following factors:

- change of mechanical behaviour of the scale/sensor caused by changing of the road surface condition, different temperatures etc.

- selection of the trucks composition, a specified sort of trucks may have an other mean value deviation m than others

- change of the calibration factor, this has to be considered in the calculations

- statistical uncertainty

The change of the calibration is probably only caused by statistical uncertainty if

$|\Delta| < 2*s_m$. Where Δ is the difference of the calibration factor between two measurements either between two different years or two different vehicle types or whatever. s_m can be estimated with equation 2.

$$s_m = \sqrt{\frac{\sum_{i=1}^{n}\left[\left(\frac{W_{dyn,i}}{W_{stat,i}} - 1\right)\cdot 100 - m\right]^2}{n\cdot(n-1)}} = \frac{s}{\sqrt{n}} \qquad \text{equation 2}$$

where:

s	standard deviation of a single measurement
s_m	standard deviation of the calibration deviation based on n single measurements
n	number of measured weights

The calibration factor may change due to the selection of the type of the vehicle. In Table 59 the two most common vehicle types are compared with each other. In 1998 in direction South 16 trucks with two and 10 trucks with three axles and 5 buses with two and 2 buses with three axles were measured. The calibration factor for trucks with two or three axles seems to be higher than the one for buses of the same sort. Because $|\Delta| \pm 2*s_m$ the difference may cause also due to statistical uncertainty. The differences may not be big, about 2% and they are below the deviation of a single measurement.

For other vehicle types such an analysis cannot be done due to a too small number of vehicles.

Assumption: The buses accuracy of weight measurement is better then the one of trucks, the standard deviation is less then 50%. This is due to better dynamic behaviour of buses, buses have got more or less the same weight and the spring-suspension is better because a better comfort for passengers is required.

The influence of the selection of vehicles to the calibration factor m is low especially if we consider that we try to make a similar selection each year corresponding to the truck traffic throughout the whole year.

Table 59. Differences between the measurement accuracy of trucks and buses, this analysis is based on 26 trucks and 7 buses

	Bus (1+1 or 1+2 axles)				Truck (1+1or 1+2 axles					$\frac{\Delta}{\sqrt{s_{m1}^2 + s_{m2}^2}}$
	n	m	s	s_{m1}	n	m	s	s_{m2}	Δ	
Gross weight	7	+1.69	1.70	0.64	26	+4.09	4.87	0.96	+2.35	+2.06
1st axle	7	+1.95	2.89	1.09	26	+4.34	6.32	1.24	+2.39	+1.63
2nd axle	7	- 0.47	2.36	0.89	26	+2.83	7.91	1.55	+3.30	+1.85
3rd axle	2	+9.37	0.55	0.39	10	+7.17	7.38	2.33	- 2.20	- 0.91

Due to dynamic behaviour the axle load measurement of axle load of a trailer may be less accurate than the measurement of the main vehicles. The data Plazzas 1998 direction south, were separated between the trailer axles and the whole rest.

There is no significant difference between the calibration factors ($|\Delta| < 2*s_m$) the measurement accuracy of trailer axles may be less, the standard deviation is in two of three cases significantly higher.

Table 60. Difference between measurement accuracy of the trailer axle loads and the other axle loads

	Axles of trailers				**The whole rest**				$\frac{\Delta}{\sqrt{s_{m1}^2 + s_{m2}^2}}$
	n	m	s	s_{m1}	n	m	s	s_{m2}	
single axles	16	- 0.1	9.7	2.42	107	+0.9	6.9	0.67	+0.40
group of axles	17	+2.6	6.1	1.48	13	+0.0	3.2	0.89	-1.51
s.a.out of group	32	+2.8	7.9	1.40	19	+0.9	8.6	1.97	-0.78

10.5 Remarks from the manufacturer to the Swiss test

10.5.1 KISTLER

The report contains all the relevant information for WIM measurements. It defines clearly the used formulas and the conditions during the acquisition of the data.

Concerning the Gotthard results of 1998 it is to remark that the Golden River capacitive sensors were in June 1998 replaced by the LINEAS Quartz sensors from Kistler Instrumente AG. Because of lack of time the calibration in June was possible with one truck only.

A more accurate definition of the mean of the gross vehicle and the different axle weights is only possible over a large population of trucks measured statically and dynamically. The first opportunity to do this kind of measurements was during the official ETH measurements.

Therefore we propose to adjust the calibration once before doing further tests.

KISTLER INSTRUMENTE AG WINTERTHUR

Marketing & sales

Juerg Kunz

Product Manager Vehicle Engineering

10.6 Aggregated calibration results

The following tables illustrate the results for each axle and the gross weigh. In these results no difference is made between single axles and group of axles. Single axle loads below 20 kN are considered as well as gross weights below 35 kN. That is why the number of gross weights and the number of axles are higher then the ones considered in the analysis according the COST 323-WIM specifications.

From the calibration test at Gotthard in 1997 see Table 62. 1997 and Table 65. 1997 the data of length measurements failed and it was not anymore possible to distinguish between single axles and group of axles.

10.6.1 Results WIM Gotthard direction South

Table 61. 1998 Results WIM Gotthard direction South

Weight	Gross weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	41	41	41	34	30	19
Mean value deviation	7,06%	6,24%	10,00%	4,80%	4,26%	1,43%
Standard deviation	3,76%	4,07%	6,42%	8,92%	8,82%	9,30%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	41	41	34	30	19	2
Mean value deviation	-3,48%	-0,25%	0,79%	-0,46%	-0,10%	-0,33%
Standard deviation	3,92%	1,89%	1,37%	1,90%	1,53%	(1,55%)

Table 62. 1997 Results WIM Gotthard direction South

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	36	36	36	25	24	11
Mean value deviation	12,7%	8,4%	13,6%	16,4%	16,2%	10,5%
Standard deviation	13,2%	8,6%	16,4%	22,9%	22,1%	20,1%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	-	-	-	-	-	-
Mean value deviation	-	-	-	-	-	-
Standard deviation	-	-	-	-	-	-

Table 63. 1996 Results WIM Gotthard direction South

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	46	46	46	42	40	21
Mean value deviation	3.23%	3.90%	1.83%	2.74%	3.37%	6.79%
Standard deviation	9.52%	8.41%	13.30%	18.85%	15.26%	18.29%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	48	48	45	42	23	-
Mean value deviation	-1.80%	-0.62%	0.80%	0.50%	0.02%	-
Standard deviation	4.19%	5.50%	3.55%	1.92%	3.99%	-

10.6.2 Results WIM Gotthard direction North

Table 64. 1998 Results WIM Gotthard direction North

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6
# axles	68	68	68	50	42	21	1
Mean value deviation	-2,41%	-1,10%	-4,20%	-4,07%	-1,83%	1,49%	6,45%
Standard deviation	6,32%	8,72%	6,40%	8,62%	9,68%	12,37%	-

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	68	68	50	42	21	1

Mean value deviation	-3,34%	0,12%	0,05%	0,50%	-0,26%	0,00%
Standard deviation	9,21%	3,24%	1,08%	1,83%	1,69%	-

Table 65. 1997 Results WIM Gotthard direction North

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	74	74	74	56	52	22
Mean value deviation	2,0%	2,5%	2,7%	0,1%	3,7%	5,2%
Standard deviation	6,1%	7,9%	10,1%	11,2%	10,9%	8,9%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles						
Mean value deviation						
Standard deviation						

Table 66. 1996 Results WIM Gotthard direction North

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	48	48	48	37	36	22
Mean value deviation	-0.55%	1.45%	-2.03%	-2.42%	0.53%	2.55%
Standard deviation	5.39%	6.39%	10.11%	9.64%	10.90%	9.92%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	48	48	37	35	21	-
Mean value deviation	-1.10%	0.39%	1.92%	0.28%	0.28%	-
Standard deviation	3.67%	2.17%	6.34%	1.56%	1.58%	-

10.6.3 Results WIM Plazzas – direction South

Table 67. 1998 Results WIM Plazzas direction South

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	67	67	67	40	24	5
Mean value deviation	1.82%	1.12%	0.29%	3.63%	3.36%	-2.24%
Standard deviation	3.94%	6.42%	6.73%	10.30%	7.95%	6.64%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	67	67	40	24	5	1
Mean value deviation	3.85%	-0.11%	-0.15%	-1.45%	0.74%	-3.70%
Standard deviation	5.03%	2.25%	4.38%	3.00%	1.66%	-

Table 68. 1997 Results WIM Plazzas direction South

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	61	61	61	31	23	8
Mean value deviation	2,7%	4,2%	1,7%	1,5%	-2,0%	4,2%
Standard deviation	4,6%	4,4%	5,8%	8,5%	15,0%	6,6%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	61	61	31	23	8	-
Mean value deviation	5,3%	1,6%	1,7%	0,6%	0,6%	-
Standard deviation	4,9%	4,4%	3,2%	2,6%	3,3%	-

Table 69. 1996 Results WIM Plazzas direction South

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	560	56	56	25	20	3
Mean value deviation	-0,2%	0,9%	-0,4%	-3,2%	-3,3%	2,1%
Standard deviation	4,5%	5,7%	7,7%	9,2%	8,6%	(5,4%)

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	56	56	25	20	6	-
Mean value deviation	8,0%	2,4%	3,0%	1,7%	2,6%	-
Standard deviation	6,9%	4,3%	5,9%	5,5%	10,5%	-

10.6.4 Results WIM Plazzas – direction North

Table 70. 1998 Results WIM Plazzas direction North

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6
# axles	77	77	77	51	36	12	1
Mean value deviation	0.69%	-3.07%	1.65%	1.08%	3.44%	1.83%	6.67%
Standard deviation	3.42%	4.87%	5.55%	8.12%	7.46%	6.11%	#DIV/0!

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	77	77	51	36	12	1
Mean value deviation	16.23%	7.87%	10.22%	10.31%	1.41%	-7.69%
Standard deviation	79.18%	52.32%	67.26%	56.66%	7.14%	-

Table 71. 1997 Results WIM Plazzas direction North

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	60	60	60	26	21	8
Mean value deviation	-1,6%	-5,3%	-0,4%	-1,6%	-1,1%	-0,3%
Standard deviation	4,4%	4,1%	6,0%	10,4%	9,0%	7,6%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	60	60	26	21	8	-
Mean value deviation	9,0%	2,2%	1,8%	-0,5%	-1,5%	-
Standard deviation	6,4%	4,3%	3,8%	5,3%	4,0%	-

Table 72. 1996 Results WIM Plazzas direction North

Weight	Gross Weight	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
# axles	62	62	62	29	25	3
Mean value deviation	-5,4%	-8,6%	-6,2%	-3,5%	-5,5%	-5,8%
Standard deviation	4,0%	4,4%	10,0%	7,7%	11,5%	4,4%

Geometry	Length	Space1-2	Space2-3	Space3-4	Space4-5	Space5-6
# axles	62	62	32	26	4	-
Mean value deviation	8,8%	3,2%	3,5%	2,2%	-0,1%	-
Standard deviation	9,9%	4,5%	26,0%	3,0%	2,9%	-

11. CONCLUSIONS

11.1 Conclusions; recommendations – Swiss test

Since October 1995 the WIM systems worked with very few interruptions, the System Golden River in the Gotthard axis as well as the system PAT in the San Bernardino axis.

The freight traffic is unusual high for Switzerland especially through the Gotthard axis.

In 1997 the capacitive strips at the Golden River had to be adjusted and during two months the traffic was not registrated.

Every year the accuracy class of the PAT system was C(15) in southern direction in northern direction the accuracy class was B(10) in case the mean value deviation (bias) was higher than the standard deviation s the accuracy class tends to be a C(15) and the one of the Golden River was C(15) and in one case an E (30) in 1996 as the WIM installation (northern direction with capacitive sensors) was to close a curve.

The accuracy is also influenced by the type of vehicles. In one calibration test period the buses with two or three axles were measured far more accurate than the trucks with two or three axles. In the same test, axles of trailers tend to be measured less accurate than the other axles. By doing a calibration test the selection of vehicles should correspond with the composition of the heavy traffic throughout the whole year and should be mentioned in the test results.

It is essential to do at least once a year a calibration check, sometimes the mean value deviation was higher than the standard deviation of a single measurement. The bias may differ from year to year, the road surface condition and the static behaviour may change during the year and after some time. The calibration factor should be adjusted after a calibration check if the calibration deviation $|m/s|$ exceeds the factor 0.5

11.2 Conclusions; recommendations – Swedish test

This report on the WP.3.1 Cold Environment Test presents the results obtained from both the Pavement WIM systems and Bridge WIM systems in an environment where the impact of the cold climate on the data registered was of particular interest. The data collected by the different WIM systems was compared primarily with reference data obtained from static weighing of vehicles, and readings taken on the temperature of ambient air and pavement surface.

The basic procedure used in the test analysis was to compare the weight of a vehicle as determined by the WIM systems with that obtained when weighing the same vehicle on static scales. The latter was considered to be the true weight unless indicated otherwise. Some of the analyses that were conducted suggested that the quality of the static scales varied. This was observed in conjunction with weighing individual axles while determining the total vehicle weight on large scales. As WIM systems constantly improve and approach the accuracy of static weighing systems, the precision of the reference weighing will become even more important.

In summary, it can be concluded that the Pavement WIM systems that proved to be best in test in Luleå were those whose sensors are not embedded in the bituminous surface. This test confirmed what has been found in the past, i.e., that it is difficult to compensate for temperature when the sensors are covered by asphalt, as in the case of the Piezocheramic bar type of sensor. These complicated-design systems have concentrated on so-called automatic self-calibration instead, whereby knowledge about the composition of traffic is used to distribute the weight of various vehicle categories on a continuous basis. However, for the quality of the data to be predictable and reliable, this presumes a relatively large traffic volume, particularly at changes in the weather.

The WIM systems whose sensors are placed on top of the surface of the pavement instead produced better results in the test. These systems are, however, more complicated to install, which becomes more time consuming. They are also considerably more expensive. PAT and Kistler-Golden River proved best in test. Despite this, they had difficulty in compensating for the extreme temperature differences between summer and winter. These problems are, however, surmountable in both cases. The bending plate technology used by PAT is reputable and reliable. It is therefore somewhat surprising that the temperature compensation in the PAT system did not work better than it did. The sensors used in the Kistler system are based on relatively new technology, and like the PAT system, gave relatively good results in the test. However, the long-term stability in cold climates of this type of sensor remains to be seen.

The Bridge WIM results in the Cold Environment Test look very promising. It is generally considered that this technology will become much more prevalent, particularly on the low traffic volume road network. The reason is simple. Much of the current need for such data is related to such social issues as regional economic development and the environment. For these matters, neither great precision in the individual surveys nor continuous data input is necessary. Data collection at specific places during shorter periods, perhaps every other year, would often be quite sufficient. In the meantime, the equipment can be used elsewhere. This makes Bridge WIM a highly viable alternative from a cost point of view. There are several advantageous to Bridge WIM systems as opposed to their pavement counterparts. These are not discussed in the report. Unfortunately, the Bridge WIM systems are still not completely developed, technically or commercially. There are too few players on the market, and too few systems. Nonetheless, it is expected that Bridge WIM will be able to completely replace today's portable traffic survey equipment using pneumatic tubes.

12. REFERENCES

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13. IMPLEMENTATION AND DISSEMINATION

The results of the Cold Environment Test (CET) have been disseminated in many different ways. For the tests conducted in Sweden, the data recorded by each of the four WIM systems taking part in the test was sent to the respective manufacturers shortly after the end of every test period along with reference data from the static weighing of both the test vehicles and vehicles selected from traffic. Information on the temperature conditions during the test period was also included. This feedback meant that the system manufacturers could analyse the performance of their systems almost immediately after a test period, and thus learn more about any faults or shortcomings in their systems, particularly as regards temperature compensation. However, the rules governing the test prevented them from implementing the findings on the specific equipment being used in the test. One of the systems taking part was a prototype, and as such was not subject to the same rules as the others. This meant that it could be modified between the different test periods. On the other hand, the system manufacturers were immediately free to implement their findings in their own product development and marketing.

Papers containing CET results have been included in the proceedings of several international and national conferences. Further, the results from the Swedish component of the CET have been presented at a number of seminars. This has resulted in widespread investment in the field. Although interest in WIM technology as a whole has increased, it has been particularly focused on Bridge WIM. There are some 22 000 bridges in Sweden, of which a large proportion lend themselves to this technology.

Traffic surveys can be carried out for heavy vehicles, as for all other vehicles, using traditional methods through which vehicle classification is based on the distance between axles (wheelbase) and axle combinations. The models used to determine pavement deterioration are often based on such surveys, from which the axle load is then assumed. However, it has been shown all too often that these models fail to satisfactorily reflect reality. WIM technology offers a good opportunity to develop models for pavement deterioration caused by traffic.

Figures

Tables