# TEST OF WIM SENSORS AND SYSTEMS ON AN URBAN ROAD

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**Abstract**

This paper describes a large scale test of six WIM systems and four additional sensors on an urban roadway in Zürich, Switzerland. Gross weights from some thousands of statically weighed vehicles were used to determine the levels of accuracy for each system, with reference to the new draft of the European specification on WIM (COST323). The accuracy of axle weights was not tested. The WIM sensors, which included one prototype were tested with the assistance of a recording and processing device supplied by the organiser. Most systems encountered some problems, failures and faults, under the carefully controlled conditions of the 30 month test. However, these were generally solved by the suppliers after some delay.
Statistics are provided on overall levels of accuracy and on trends with season and time. In addition, a brief history of system malfunctions and failures is provided. Nevertheless the scope of the conclusions are limited by the traffic conditions and the test plan.

**Keywords**
weigh-in-motion, WIM, systems, sensors, traffic, test, trial, accuracy, durability, weight.

**Biographical Notes**

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## 1. INTRODUCTION

This paper describes a field test of commercially available weigh-in-motion (WIM) systems carried out on an urban road in Zürich, Switzerland in the period 1993 to 1995. The test was first proposed by the Swiss Federal Institute of Technology (ETH) but was subsequently overseen by COST323, the European coordination group for WIM. The objective was to assess the accuracy and durability of WIM systems and sensors available on the commercial market, to evaluate their long-term behaviour and to establish the required maintenance.

COST 323 is an action supported by the COST Transport part of the European Commission's Transport Directorate, DG VII. Following a proposal of the FEHRL group (Forum of European Highway Research Laboratories), COST323 was initiated in 1992 and is planned to end in late 1998. Since 1993 it has been run by a Management Committee consisting of scientific and technical experts. The objective of the group is to promote the development and implementation of WIM technology, and to facilitate an exchange of experience between different European countries (Jacob 1994-5). In 1996, 17 countries were participating in the action (Jacob 1996).

One of the objectives of the COST 323 action is to collect information and to evaluate existing WIM systems, particularly with reference to the new draft European specification (COST323 1997a, Jacob et al. 1997). It was for this reason that the Management Committee undertook to oversee the Zürich test in 1993. Two further tests are being overseen by the COST323 group, at Luleå in Sweden and on the A31 between Metz and Nancy, France.

Preliminary results of the Zürich test have been presented by Doupal and Caprez (1995). In addition, a comprehensive report has been published (COST323 1997c).

## 2. CHOICE AND DESCRIPTION OF THE TEST SITE

The site selected for the WIM test was at Hagenholz in the suburbs of Zürich in Switzerland. The road geometry and pavement make-up and condition at this site meet most of the criteria recommended by the COST323 Management Committee (COST323 1997a, Ma & Caprez 1995) as can be seen in Table 1. About 200 metres beyond the test site lies the entrance to the AWZ incinerator factory (City of Zürich). All vehicles transporting urban waste to be incinerated at this factory are weighed at the entrance on an approved weighing system. Up to 200 vehicles are weighed per day by this static weigh-bridge; half of them lorries and half vans or cars. The management of the AWZ incinerator factory provided free access to all truck weight results for the duration of the test. These favourable circumstances allowed a great number of static checks to be carried out on the Gross Vehicle Weights (GVW's) of lorries which had passed over the WIM sensors and systems. It was possible to compare WIM measurements to the corresponding statically determined gross weights, without police participation and without disturbance to the traffic flow.

| Criteria | Value | Limit (class III) |
|---|---|---|
| longitudinal slope | - | ≤ 2% |
| slope in the transverse direction | 1% approx. | ≤ 3% |
| radius of curvature | 1000 m | > 1000 m |
| Maximum Rutting | 12 mm (*) | ≤ 10 mm |
| Mean deflection (flexible pavement) | 0.83 mm | ≤ 0.75 mm |
| Deflection difference (left/right) | | ≤ ± 0.15 mm |
| Evenness (IRI) | 3.7 | ≤ 4 |

(*) measured with a 4 m beam instead of a 3 m beam; may be considered equivalent to 10 mm.

Table 1 - COST 323 Specification, site criteria and values recorded in Zürich (*average*, class III)

The test site, where all of the WIM sensors and systems were installed, is 150 m long. The road at this point is part of a large left-hand bend (radius 1000 m) with a slope transversely of about 1%. A fenced car park was available adjacent to the track for the storage of WIM signal processing equipment. On working days the daily traffic flow in the measuring direction is 7000 vehicles of which 10% to 15% are lorries. The site is in a 50 km/h zone and the average speed of all vehicles is 45 to 50 km/h.

The road at the test site was constructed in 1975 with the flexible pavement illustrated in Fig. 1. The wearing course consists of a 40 mm thick bituminous layer (40 mm asphalt concrete with a maximum grain size of 16 mm). The base course has a thickness of 200 mm with bituminous bound material (200 mm of hot mixed base course) and the sub-base consists of a 250 mm gravel layer. The Young's modulus of the capping layer is 40 MPa. The mean deflection measured (Swiss standard SN670 362a) with a Benkelman beam under a 100 kN axle and a temperature of 4°C was 0.643 mm in January 1994; that corresponds to 0.83 mm under the specified 130 kN axle, which is a little more than the accepted limit for such a pavement (Table 1).

The pavement longitudinal evenness at the Hagenholz site was measured using an ARAN at the beginning of the test in 1993, to determine the International Roughness Index (IRI). The transverse profiles were measured manually. The measured IRI value, at 3.7 mm/m, indicated a surface which was relatively rough but which is a realistic representation of the conditions encountered on many urban roads. The left and the right side rut depth as well as the maximum measured value are given in Table 1. According to all criteria, the site was deemed to be suitable for WIM measurements, according to the limits of the European specification (COST323 1997a) which classifies it as 'acceptable' (class III).

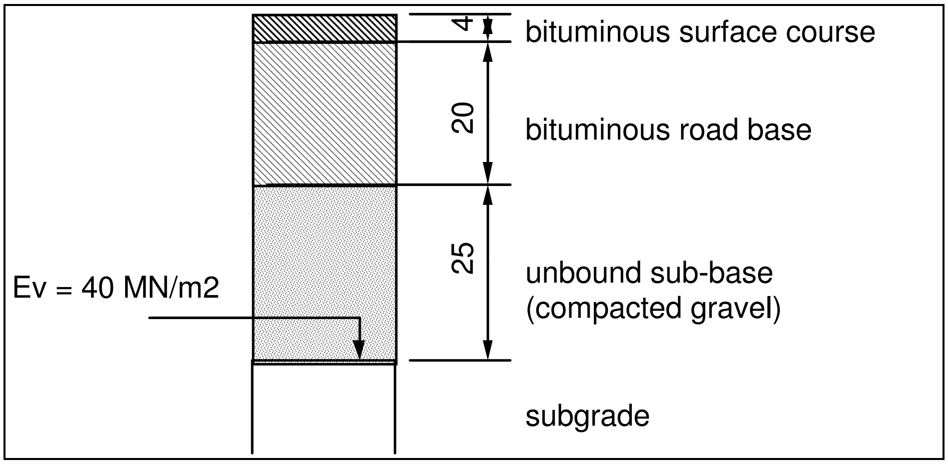



Figure 1 - Section through road pavement at test site

## 3. WIM SYSTEM/SENSOR DESCRIPTION

For the test, seven complete WIM systems were provided, but only six are described here (A1 to A6 in Fig. 2), because the last one was installed at the end of the test and did not provide results. In addition, four manufacturers provided only sensors (B1 to B4) which were operated by the staff of ETH. For one of the WIM systems (A6), sensors and electronics were supplied by different companies.

Despite the efforts of the test organisers, it was not possible to install all of the WIM systems and sensors at the same time. Between the end of June and October 1993, the road had to be closed four times for various installations. The air temperature during the installations was generally between 15° and 25°C. However, for some of the later systems, temperatures lower than 10°C were recorded. The relative humidity during installation was between 70 and 95 %.

Six complete WIM systems were provided and tested. They are referred to here as Systems A1 to A6 and are described briefly below. A complete description of each system is given by COST 323 (1997c). System A1, a Golden River Marksmann (Moore et al. 1989), consisted of four capacitive strip sensors and two inductive loops as illustrated in Fig. 2. The length of the capacitive strips was one half that of the lane and two of them were installed end to end across the lane to weigh the left and right wheels simultaneously. System A2, AWACS by Peek Traffic, consisted of two piezoceramic bars and one off-scale sensor, combined with an inductive loop, as illustrated in the figure. System A3, by Mikros (TEL-2CM), consisted of a 2 m wide capacitive plate and two inductive loops. System A4, *Hestia* (Maeder et al. 1992), was supplied by ECM (F-Nancy). It consisted of two piezoceramic weighing sensors (bars) patented by the LCPC (MULT-LCPC, 1985), combined with an inductive loop. The active sensor was a Vibracoax piezoceramic cable (Class I). The processor for this system incorporated an automatic self-calibration algorithm based on recalibration to a pre-specified target value, after the passage of 30 vehicles of the same characteristic class. This self-calibration procedure was only active for some of the test period as will be discussed in Section 6.2. System A5, the DAW 100 by PAT (Samuels 1988), consisted of two 1.75

m × 0.5 m bending plates and two inductive loops, as illustrated. Finally System A6 was a prototype consisting of two QEX piezo-quarz sensors manufactured by Kistler, two inductive loops and the AVC 100 system (Automatic Vehicle Classification) from PAT.

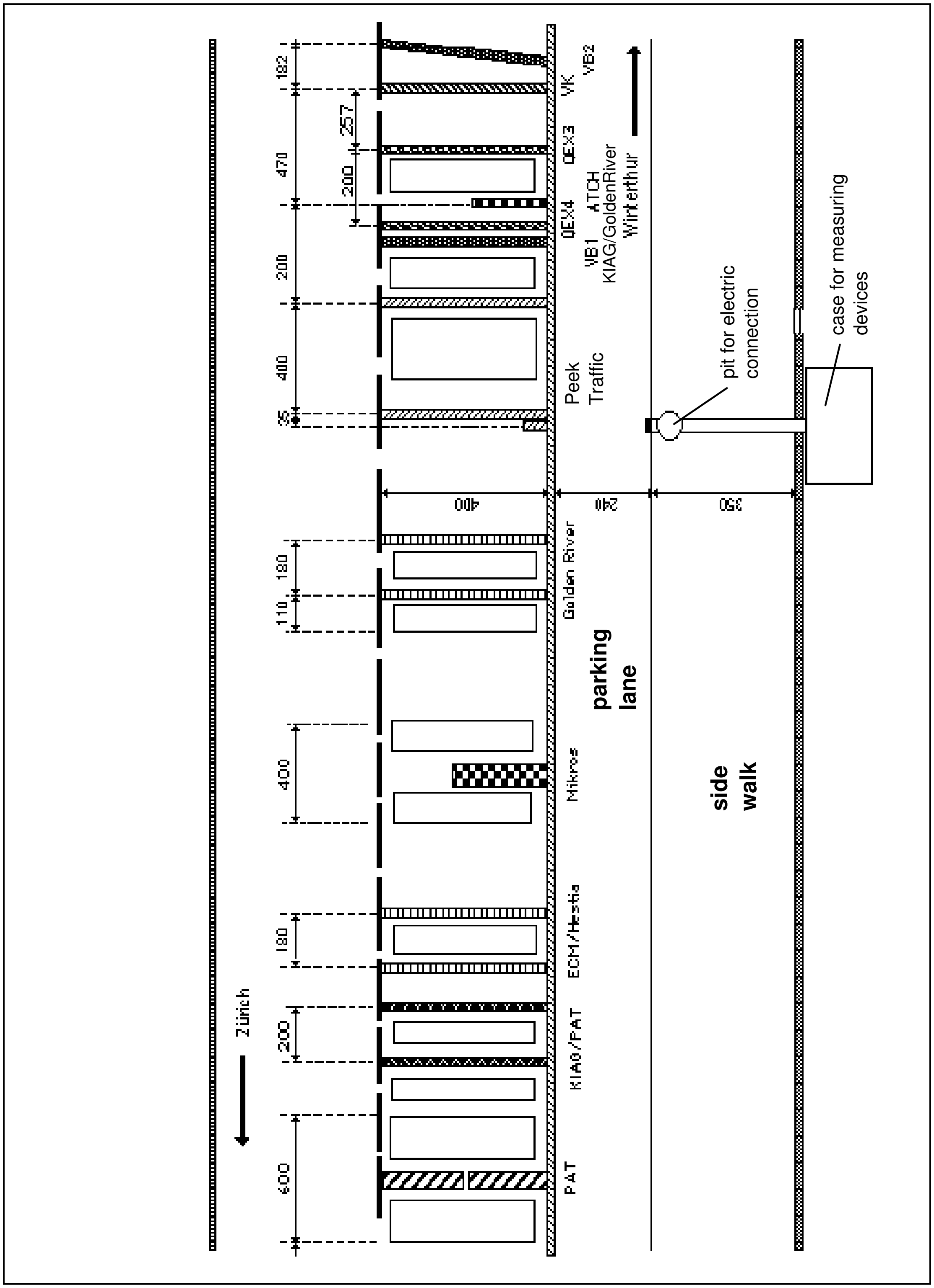



Fig. 2 - Layout of WIM systems and sensors at test site

Four WIM sensors were provided to the test organisers, ETH, for testing. The sensor signals were measured by ETH staff using a charge amplifier and a digital oscilloscope. In this way, typical signal shapes and amplitudes due to the passing vehicles were measured, registered and stored on floppy disks. The signal evaluation was done directly with the oscilloscope (signal amplitude and spread) or with internally developed signal integration software adapted to the sensor properties and written separately for each sensor.

As a result of tests carried out previously on a circular test track (Beligni et al. 1995), the signal amplitude was known to be less sensitive to the applied load than the integrated signal. This lead to the choice of integration of the signal; the integral was multiplied by the velocity.

The layout of the four sensors tested, referred to here as Sensors B1 to B4, is illustrated in Fig. 2 and each sensor is described briefly below. Further details are given by COST 323 (1997c). The EHAG company (agents of ATOCHEM, USA), provided the test organisers, ETH, with Sensor B1. The Road-Trax-C-003467-00 sensor consisted of a piezopolymer strip, coated in a hard rubber profile, and embedded in an aluminium profile. Sensor B2 was *Vibetek* by FOCAS Ltd., in the United Kingdom. It was a piezopolymer coaxial cable sensor with a diameter of 2.5 mm. The piezoelectric material was a plastic dielectric polyvinyl fluoride. Sensor B3 was a new QEX sensor manufactured by Kistler (Jahreiss & Calderara 1995). Piezoelectric quartz crystals were used to measure the axle loads. Sensor B4, Vibracoax, was a piezoceramic pressure sensor, available from Thermocoax, a Philips subsidiary company in France (Lear et al., 1989).

## 4. CALIBRATION

### 4.1 Basic Procedure

All systems and sensors were calibrated using the same method and the same calibration vehicle. It was a three-axle truck with an integrated water tank with a capacity of 6000 litres. The water tank was divided in order to prevent any dynamic effects on the axle load during braking or accelerating. The gross weight as well as the static axle loads were measured before calibration on an accurately calibrated static bridge scale (accuracy $\pm$ 20 kg) and with a wheel weighing scale. The static axle loads of the loaded test lorry were 6800 kg, 5000 kg and 8200 kg for the front, second and rear axles respectively; the distance between the first and second axles was 3.2 m while the tandem axles were spaced by 1.35 m. The total length of the lorry bumper to bumper was 8.375 m.

The same calibration procedure adopted for all the systems and sensors was chosen in accordance with the instructions of the suppliers or their representatives. It consisted of 10 runs of the loaded calibration lorry, driven at a speed of 50 km/h. The suppliers or their representatives programmed the calibration factors into the WIM systems. After this initial calibration, the calibration factors were not changed except in the case of a breakdown and replacement/repair of a sensor/system, in which case the same calibration procedure was repeated.

In accordance with the draft European specification (COST323 1997a, Jacob et al. 1997), this calibration was in conditions of ‘Full Repeatability’, i.e., the same vehicle passing repeatedly at the same speed and load. It was considered acceptable for this test because only a few types of lorries were to be weighed, most of them similar to the calibration vehicle, and because the speed range at the test site was relatively small (most lorries were travelling at 40 to 50 kph).

### 4.2 Calibration checks

During the test period, 4 to 5 additional calibration checks were carried out with the test vehicle in order to survey the calibration factors of the WIM sensors and systems. However, no change was made in the system calibration factors, except after the replacement or repair of a sensor/system.

The results of these calibration checks are presented in Table 2. Some of the systems/sensors did not register the calibration check runs because they were out of order at the time of the check. Sensor Nos. B2 and B4 did not register these runs because they were not connected to the electronics during these periods. The number of records, the mean and the standard deviation of the relative errors are given. Some of the checks constitute ‘Full Repeatability’ conditions (Jacob et al. 1997), i.e., the same vehicle passing repeatedly with the same load and at the same speed. Others constitute ‘Extended Repeatability’ conditions, i.e., the same vehicle passing repeatedly but with different conditions of load and different speeds. It can be seen that some systems have a consistent bias in the results and that the variation in results in some is considerably greater than that in others.

| WIM-systems | number of runs | condition (no. of days) | IF: mean value | IF: standard deviation |
|---|---|---|---|---|
| **System A1** | 62 | r2 (2) | 1.08 | 0.06 |
| **System A3** | 45 | r2 (1) | 1.13 | 0.08 |
| **System A4** | 65 | r1 (2) | 1.06 | 0.06 |
| **System A5** | 48 | r1 (1) | 0.99 | 0.01 |
| **System A6** | 37 | r1 (1) | 1.00 | 0.02 |
| **Sensor B3** | 45 | r2 (1) | 1.00 | 0.03 |

Table 2 - Results of calibration check (IF = Impact Factor, r1 = full repeatability, r2 = extended repeatability)

## 5. SYSTEM/SENSOR BEHAVIOUR AND DATA COLLECTION

### 5.1 Data collection

The data for the test was gathered in the period, August 1993 to November 1995. In the Summer of 1993, Systems A1 to A3 and Sensors B1 to B4 were installed. The other systems were installed later; A4 in October 1993 and both A5 and A6 in October 1994.

The latter three systems took part for less than half of the test period and recorded only about one tenth of the total data.

The measurement procedure was as follows: after a vehicle passed the WIM site, its licence plate number was transmitted by radio to an operator standing next to the static weighing scale. The time of arrival at the weighing scale, the plate number, the statically measured gross weight, and the vehicle class and number of axles were noted. The WIM systems (A1 to A6) automatically recorded the vehicle gross weights (and axle loads) and assigned to them a serial number. These serial numbers were noted together with the plate number by the operator at the WIM site. The individual sensor signals (Sensors B1 to B4), were identified with an analogue signal and the vehicle numbers, and the output from the digital oscilloscope was stored on floppy disks for later processing.

The static scale, supplied by Pfister Waage, is calibrated annually (in October) and is accurate to ± 20 kg. Only gross vehicle weights were recorded with it.

During the main test period (July 1993 - November 1995), there were a total of 86 days of measurement (30 days in 1993, 41 days in 1994 and 15 days in 1995). In all, 3422 vehicles were weighed statically, but not all could be recorded by the systems because of failures, the fact that they were not always in operation or because they were not connected to the sensors. The maximum number of vehicles recorded by any of the WIM systems was 2128, with large differences in the numbers of recorded weights according to the periods of successful operation of the systems. Because of the absence of automatic recording procedures, the period during which the WIM sensors were being monitored, was considerably less. During the period of monitoring, 1471 vehicles were weighed statically. The numbers weighed by the individual systems are given in Table 3.

| **WIM-systems** | **number of vehicles** | **IF: mean value** | **IF: standard deviation** |
|---|---|---|---|
| **System A1** | 1255 | 1.02 | 0.24 |
| **System A2** | 1265 | 0.94 | 0.22 |
| **System A3** | 1325 | 1.04 | 0.09 |
| **System A4** | 1084 | 0.99 | 0.16 |
| **System A5** | 155 | 0.97 | 0.06 |
| **System A6** | 137 | 1.02 | 0.10 |

Table 3 - Summary statistics for ratio of WIM weight to static weight (IF) for lorries over 3500 kg

The measurements only applied to the gross weights of vehicles carrying waste to the incinerator nearby. About 65% of the vehicles measured were lorries, the rest being small vans. 30% of the lorries were two-axle rigid with typical gross weight in the range 8-15 tonnes, 40% were three-axle rigid with typical gross weight in the range 13-25 tonnes while 30% were 4-axle lorries with typical gross weight in the range 16-28 tonnes.

## 5.2 System/Sensor Durability

The periods during which each of the sensors/systems functioned are indicated in Fig. 3 (see end of paper). The nature of the breakdowns are broadly classified in this figure into four categories: sensor defect, software problem, miscellaneous hardware problem and charge problem.

For System A1, the Marksmann 600 data processing system was replaced in March 1994 by a new type of processor, the Marksmann 660. In February 1995, the sensors were found to have failed and, in July 1995 all four were replaced. The results were improved afterwards.

For System A2, the 6000 Series AWACS and the Serial Data Port were out of use between June and December 1994 after which they were repaired by Peek Traffic in England. The power supply failed in February 1995 and was repaired during March and April. After two years of operation, some failures occurred in the pavement in the road adjacent to the sensors.

Some axle loads were missed in System A3 in September 1993 but this was rectified in October when Mikros replaced a defective EPROM. Because of a mechanical fault on the surface of the sensor the upper gum-pad was replaced with a new one in August 1994. In September of that year, the system failed due to a defective sensor element. It was replaced in March 1995, but this new sensor mat also failed after three weeks and was not repaired.

In late August 1994, the installed Hestia station for System A4 was changed. The internal 3 Volt lithium batteries were replaced. The power supply, a 12 V accumulator, was also replaced after a technical failure in January 1995. There were also occasional problems of communication between the Hestia station and the computer storing the data. The initial automatic self-calibration, based on French traffic patterns, did not work satisfactory at the test site because of the lack of characteristic lorries in the traffic flow. Therefore it was deactivated in late November 1993. A new algorithm was installed in late August 1994, but it did not work properly. ECM explained that the intermittent use of the system, characteristic of this test (data was only recorded for a few days each month), was inappropriate for the self calibration process. The system could be expected to self-calibrate more effectively if it were being operated continuously.

Following the installation of System A5 in October 1994, there were some unexplained problems with the DAW 100 software, which prevented the taking of measurements. These were only solved by PAT (Pietzsch) in the Summer of 1995. Due to these delays in installation and repair, only a small number of measurement were recorded during the last 3 months of the test.

There were some difficulties at first finalising the data acquisition software for the combined prototype, System A6. The data processing software had not been adapted for the new application and the sensor signals were measured using two digital oscilloscopes. After a new version of the software was developed in July 1995, the system worked well and continued to provide results for the last 6 months of the test.

Sensor B1 was installed in July 1993 and failed in November of that year, after only 4 months. Because it was not replaced by the supplier, very little data was available and it was difficult to draw any firm conclusions. However, the installation technology used appears to be good because the sensor continued in good mechanical order and there was no damage or change in the surface conditions.

Sensor B2 was only used during the first year of the test, up to August 1994. Because of the very high scattering of the results, increasing with time, data acquisition was abandoned. Nevertheless the physical conditions of the two sensors in the pavement was still good after two years.

After a period of two and half years at the test site, the signals from Sensors B3 and B4 had not changed. Further, the surface of the road showed no damage in the area of these sensors.

## 6. RESULTS

### 6.1 Overall Accuracy Assessment

The static gross weights recorded at the incineration factory were used as the reference values for the assessment of system/sensor accuracy. In Fig. 4 the recorded WIM weight, $W_d$ , is plotted against static weight, $W_s$, for Systems A1 to A6 and Sensors B1 to B4. In all the graphs there is a cluster of points centred about a static weight of about 3000 kg. This corresponds to recorded vans. Summary statistics are presented in Table 3 for all vehicles with a static weight in excess of 3500 kg. Some sensor designs are clearly better suited to the estimation of static weights than others. In Fig. 4, satisfactory results are apparent from Systems A3 and A5 both of which utilise a sensor with a relatively wide base.

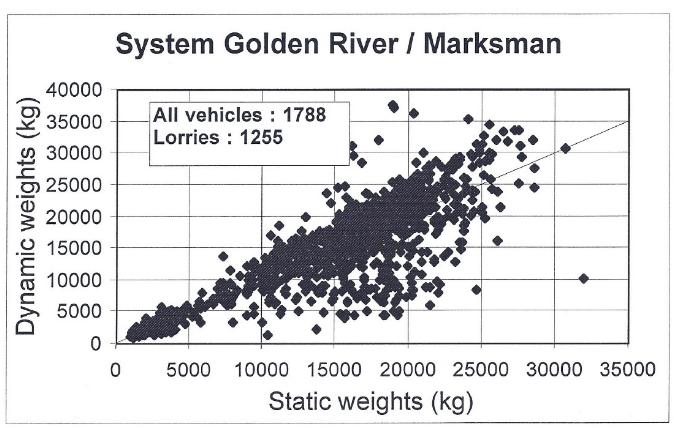



Fig. 4a - Results of the Marksman system (Golden River)

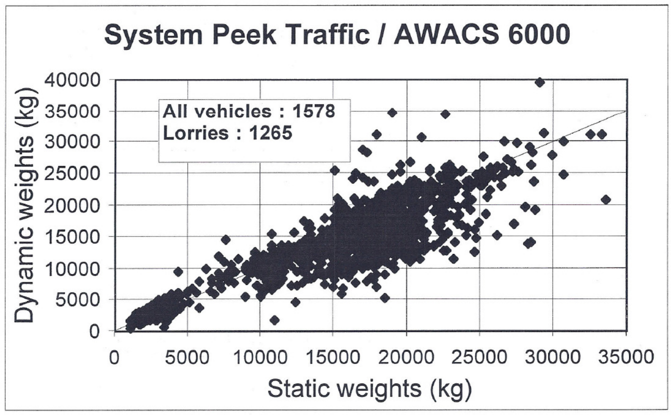



Fig. 4b - Results of the AWACS 6000 system (Peek Traffic)

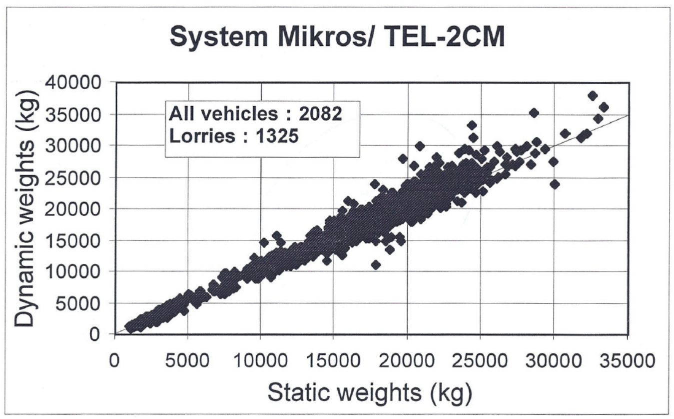



Fig. 4c - Results of the TEL-2CM system (Mikros)

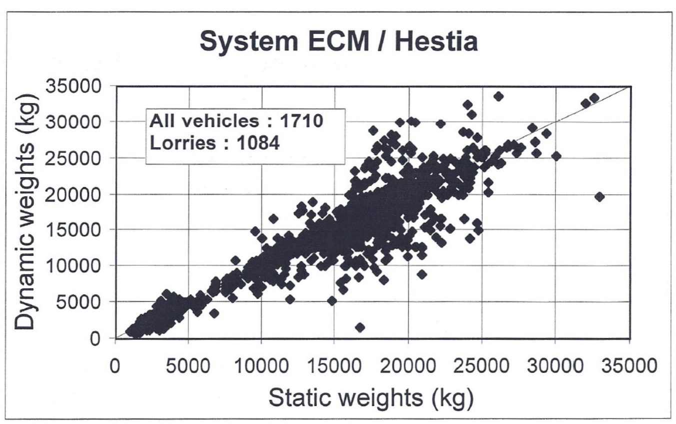



Fig. 4d - Results of the Hestia system (ECM)

Fig. 4 - Recorded WIM gross weight versus static weight: (a) System A1 (capacitive strips), (b) System A2 (piezoceramic strips), (c) System A3 (capacitive plate), (d) System A4 (piezoceramic strips), (e) System A5 (bending plates), (f) System A6 (piezo-quartz strips), (g) Sensor B1 (piezopolymer strip), (h) Sensor B2 (piezopolymer strip), (i) Sensor B3 (piezo-quartz strip), (j) Sensor B4 (piezoceramic strip)

The accuracy of each of the systems has been classified with reference to the draft European WIM standard (COST323 1997a, Jacob et al. 1997). As static weights for individual axles were unavailable, this classification applies only to the gross weights. In the context of the standard, the test satisfied conditions of 'full reproducibility', i.e., the test sample was large, was taken from the general traffic flow and was representative of it. In addition, the test satisfied conditions of 'full environmental reproducibility', i.e., it spanned a reasonable range of temperature and climatic conditions. For such conditions the standard specifies a required minimum level of confidence in the results depending on the number of records in the sample. This can be shown to be 90% for about 150 lorries (as in the case of Systems A5 and A6) and 92% for 1000 to 1500 lorries (as in the case of the other systems).

Table 4 gives the sample percentages of results within various centred confidence intervals for each system. The accuracy classification is based on the width of the interval within which the required percentage of sample results falls. If the required number of records are within 5% of the static values, the system is classified as Class A(5). Similarly, systems are classified as Class B(10), C(15), D+(20), D(25) or E if the required number of records are within 10%, 15%, 20%, 25% or more than 25% of the static values respectively.

| **Width of the confidence interval** (centred on the static weight) | **Percentage of results in the confidence intervals** | | | | | |
|---|---|---|---|---|---|---|
| | **System A1** | **System A2** | **System A3** | **System A4** | **System A5** | **System A6** |
| **± 5 % (A)** | 21.0 % | 25.1 % | 42.7 % | 34.8 % | 71.0 % | 37.2 % |
| **± 10 % (B)** | 37.5 % | 45.5 % | 73.7 % | 61.1 % | 86.5 % | 67.9 % |
| **± 15 % (C)** | 52.0 % | 59.4 % | 87.7 % | 75.9 % | <u>93.5 %</u> | 89.1 % |
| **± 20 % (D+)** | 64.8 % | 68.9 % | <u>95.3 %</u> | 82.7 % | 98.7 % | <u>97.8 %</u> |
| **± 25 % (D)** | 76.6 % | 76.0 % | 97.9 % | 86.3 % | 98.7 % | 98.5 % |
| **± 30 %** | 84.4 % | 81.8 % | 99.0 % | 90.8 % | 100 % | 99.3 % |
| **± 35 %** | 87.5 % | 87.3 % | 99.5 % | <u>94.0 %</u> | - | 100 % |
| **± 40 %** | 90.2 % | <u>93.0 %</u> | 99.8 % | 96.0 % | - | - |
| **± 45 %** | <u>92.0 %</u> | 96.3 % | 100 % | 97.9 % | - | - |
| **Accuracy class** | **E (45)** | **E (40)** | **D+(20)** | **E (35)** | **C (15)** | **D+(20)** |

Table 4 - Statistical accuracy of WIM systems relative to static gross weights (The underlined levels of confidence are the least values in excess of the acceptance thresholds. After the letter **E**, the accuracy classes according to the results are given, as defined in the specification).

For example, for System A5, the minimum level of confidence is 90% so the classification is based on the width of the confidence interval within which 90% of results fall. As only 86.5% of WIM results fall within 10% of the static values, the system cannot be classified as Class B(10). As more than 90% of results fall within 15% of the static values, it is classified as Class C(15). Only the results of System A5, which used bending plate technology, strictly meet Class C(15). System A6 with a piezo-quartz strip sensor, only misses Class C(15) by 1% of results (1 or 2 measurements) and is in

Class D+(20). Both System A5 and A6 only took part in the test for a relatively short period because of software problems (the same electronics was used in both), and were therefore exposed to a lesser range of environmental and temperature conditions than the other systems.

System A3, the capacitive plate, meets the Class D+(20) requirements. All the other (strip sensor) systems fail to meet the Class D(25) requirements and should be placed in Class E. There are however some clear differences between them, as shown by the levels of confidence given in Table 4. System A4 is in Class E(35) with a level of confidence of 94%, while System A2 is in Class E(40) with 93% confidence and System A1 is in Class E(45) with 92% confidence.

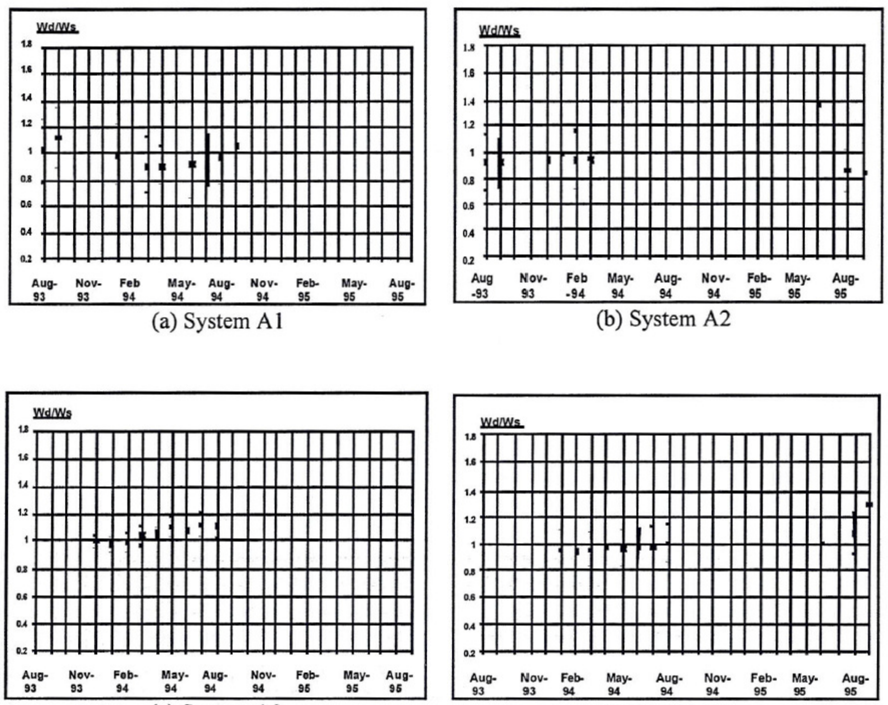
The generally low accuracy classifications, even from wide-base sensors, are to be expected from a site with these characteristics (Site Class III in accordance with the draft specification). The capacitive mat of System A3 was affected by some sensor failures and electronic problems and System A4 was partly affected by the inappropriate conditions for its self-calibration, which may explain the reduced accuracy. The reliability of the capacitive strip sensors of System A1 was rather poor, which reduced the system accuracy. System A2 was more affected by hardware problems, but also by a sensor failure due to the mounting technique. The strip sensors (Systems A1, A2 and A4) are more sensitive to dynamic effects resulting from the pavement/vehicle interaction, which increases significantly with pavement roughness. However, only the highest eigenfrequencies (approximately 15 Hz) of the non-suspended masses (axle hop), which correspond to the shortest wavelengths of the signal on the road (1 m), are partially smoothed with the wide-base sensors. The lower eigenfrequencies (from 0.5 to 3 Hz) which correspond to wavelengths between 5 and 30 m and to the main vehicle bounce and pitch motions, are not filtered by any WIM sensor. Therefore, it might be expected that less than half of the dynamic increment would be eliminated by the large scales, according to extensive studies carried out in the OECD/DIVINE project (Jacob 1995, Jacob & Dolcemascolo 1997).

System A6 used a Kistler strip sensor combined with electronics provided by PAT. It is interesting that the accuracy classification is close to but less than that of System A5, the wide-base bending plate provided by PAT. This suggests that the dynamic phenomenon (dynamic increment with short wavelength) has an order of magnitude of 5 to 10 % on this test site. Such a difference would be critical for Class A(5) or B(10) systems but is clearly less important for the lower accuracy classes. It might therefore be expected that, on smoother pavements with much smaller dynamic increments, high performance strip sensors could provide results similar to those of the wide-based sensors.

## 6.2 Analysis for Time and Seasonal Trends

Data from four WIM systems, A1 to A4, was analysed in greater depth to examine the relationship between WIM accuracy and time or season. Two analyses were carried out. For the first, accuracy was calculated by month in chronological order. For the second analysis, three types of season were identified and accuracy was calculated once for each season type.

The purpose of the first analysis was to determine if the WIM system accuracy tended to deteriorate with time. The mean by month of the ratio of WIM weight to static weight is presented in Fig. 5 for each of the four systems. For Systems A1 and A2, there is no apparent tendency to drift with time. For System A3 on the other hand, the capacitive plate, there seems to be a tendency for the mean ratio to deviate from unity with time. This has significant implications for accuracy classification. On the basis of these results, the system classification would change from Class B(10) in December 1993 to C(15) in March 1994 to D+(20) in May 1994 and to D(25) in July 1994. Furthermore, this preliminary result would suggest that, if the tendency to drift can be overcome, there is scope for considerable improvement in the accuracy of results.




(a) System A1 (b) System A2

(c) System A3 (d) System A4

Fig. 5 - Mean ratios of measured WIM weight to static weight by month

If a self-calibrating WIM system were functioning correctly, it would be reasonable to expect no variation in mean accuracy with time or season. For the reasons explained above, the self-calibration algorithm for System A4 was deactivated throughout the period, January through August 1994. It can be seen from Fig. 5(d) that there is a relatively small drift through that period during which the system accuracy actually improves. In 1995, the self-calibration algorithm was reactivated. However, for each of the three months for which data is presented, there were no more than two consecutive days of recordings which is considered to be insufficient for such a system to function properly. The results can be seen to be worst for September 1995 during which there were only two days of recording separated by one week. These results highlight the potential problems that can occur with intermittent use of self-calibrating systems.

A second analysis was performed to determine if there was a consistent variation in accuracy with season. Fig. 6 shows some typical pavement temperatures, as recorded by System A4. On the basis of the trend evident in this graph, it was decided to define three seasons as follows: 'cold' for December, January and February, 'warm' for June to August and 'mid-season' for the other months. Where data for more than one year was available, it was combined to give only one value for each season. However, there was often insufficient data to achieve this.

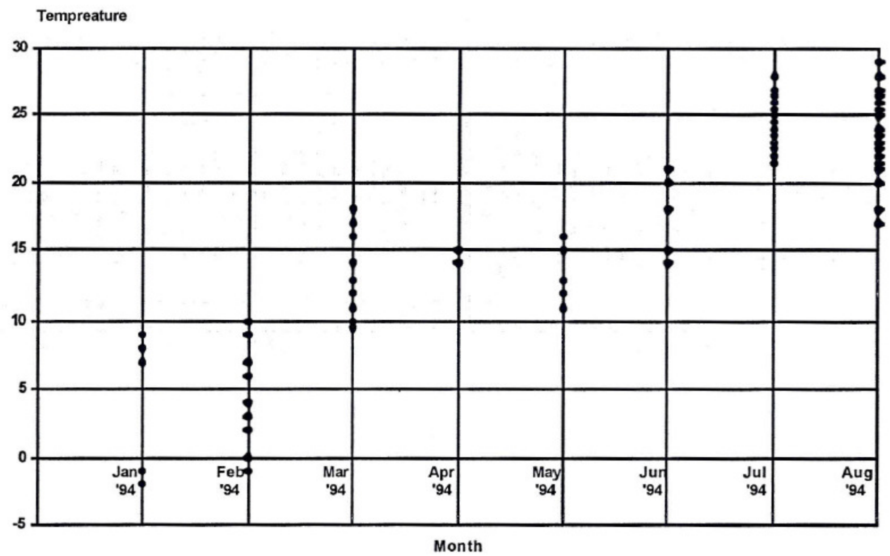



Fig. 6 - Typical pavement temperatures recorded by System A4

The seasonal means and standard deviations of the ratio of WIM to static weight are presented in Table 5. It can be seen that there is no apparent trend by season for Systems A1, A2 and A4. For System A3, the capacitive plate, the data only extended over nine months with the result that it is not possible to determine whether the drift apparent in Fig. 5 is due to climatic effects or not.

| | **System A1** | | **System A2** | | **System A3** | | **System A4** | |
|---|---|---|---|---|---|---|---|---|
| | **Mean** | **St. Dev.** | **Mean** | **St. Dev.** | **Mean** | **St. Dev.** | **Mean** | **St. Dev.** |
| **Winter** | 0.99 | 0.23 | 0.96 | 0.21 | 0.99 | 0.06 | 0.94 | 0.14 |
| **Mid - Season** | 1.09 | 0.24 | 0.92 | 0.19 | 1.05 | 0.07 | 1.03 | 0.20 |
| **Summer** | 0.97 | 0.21 | 0.96 | 0.26 | 1.11 | 0.09 | 0.99 | 0.15 |

Table 5 - Results of seasonal analysis (St. Dev. = Standard Deviation)

## 7. CONCLUSIONS

Although individual axle weights were unavailable, this test proved to be of considerable interest in providing information on the durability and reliability of WIM sensors, electronics and software over an extended period. A preliminary indication of the levels of accuracy that can be expected from commercially available WIM systems on a typical urban road is also given. Also, this test provided an opportunity for the first application of the new European WIM specification, which was found to be quite useful as a means of comparing results from systems that recorded different quantities of data.

For the gross weight criterion, the results are in good agreement with those indicated in the specification. The levels of accuracy were not as good as might be expected, perhaps as a result of the *average* pavement conditions. The specification clearly distinguishes several accuracy levels from one system to another. Roughly it may be seen that, the more expensive the whole system, the better was the accuracy. The new prototype piezo-quarz strip sensor appears to be promising with a level of accuracy (when incorporated in a complete system) close to that of the large bending-plate system. None of the other strip sensor systems met Accuracy Class D(25). However, some had lower levels of accuracy than others which can be explained mainly by sensor faults and/or software problems.

The time-dependent and seasonal analysis did not provide any clear proof of a seasonal trend and in some cases, there is evidence of an absence of such a trend. There is no evidence of drift for Systems A1, A2 and A4. However, System A3 appears to be drifting with time. This has important implications for the integrity of the accuracy classification which clearly varies over time. For the intermittent pattern of recording used in this test, System A4 proved to be less accurate when the self-calibration system was activated than when it was deactivated. This has important implications for users of such systems who wish to record for short periods only.

Among the 2 piezopolymer sensors, Sensor B2 is clearly not suitable for WIM, while Sensor B1 did not work for enough time to be properly evaluated. The piezoceramic sensor, B4, provided satisfactory results.

This test provides quite useful information, particularly on the durability of sensors and systems. The site and traffic conditions, with only a few types of lorries and small velocity range, slightly limits the scope of the conclusions. Consequently two complementary large scale trials are currently underway in Europe, the Continental Motorway Test (CMT) in Eastern France on a busy motorway, and the Cold Environment Test (CET) in Northern Sweden, which is also part of the European WAVE research project (Jacob and O'Brien 1996).

## 8. ACKNOWLEDGEMENTS

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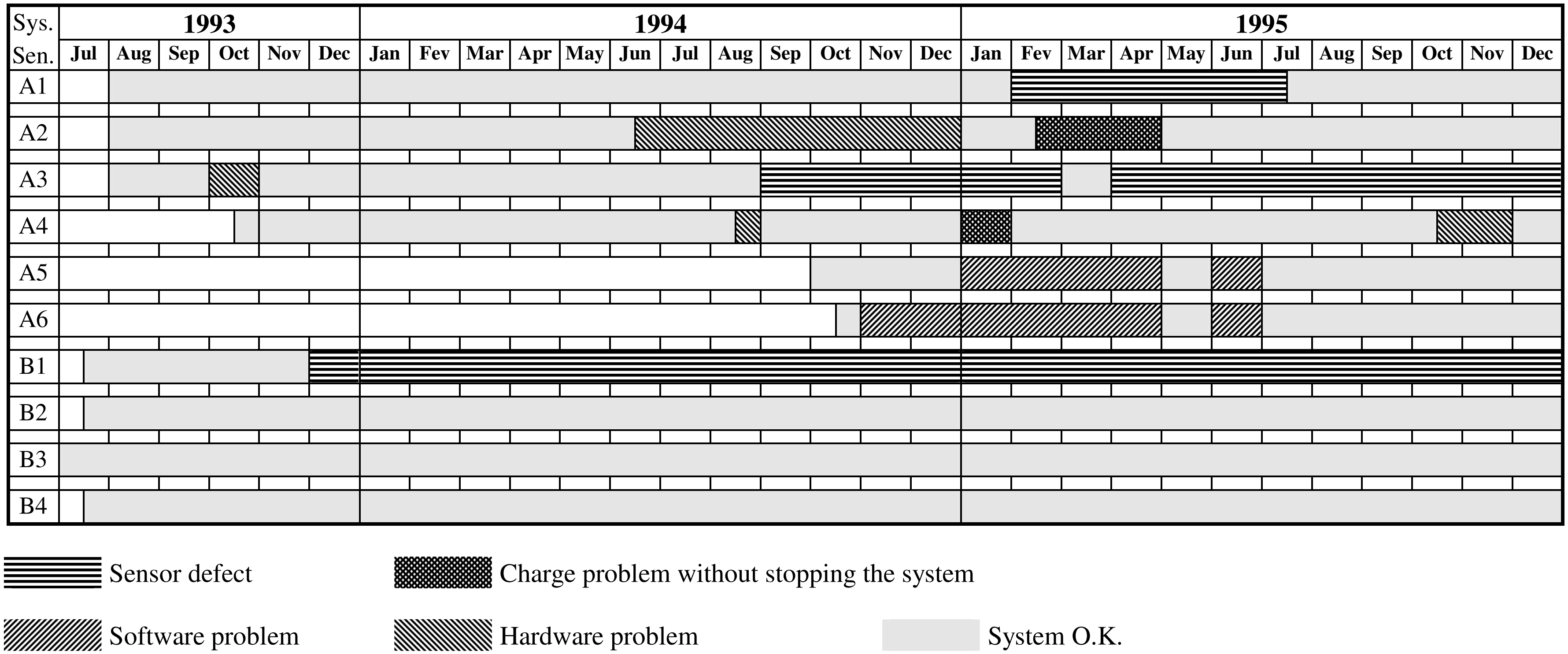


Fig. 3 - Summary of system and sensor behaviour over the test period