

Culway Calibration Procedure

Version 1.0

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1.0 Introduction

Any weighing device whether it is a bathroom scale or a Weigh in Motion system must be calibrated at some time to relate the output from the device doing the measuring to some unit of weight. This is achieved by loading the platform (culvert) with objects of known Mass and recording the various outputs from equipment so that a mathematical relationship between the two can be derived.

Culway WIM sites use a similar procedure by driving vehicles of known mass across the site so that a mathematical relationship between strain output and vehicle weight can be derived.

Recent advances in specialised Culway calibration software have significantly improved and simplified the on-site and off-site activities associated with WIM site calibration.

The procedures defined in this document are based solely on the specific requirements of the WimCal calibration package method, which uses a mixture of specific rigid and articulated test vehicles to calibrate. This method has become the most accepted approach to calibrating Culway WIM sites across Australia because of its simplicity and its ability to provide consistent results in accessing WIM site accuracy.

DRAFT

1.1 About this Document

This document is intended to describe the procedures and processes associated with the On-site and Off-site activities of a Culway WIM site calibration using WimCal.

1.2 Audience

This document is intended for all personnel who are responsible for;

- Planning for a Culway calibration
- Coordinating the on-site activities of a WIM calibration
- Analysis and reporting of calibration results

1.3 Culway Overview

Culway is an unmanned highway speed vehicle weighing and classifying system. This is achieved by using existing standard concrete culverts as dynamic scales to measure weight of axles as they pass over the culvert. Specially developed strain gauged transducers are attached to the roof of a culvert which produce a small voltage as the culvert roof bends when loaded. The amount of voltage produced is proportional to the amount of loading occurring on the culvert. A specialised micro-processor based data logger records the strain gauge information along with other vehicle parameters.

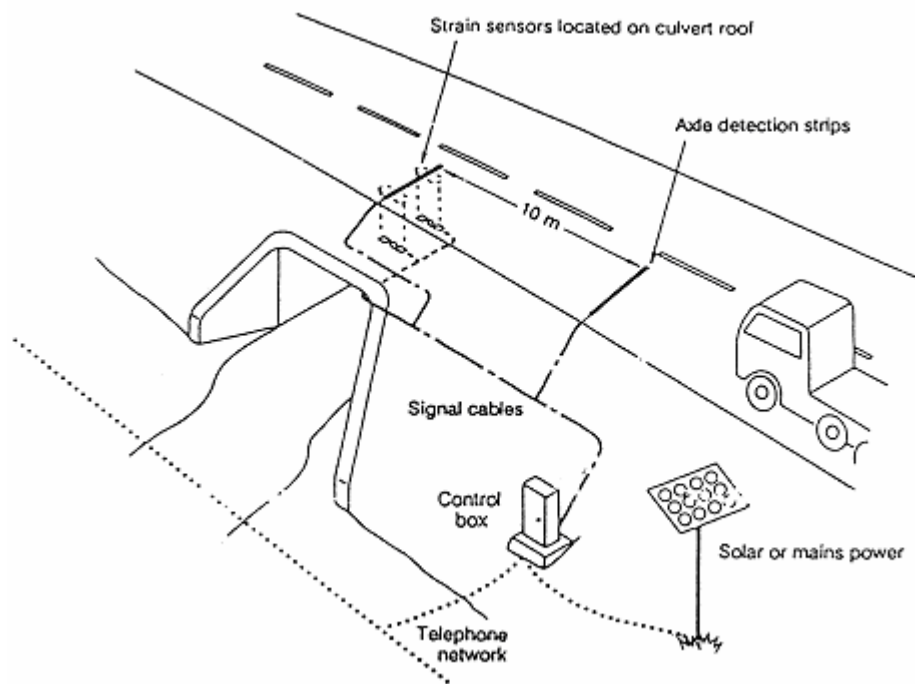


Figure 1: Typical Culway Installation

The Australian 'Culway' system was originally conceived and tested by Main Roads Western Australia in 1984. It has been used widely throughout Australia since then, with over 200 systems currently in operation. Arguably its greatest features are its robustness, low cost and acceptable accuracy. Unlike most WIM systems, the sensors are not subject to the battering of tyres and the vagaries of the weather, with the result that Culway needs little or no site maintenance.

Much work has been undertaken in the area of accuracy. Culway has been found to typically estimate static gross vehicle weight within $\pm 10\%$, and the individual axle weight within $\pm 15\%$ at 95% confidence limits (4). The accuracy at some sites has been found to be better than this, and at others to be worse. This level of accuracy allows Culway to meet the functional performance requirements of a TYPE 1 WIM system as defined in ASTM E 1318-94.

One of the major advantages of Culway is the fact that culverts do not seem to vibrate when a vehicle passes over them. They are totally restrained and damped by the surrounding embankment and pavement. This means that the strain measured on the roof of the culvert is simply that induced by the mass of the vehicle's wheels, and to a minor extent the dynamic load of the vehicle. The pavement also filters and dampens out high frequency vibrations. The strain signal is clean, and does not require any filtering to remove any extraneous influences. Despite this, the pavement material is adequately stiff to transmit the wheel loads to the concrete culvert. The following picture is from typical unfiltered strain response to the passage of a heavy truck.

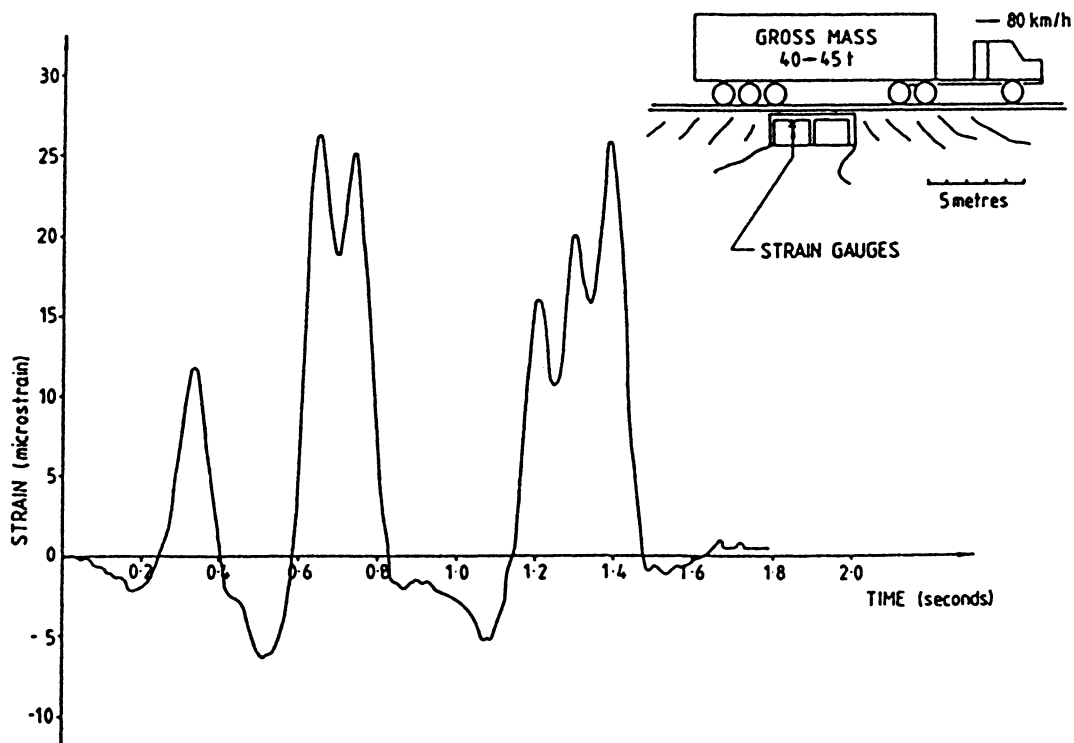


Figure 2: Typical Culway strain response for a A123 semi articulated (Peters 1986)

Another significant advantage is that Culway installations do not introduce any discontinuities into the riding surface (no expansion joints, no junctions between stiff and flexible materials, no steps) means that there is no excitation of the vehicle dynamics as a result of the weighing installation. The vehicle is truly unaware of having been weighed. This means that the only dynamic effects are those inherent to the vehicle and the normal road surface profile. When culverts were first instrumented in the formative days of Culway, the strain responses were soon seen to be very clean, making the development of an algorithm to convert the strains into mass very much simpler. The algorithm developed at that time, and still used, is described in detail later in this document

2.0 Calibration Objective

The aim of a calibration is to establish the accuracy class tolerance of the single lane Culway system, via acceptance testing procedures adopted by Pentagon Systems, and based on the E 1318 – 94 Standard specifications for Highway WIM systems specification, which was developed by the American Society for Testing and Materials (ASTM). E 1318-94 classifies WIM systems as type 1,2,3,4 according to their application. The following table shows the functional performance requirements for WIM systems.

Function	Tolerance for 95% Probability of Conformity				
	Type 1	Type 2	Type 3	Type 4 Value > Kg	Type 4 ± Kg
Wheel Load	± 25%	n/a	± 20%	2,300	100
Axle Load	± 20%	± 30%	± 15%	5,400	200
Axle-Group Load	± 15%	± 20%	± 10%	11,300	500
Gross Vehicle Weight	± 10%	± 15%	± 6%	27,200	1,100
Speed	Speed ± 2 km/h				
Axle Spacing	Axle Spacing ± 150 mm				

Table 1: Functional Performance Requirements for WIM systems

Our objective is to determine if the WIM site will meet the E1318-94 standard. Culway will easily meet Type 1 WIM system accuracies if the site is suitable and meets the minimum requirement for installation. Culway sites in most installations will meet Type 1 or Type 2 performance requirements. Only in exceptional circumstances will a Culway WIM site achieve the functional performance requirements similar of a Type 3 WIM system.

In most instances, Australian WIM owners have adopted the American E 1318-94 WIM standard as a reference to grading their WIM site accuracy. A European standard also exists (Cost 323) for Weigh in Motion system classification. This has only been mentioned to make you aware that care must be taken when comparing results from different systems that may have been classed using the alternate standard.

3.0 WimCal

WimCal (Version 2.2) is a Windows™ software application developed specifically for Culway WIM site calibration. The program replaces the earlier DOS based program cal43.exe. WimCal presents a tremendous breakthrough in the way Culway sites are calibrated mainly by automating a number of tedious tasks, which had to be performed in the past.

WimCal has a defined set of requirements in order for the procedure to work correctly. These requirements are discussed in more detail in the available user manual.

The other main advantage is the application automatically generates all calibration factors within seconds of the last calibration pass. The automated processing of calibration data provides a consistent approach to the way calibration factors are derived.

The well laid out user interface makes the task of identifying and tagging calibration vehicles extremely easy virtually eliminating any chance of mistakes being made.

The inbuilt calibration reports and summary error statistics are consistent with the previous cal43 version. WimCal makes it possible to re-process previous calibration files so that calibration factors can be derived to 6 decimal places

3.1 WimCal overview

- The application simplifies the whole calibration procedure significantly as well as virtually eliminates any chance of errors being made during the logging of reference vehicles and the analysis of calibration data.
- This package interfaces directly with the Culway hardware effectively replacing “Wimps” for the on-site element of the calibration process. All onsite paper work is eliminated as vehicles are tagged and logged directly into the application in real-time.
- Calibration factors are generated almost immediately after the last reference vehicle has made it pass.
- A number of inbuilt features within WimCal allow the calibration onsite supervisor to monitor calibration proceedings to help determine if the calibration will be successful. The real-time information made available to them will help access if the calibration should continue or be aborted due to some unforeseen problem with the site.

4.0 Site Factors

The quality of results depends largely to keeping the potential sources of variance to a minimum. In order for any WIM system to perform properly, the user must provide and maintain an adequate operating environment. Several factors that influence the performance of a Culway WIM system are in the geometric design and pavement condition of the roadway and the condition, size and construction of the culverts. These factors may influence the dynamic behaviour of the vehicle and thus influence the accuracy of the estimate of the static weight made by the WIM. The following minimum site conditions need to be in place for optimum results.

- The horizontal curvature of the roadway lane 45 m in advance of and beyond the WIM site shall have a radius not less than 1.7km measured along the centreline of the lane.
- The longitudinal gradient of the road surface for 45m in advance of and beyond the WIM site shall not exceed 2%.
- The cross slope of the road surface for 45m in advance of and beyond the WIM site shall not exceed 2%.
- ASTM states that for a distance of 46m before the first detector and after the last detector the pavement shall be maintained in such a condition that a 150mm circular plate 3mm thick cannot pass beneath a 6 meter long straight edge or and $IRI \leq 1.3$ m/km if using a laser profilometer.
- Minimum culvert size is 900 x 900, (ideal, 1200 x 1200 mm with 125 mm Lid.).
- Minimum fill height over culvert, to finished pavement level, is 600 mm.
- Culvert span width, plus twice fill depth over culvert, should fall within the range of 3 to 5 metres.
- Culvert units shall be segmented with a desirable length of 1.2 metres.
- Culverts used for drainage shall have approximately 300 mm of freeboard (based on 50 year ARI) to avoid damage to Culway equipment.
- Maximum allowable drainage culvert skew to road alignment is 10° , with a maximum permissible skew of 30° .
- The culvert is to be positioned a minimum of 200 metres beyond any bridge abutment, ramp taper or expansion joint.
- The culvert is not to be located where merging/diverging traffic would result in poor lane discipline.

- The pavement type over the culvert shall be flexible, either sealed bitumen, open grade friction coarse or chip seal (granular pavement).
- WIM location characteristics
- Pavement deflection
- Pavement surface condition (rutting, cracking, depressions, shoving, heaving, etc.).
- Vehicular characteristics
- Vehicle speed, acceleration, deceleration, body and suspension type, tyre condition, aerodynamic effects, etc. are all factors that affect the performance of WIM systems. To this effect, vehicular characteristics are interconnected with location characteristics in that installation sites and their approaches are usually chosen so as to minimise or control vehicular characteristics.
- Environmental characteristics.
- Temperature (air and road pavement).

5.0 Calibration Factors

5.1 Sensitivity

This parameter relates tonnes per raw strain count for the culvert. This value would typically range from 0.005 for a highly sensitive culvert to 0.1 for a low sensitivity culvert.

This factor is multiplied by the averaged strain count recorded from the logger to produce an axle mass.

$$A = M \times S$$

Where

A = Axle Mass (Tonnes)

M = Measured value of strain for axle

S = Sensitivity

In order to determine this factor we need to know how the culvert responds to loading. If we think of the culvert as a simply supported span, we need to measure the amount of flex (strain) in the culvert roof when it is loaded with a known mass. The following graph shows a typical relationship between recorded strain counts and static single axle weight.

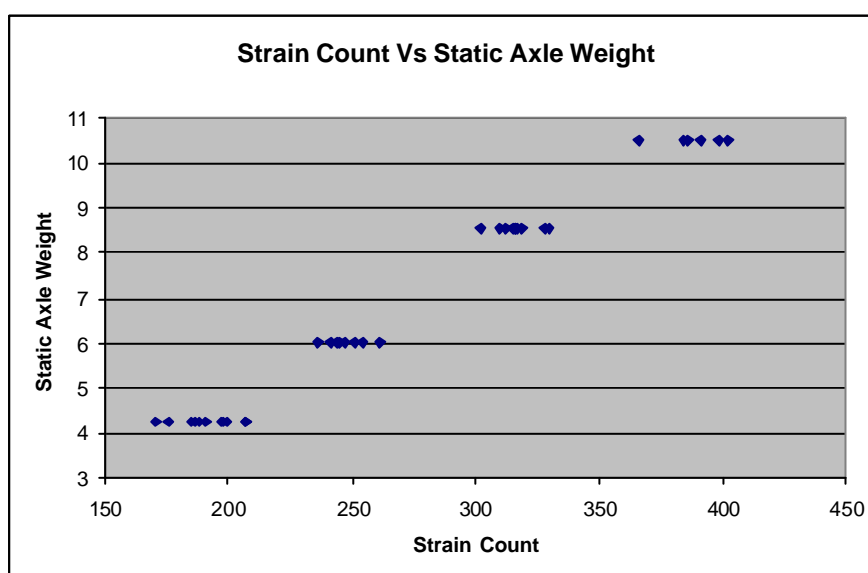


Figure 3: Strain Vs static axle weight plot

An important part of the WimCal calibration procedure is to use vehicles of single steer and single drive to make passes across site with different loads. The axle spacing for these vehicles must be greater than the *Effective Culvert Span* of the site (See page

11). This will ensure that there are no other axles on the span when measuring the amount of flex (strain). Axle spacings less than the *Effective Culvert Span* will be overweighed fractionally because of the other axles on the span.

Therefore, based on this approach for determining sensitivity WimCal only uses rigid vehicle drive axle data for this part of the analysis.

5.2 Power Factor

This is a non-linear response compensation factor. A figure of unity is used for a linear transfer response. Positive figures fractionally less than or greater than 1.0 compensate for non-linear transfer functions.

This factor was introduced because some Culway sites exhibited a non-linear response when loaded. As axle loads were increased the response from the culvert could either increase or decrease more that you expected by using simple proportions. To compensate for this non-linear response the following algorithm is used to calculate axle weight.

$$W = S \times M^{Pf}$$

<i>W</i>	<i>Axle weight</i>
<i>S</i>	<i>Sensitivity</i>
<i>M</i>	<i>Strain for the axle</i>
<i>Pf</i>	<i>Power factor</i>

The following graph illustrates a site with a non-linear response.

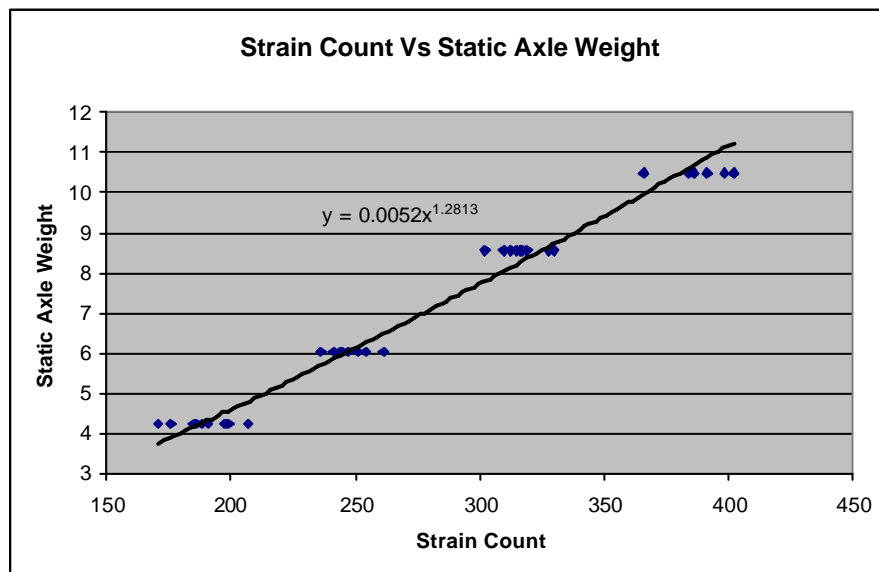


Figure 4: Strain Count Vs Static Axle Weight with power factor curve

The power factor may be determined by doing a log-log plot of the *measured axle weights* Vs *static axle weights* for rigid vehicle drive axles only. All steer axles are excluded. Initially all measured axle weights can assume a power factor of 1.0.

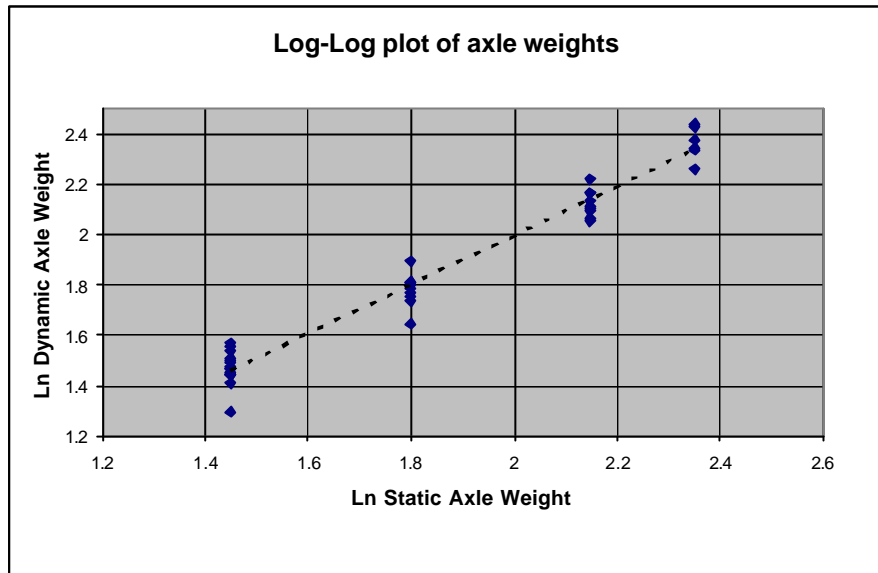


Figure 5: Log-Log plot of axle weights to derive power factor

In order to determine power factor correctly we need an absolute minimum of 3 preferably 4 differently weighted rigid R11 vehicles to make their set of passes. The above diagram shows 4 test weights were used during this calibration. The more sets of points the more accurate we can determine the power factor for a particular site.

If for some reason only 2 sets of passes were made by the rigid vehicle your line of best fit is always straight between two points therefore your power factor will always be equal to 1.0.

5.3 Unit Influence Line (UIL)

When a wheel approaches and passes over a culvert, the response from beginning to end is described as the influence line. This is the effective longitudinal culvert length. This figure is approximated to the actual culvert length plus twice the depth of fill, in metres.

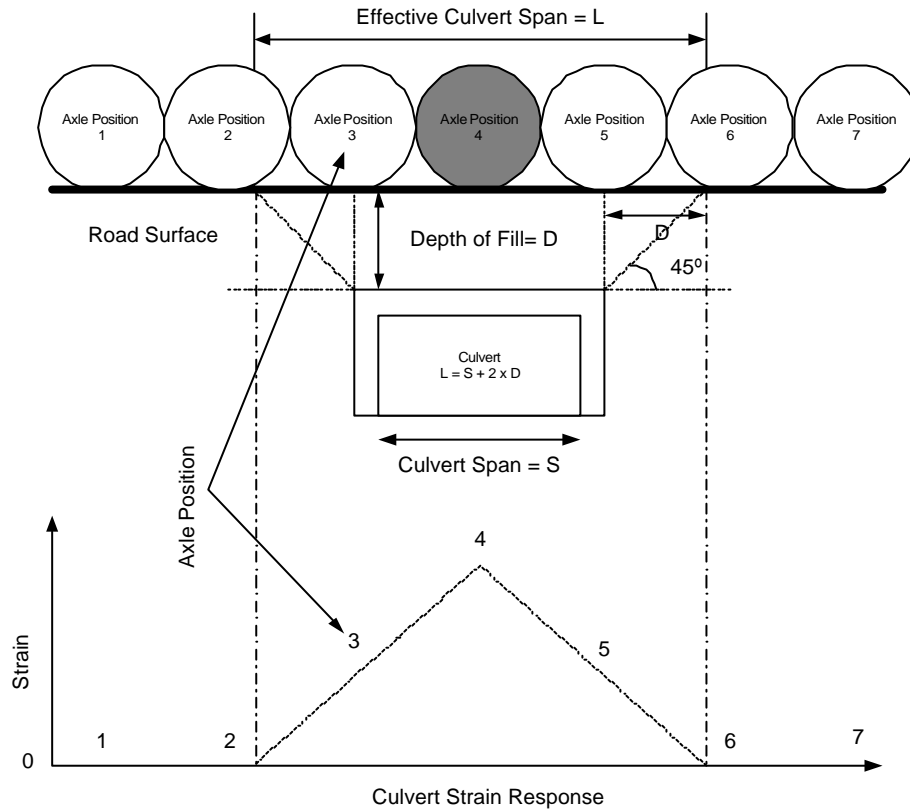


Figure 6: Culvert Response for a single axle without any mutual influence. The influence line is equal to the base of the triangle. (Peters 1986)

$$\text{Effective Culvert Span} = \text{Culvert Span} + (2 \times \text{Depth of fill})$$

This unit of length represents a distance in metres which axle group weights are adjusted to compensate for strain overlap. Any axles within a group being weighed with spacings less than the UIL will be adjusted. Any axles with spacings greater than the UIL value will not require adjustment. This can be best described in the following diagrams.

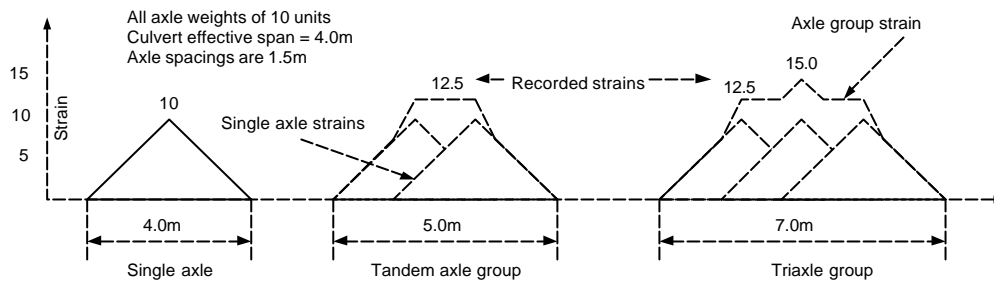


Figure 7: Strain Overlap with superposition with close axle spacings (Peters 1986)

If the axle spacing is greater than the influence length then strain overlap will be negligible since at the time one axle is being measured adjacent axles are out of the influence area. This is represented in the first part of the above figure.

When axle spacings are less than the influence length influence will occur which is referred to strain overlap. In the above diagram we stated all axle weights are equal to 10 units. Therefore the group weight for the tandem axle group should equal Axle 1 + Axle 2 = 20 units. Due to strain overlap both axles were measured with individual axle weights of 12.5 units giving us a total of 25 units. In this example the tandem axle group was overweighted by 20%. The UIL factor determined for each site is used to adjust for this error.

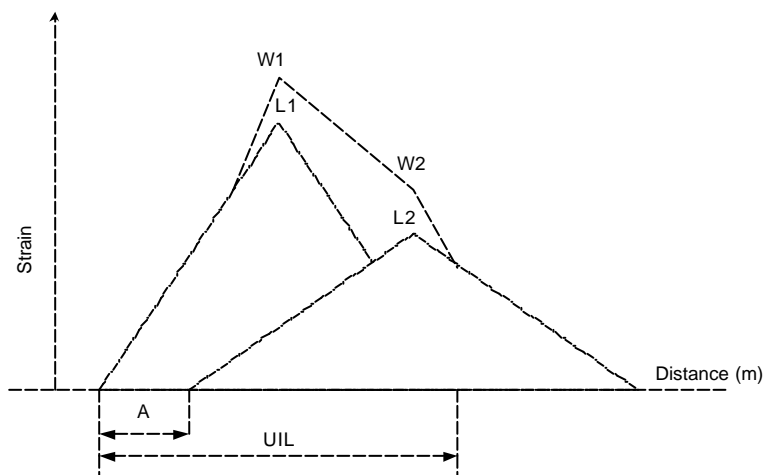


Figure 8: Diagram for Tandem group weight algorithm (Peters 1986)

$$W_1 = L_1 + \left[\frac{\left(\frac{UIL}{2} - A \right)}{\frac{UIL}{2}} \times L_2 \right]$$

** All strain reading must be converted to weight before using these algorithms.*

$$W_2 = L_2 + \left[\frac{\left(\frac{UIL}{2} - A \right)}{\frac{UIL}{2}} \times L_1 \right]$$

$$\text{Let } A = \frac{\left(\frac{UIL}{2} - A \right)}{\frac{UIL}{2}}$$

$$\Rightarrow \begin{aligned} W_1 &= L_1 + (A \times L_2) \\ W_2 &= L_2 + (A \times L_1) \end{aligned}$$

$$\Rightarrow L_2 = \frac{(A \times W_1) - W_2}{A^2 - 1}$$

$$L_1 = \frac{W_2 - L_2}{A}$$

SYMBOLS

$$W = S \times M^{Pf}$$

W	<i>Axle weight</i>
S	<i>Sensitivity</i>
M	<i>Strain for the axle</i>
Pf	<i>Power factor</i>
W₁	<i>Weight value measured for first axle</i>
W₂	<i>Weight value measured for second axle</i>
UIL	<i>unit influence line length (m) (Culvert effective span)</i>
A	<i>Axle group spread (m)</i>
L₁	<i>Weight value of first axle if second axle had not existed</i>
L₂	<i>Weight value of second axle if first axle had not existed.</i>

$$\text{Tandem Weight} = L_1 + L_2$$

Tandem group weight algorithm (Peters 1986)

*** Note**

An extension of the above procedure is used to calculate UIL compensated axle weights for axle groups with more than 2 axles.

5.4 Complex U.I.L

Structures such as pipe culverts or where a slab is cast over a number of culvert sections may result in complex influence lines. This means that strain responses from the culvert are disturbed from culvert design influences and can no longer be adjusted using triangular proportions as discussed in previous techniques.

One major factor of complex representation is significant negative influence created from other axle groups on other sections of a culvert while an axle is being weighed. This can be demonstrated in the next diagram. Because of the culvert construction it is no longer a simply supported span.

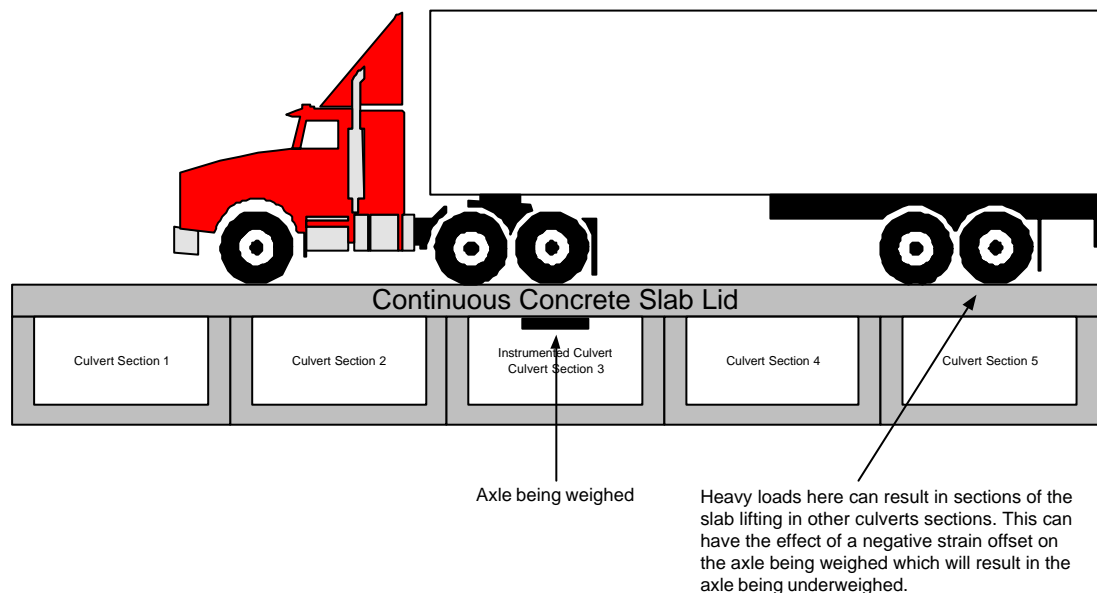


Figure 9: Negative influence on axle being weighed as a result of adjacent axles on adjacent culvert sections.

Sites which suffer from this condition can be calibrated using the current technique however the UIL factor is replaced by loading a UIL file into the Culway post processing analysis software. The UIL file is generated by performing a series of strain dumps on rigid R11 vehicles. The dumps are later processed to produce a UIL file. All other site factors remain the same as derived.

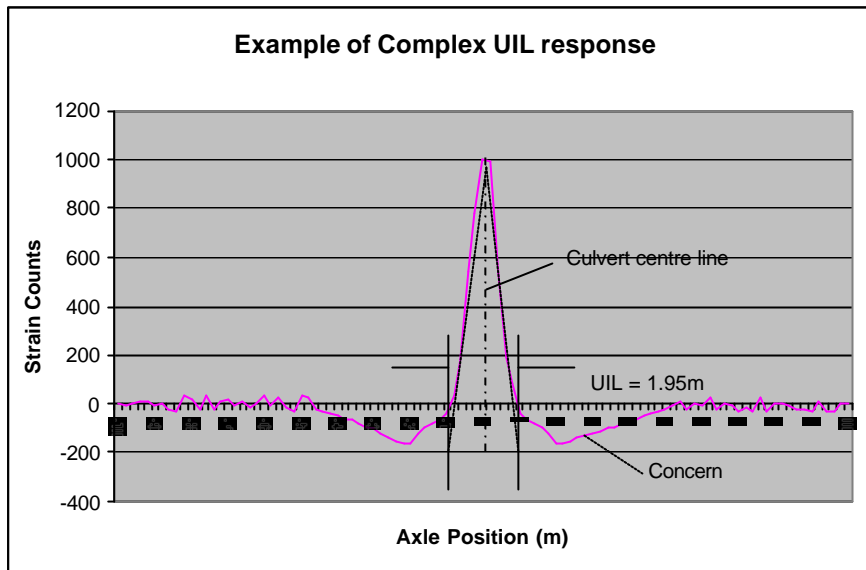


Figure 10: Example of complex UIL response

The above diagram displays the characteristics of a site with a complex UIL response. The negative strain responses marked “concern” on either side of the culvert centre line will affect accuracy when weighing axles.

Note

All calibrations should include a number strain dumps from rigid axle vehicles so that a plot as shown above can be produced and then observed to determine if there may be some complex influence.

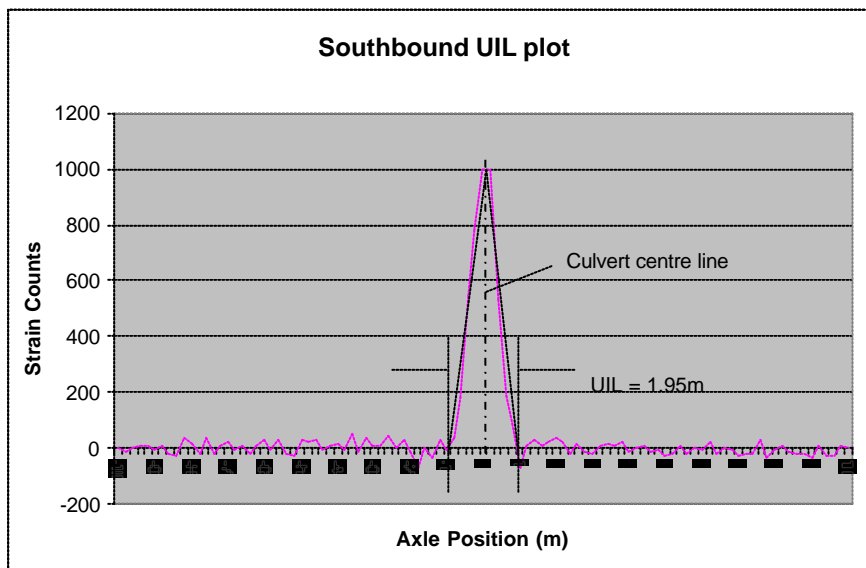


Figure 11: Shows a typical UIL plot from a site that exhibits negligible negative influences.

5.5 Steer Factor

Culway has an inherent problem with continually under weighing steer axles. Many theories have been put forward as to why, but the issue has never been resolved. The theories include:

- Smaller contact area of tyre - seems counter intuitive;
- Strain non-linearity of concrete - evidence seems to cast doubt on this; and
- Dynamic weight of steer axles is less than the static weights because of aerodynamic and torque effects.

To overcome the tendency to under weigh steer axles compared to other axle groups a new calibration factor has been added to the analysis software. The steer factor (S_f) is a value that is used to multiply the original calculated Steer Weight (SW of a single steer axle to bring the average error on steer axles close to zero. Typically the value lies between 1.0 (if steers produce similar strains to other axles) and 1.5 (if steers produce smaller strains than the equivalent weight on another axle). Values of less than 1.0 can occur if steers are overweighed. Use this formula to convert Culway strain counts to steer axle weight for single steer vehicles.

$$W = S \times M^{Pf}$$

Where:

W = Corrected axle weight

S = Sensitivity

M = Measured value of strain for the axle

Pf = Power factor

5.6 R squared

The *R-square* value is an indicator of how well the linear regression fits the data (e.g., an *R-square* close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the regression). It has been included in the WimCal reports as a numerical representation on the predictability of the data it has analysed for the rigid vehicles passes.

6.0 Conducting a Calibration

There are numerous factors to consider when conducting a calibration. They also need to be well planned and organised to ensure it will run smoothly and cause the least amount of disruption to passing motorists.

These are the items you will need to consider before, during and after the calibration to ensure it will be successful. They will be discussed in greater detail in the following passages.

1. First ensure that site is suitable before going to the expense of a full-blown calibration.
2. Have the site serviced just before the calibration.
3. Organise calibration vehicles, loading material, and loading equipment.
4. Organise Weigh Bridge or portable scales for static weighing.
5. On-site safety and traffic management
6. Organise appropriate support staff.
7. Organise tools and equipment to be used On-site.
8. Spare equipment in the event of failure.

6.1 Pre-Calibration Site Suitability Check

This is a very important and often the most ignored task in assessing site suitability. It is a fact of life that some sites are just not suited to WIM unless extensive site works are carried out to rectify any irregularities. Most of the items that can cause site related problems are well discussed throughout this document.

By carrying out these checks prior to a calibration you can feel reasonably confident that valuable time and money is not wasted trying to calibrate a bad site.

The procedure required to conduct a site suitability check falls outside the scope of this document.

6.2 Pre-Calibration Site Service

It is strongly advised that the site receive a thorough check over just prior to the calibration to ensure all systems are functioning correctly and conditions on site have not changed to a point where it will affect results. Attempting to correct faults on the

morning of a calibration can cause the budget to blow out very quickly especially when you are paying truck drivers \$300-400 per/hr just to sit around.

Some of the main items to check are:

1. To ensure that all equipment has been installed correctly.
2. To ensure that all equipment is working correctly.
3. Piezo detectors are working and interfaces have been adjusted for optimum axle detection.
4. All strain gauges are tested for a response back to the Culway terminal.
5. All cable connections are tight.
6. All Culway loggers are using latest version firmware.
7. The condition of the pavement has not deteriorated. Ideally you should not be able to feel any bumps when you drive over the site in a passenger vehicle.
8. The culvert should be inspected for cracks or excess vibration. A number of strain dumps can verify any problems.
9. The bolts attaching strain gauges to the culvert roof are tight.
10. Onsite power – 240v/ solar.
11. Culway loggers have been serviced within the last 12 months.
12. Buffer boxes have been reset if they are of the auto balance type.

6.3 When to calibrate

A number of factors need to be taken into account when you are trying to select a suitable day to calibrate. Firstly, you should avoid any calibrations if rain is forecast. Calibrations should also be postponed for a week or two to let the site dry out if it has experienced a major downpour.

Another consideration would be to calibrate sites around the same time each year to minimise the effects of seasonal drift especially if the particular site suffers from this. Some sites tend to drift more than others primarily in locations that experience large temperature variations.

The best time of the day to conduct a calibration is when traffic levels are at their lowest. The passage of a calibration vehicle across the site must be unimpeded and allowed to travel across the site at a constant speed without having to avoid other

vehicles. Another factor is that calibration vehicles can be overweighed if the traffic is sufficient in adjacent lanes. Culway by design cannot disseminate loading from one lane to another. If another vehicle happens to be on the culvert at the same time, some of the loading it creates on the culvert will filter across to the other lane. If the amount of traffic is a concern then a time during the middle of the day may be more suitable.

6.4 Calibration Checklist

Item No	Equipment	Details
2	Laptop Computers	Refer to WimCal specification, ensure Wimps and piezo talker are also installed for Culway set-up.
1	Software	Suitable software for processing and analysing strain dumps. i.e. culview.exe and MS excel or similar
2	Comms Cables	Used to connect laptop to Culway logger
2	40ch UHF radios	Used to communicate with truck drivers
1	Assorted Tools	Tools required to service Culway equipment inc MSA
1	Generator	If 240v is not available for powering laptops for a minimum of 5.0 hrs
1	Equipment stand	Suitable table/stand for supporting laptops on site
1	20m tape	Used for measuring axle spacings for all calibration vehicles
2	Floppy disks	Backup of calibration data
1	Safety equipment	All onsite staff must abide by appropriate safety standards
1	Camera	Taking site photos for verification
1	Spare Culway Logger	Backup
2	Spare MSA + Buffer box	Backup
1	Spare Piezo or treadle interface	Backup
2	MSA leads	Spare leads between buffer box and MSA
2	Axle detectors	Spare surface mount detectors that can be installed immediately if required.
1	Bitumen tape	To hold down detectors
1	Mobile phone	Emergency communications

Table 2: Equipment checklist for calibration

7.0 Safety Requirements

7.1 Traffic Management

As with any on-site road side activities the calibration contractor must provide traffic management in accordance with Australia Standards AS1742.3-1996: Manual of Uniform Traffic Control Devices, Part 3: Traffic Control Devices for Works on Roads and associated field guides.

When out of the vehicle, employees shall wear their safety jackets fastened at the front at all times and arrange their work in a manner that minimises the danger to themselves and other road users and has the least disruption to traffic.

All survey and support vehicles shall be equipped with operational warning devices and appropriate signing in accordance with AS 1742.3 Manual of Uniform Traffic Control Devices and HB81.3 Field Guide for Traffic Control at Works on Roads, Part 3: Mobile Works. These devices must be fully operational at all times when data collection is being undertaken.

Particular attention should also be given to parking of the vehicle during fieldwork to avoid creating any form of safety hazard - preferably well clear of the roadway (particularly on rural roads). It is illegal to park or stand a vehicle facing the on-coming traffic on the opposing side of the roadway. The vehicle must be fitted with clearly visible roof mounted rotating amber lights. Consideration should also be given to the use of the vehicles hazard lights.

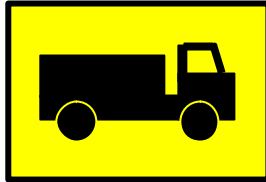
Rotating amber lights must be used whenever the vehicle is parked on the roadway. Furthermore, if the roadway is restricted by the activities of personnel for periods exceeding five minutes the rotating amber lights must be activated and warning devices/signs placed as per AS1742.3 Part 3.

7.2 Calibration vehicle safety

All vehicles associated with the On-site calibration activities must abide by the state traffic laws.

Calibration vehicles must ensure that appropriate turning points are selected in highly visible areas for approaching traffic. If calibration vehicles do not have safe areas to turn trucks around (parking bays or ring routes through side roads) then U-turns will be permitted. However, this does not include 3-point turns or any other combination of such. A U-turn may only be undertaken if:

- The turning truck has sufficient sight distance (at least 500 metres).
- The truck is fitted with roof mounted rotating amber light that must be activated each time the vehicle is undertaking a U-turn.
- An advance warning sign (Trucks Crossing or entering, symbolic sign T2-25) must be used where trucks are frequently creating a potential hazard. The sign should be displayed only when the need exists and removed when truck activity has ceased.



Trucks Crossing or entering (symbolic sign T2-25)

8.0 Selecting Test Vehicles

In order to use WimCal successfully you must ensure that the following requirements are met when calibration vehicles are selected.

- A minimum of two vehicles types must be organised for the calibration.
- First vehicle must be a Rigid with single steer and single drive *only*.
- Axle spacing of this vehicle must be greater than the effective Culway span for the site. This can be calculated by the following equation.

$$\text{Effective Culvert Span} = \text{Culvert Span} + (2 \times \text{Depth of fill})$$

- Rigid vehicle must have a GVM (gross vehicle mass) of at least 15 tonnes. (This will allow the rear axle to be loaded to at least legal limit.
- Must be capable of being loaded to GVM.
- Vehicle and suspension must be in good condition.
- Leaf sprung suspension is preferred.
- Must be suited to carry the arranged loading material.



Figure 12: Example of a suitable rigid vehicle

- The second vehicle *must* be a Semi-Articulated A123 vehicle.
- *Must* have a single steer axle only.

- **Must** have a tandem drive axle only.
- **Must** have tri-axle group trailer only.
- **Must** be suited to carry the arranged loading material.
- **Must** be rated to carry GVM of 42.5 tonnes.
- Vehicle and suspension must be in good condition



Figure 13: Example of a suitable semi articulated vehicle A123

8.1 Suspension Air Vs Spring

Some time ago the theory was always to use leaf sprung suspension on calibration vehicles only. Vehicles with these suspension configurations are becoming difficult to source, as air bag suspension has become the predominant configuration on our roads.

Type of suspension greatly affects WIM data. Air suspensions are more likely to distribute the load equally between the axles within a tandem set when the truck is accelerating than will steel-leaf springs. When the truck is braking, the variation in load distribution between axles of the tandem and between tandem and steering axle is much larger for air-suspension systems than for steel-leaf suspension systems. Why is there such a difference between air-suspension and steel-leaf spring systems?

- Steel-leaf springs are rigidly attached to the frame.
- Air-suspensions involve a rubber bag mounted to the frame and axle. When the force vector is well above the elevation of the fifth-wheel, as is the case for a fully loaded truck, the rubber bag will stretch vertically and will cause some "lifting" of the load off the axle.

- The rigidity of the steel leaf-spring suspension system reduces the "lifting" of the load off the axles.

Due to changing vehicle designs over the years the approach these days is to use calibration vehicles fitted with whatever is the prominent suspension configuration for that vehicle type.

8.2 Test Vehicle Loading

Loading is a trial and error process requiring several static weighing before optimum load coverage is achieved. In order to determine the true accuracy of any site a calibration should be performed by loading all test vehicles to specific weights that cover the full load spectrum of the site. This will ensure that accurate error statistics can be determined for unloaded to fully loaded vehicles.

The rigid vehicle should be loaded to the following approximate weights;

1. **Empty**
2. **1/3 loaded**
3. **2/3 loaded**
4. **Full**

The semi should be loaded to the following approximate weights;

1. **Empty**
2. **1/2 loaded**
3. **Full**

Vehicle ID	Axle Config	Type	Grp1Wt	Grp2Wt	Grp3Wt	GVM
1	11	Rigid	3.66	4.26		7.92
2	11	Rigid	3.94	6.04		9.98
3	11	Rigid	4.44	8.56		13.00
4	11	Rigid	5.44	10.5		15.94
5	123	Semi	4.44	17.44	23.56	45.44
6	123	Semi	4.56	11.72	14.28	30.56
7	123	Semi	4.66	6.72	6.98	18.36

Table 3: Charts shows typical loading details using semi and rigid vehicle

The figures that have been provided are only a guide to give you a better understanding of what is required. It is important that every attempt is made to distribute the loading evenly for each vehicle. In the above example you will notice that the weights on the drive axle for the rigid vehicle go up in approximately 2 ton increments.

Experience has shown that 7 sets of passes (4 from the rigid and 3 from the semi) are adequate in achieving good calibration results were sites are suitable. If time and resources permit more sets of passes can be made using different weights.

8.3 Loading material

The type of loading material to use depends largely on the resources that may be available at the time within the local area.

Materials can consist of road base, gravel, concrete blocks, steel blocks etc to name a few. The options available are too numerous to list and too a large part will be dependent on what is available within a reasonable distance to the site. Water tankers or any liquid loads must be avoided as calibration vehicles due to the amount of movement in the load.

These details will need to be addressed irrespective of the loading material.

- Loading material must not move while vehicle is making calibration runs. If the load is suspected of moving the vehicle should be re-weighed immediately.
- All solid loads should be secured firmly.
- Loads with loose soil particles should be covered.
- Loads should be covered in the event of light rain.
- Suitable equipment is on hand for the loading and unloading of respective materials.
- Calibration vehicles must be suitable to carry the selected load.



Figure 14: One method is to use a forklift to load steel blocks

8.4 Static weighing calibration vehicles

The recording of static weights is probably the most important aspect to any calibration. Any inaccuracies occurring at this point could easily result in a poor calibration that would need to be repeated.

WimCal requires all axle groups to be weighed individually for each test vehicle.

There are basically two methods that are used for this task

1. Use of a certified weighbridge capable of split weighing axles.
2. Use of portable scales (*conditions apply*).

Certainly the most preferred option is to use a certified weighbridge. There is very little chance of error occurring, which can ruin the calibration. Unfortunately, weighbridges are not all that common and the nearest one may be some distance from the site. The second option is to use portable scales. Extreme care must be taken if using this method as these scales can give very inaccurate results if not used properly in a controlled environment. The following items need to be considered to ensure accurate results.

When you split weigh axle groups on any weighbridge it is most important that approaches leading too and from the bridge are flat, otherwise inaccuracies will result. The following procedure should be used when split weighing axles.

- Run the steer axles of vehicles onto the bridge and take reading. (Ensure driver is off the brakes).
- Gross weigh the rigid vehicle. Weigh tandem drive + steer for the semi articulated.
- Place steer axle of rigid on bridge and weigh drive axle only. Gross weigh semi articulated.
- Drive steer of semi articulated off weighbridge and weigh.
- Drive steer + tandem drive of semi off bridge and weigh tri-axle group only.

By following an approach similar to this you get to cross check your results and you get to see if the weighbridge is giving repeatable results.



Figure 15: Sample of a full-length weighbridge



Figure 16: Sample of a full length weigh bridge capable of split weighing axles accurately due to the long flat approach.

Portable scales should only be used if no other means are available for weighing the calibration vehicles. The accuracy of these devices depends largely on how level the surface is around the area you plan to use them. A guide to weighing vehicles using portable scales is available from Austroads otherwise refer to the manufacturer's literature.

1. Portable scales must have a certification tag.
2. The site you intend to use must not have a gradient greater than 2%.
3. An absolute minimum of 2 scales are needed, 6 scales would be preferable as it allows each all axles within a group to be weighed simultaneous (i.e. tri-axle group), ideally 12 scales would allow you to weigh the complete semi articulated vehicle in one step for better accuracy.
4. If using less than 6 scales either mats or blocks must be used to keep the axle group level with the surface when sufficient scales are not available.
5. Ensure driver is off the brakes as this can cause some undesirable weight transfers to occur to other axle groups that are not being weighed at the time.



Figure 17: This photo shows 6 scales being used to weigh the steer and tandem drive axles together. Once these axles have been weighed the vehicle is moved and scales are repositioned to weigh the tri-axle group.



Figure 18: Rigid vehicle being weighed with portable scales

If access to a suitable weighbridge is not possible one alternative is to pre weigh the entire calibration vehicle fleet with their various loads in advance. This will only work if you are using steel blocks (as a load), which can be positioned very accurately on the tray. The blocks positions can be recorded for the designated load and the vehicle can be weighed with a known amount of fuel.

When it comes time to carry out the calibration runs on site the driver can load the vehicle based on the recorded configurations. The weights should be identical as long as the fuel quantity in the truck is similar to when the vehicle was originally weighed.

9.0 Calibration passes

An important characteristic of any good WIM site is to obtain consistent repeatable results. The main objective of making multiple passes using the same vehicle at the same weight is to determine the repeatability of recorded dynamic weights. All calibration vehicles should perform a minimum of 5 passes at each of the designated weights. More passes may be required if a site is experiencing poor repeatability which in most cases is a result of a poor pavement surface. The calibration supervisor should try to get as many passes as possible in the time available.

Sites that show a significant amount of variance in the data should allow for more passes at varying speeds. The variance or spread of data can usually be attributed to the condition and the smoothness of the pavement.

WimCal has a feature that can display the recorded strain counts for rigid vehicle drive axle in real time to help the supervisor determine approximately the repeatability of the site. The supervisor should be looking for tightly bunched points at each of the designated weights. More passes should be made at sites where the points are more scattered ($\pm 15\%$ of each other)

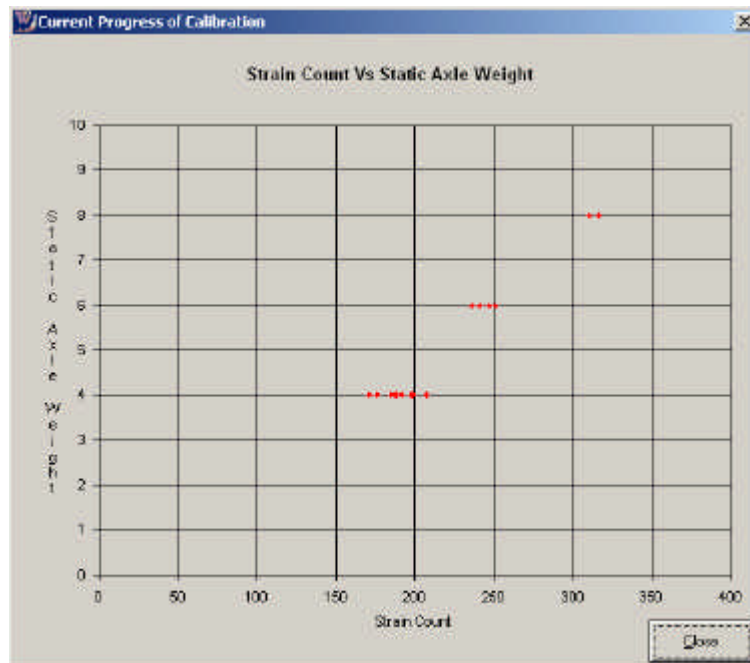


Figure 19: Variance in strain Vs static axle weight plot

Most if not all Culway operators these days do not bother to collect additional data to calibrate for lateral position. There are a number of reasons why this has occurred:

1. The extra cost associated with hardware i.e. piezo detectors, piezo interfaces.
2. Higher site maintenance costs.
3. Increased risk to pavement damage as a result of cutting additional slots especially in already thin chip seal pavements.
4. The additional effort and cost required during a calibration.
5. The lack of available software capable of utilising this additional variable.

There is no doubt that the accuracy of a vehicle being weighed at a Culway WIM site can be affected by its lateral position in the lane. Many tests have been carried out in the past proved this, but the reality is that the cost benefits of applying this method to Culway are not viable. Many people feel that the money would be better spent improving the site and forcing drivers to sit in the middle of the lane by improving line markings, adding audible line marking, adding centreline reflectors (fish eyes) and improved signage to alter driver behaviour.

Calibration vehicles drivers are therefore asked to use existing wear patterns on the pavement as a positioning guide when making their passes across the culvert.

Culway has proved over time that speed should not be an influencing factor at sites that have perfectly smooth flat pavements. Speed only becomes a factor when pavements are rough which causes exaggerated axle hop across the culvert resulting in strain data with impact factors. At sites where pavement condition is average calibration vehicle drivers should vary their speed by +/- 10% of the signed highway speed.

9.1 Calibration using live traffic

There is a possibility of using live traffic to calibrate a WIM site if a facility is available to intercept and weigh passing traffic across a Culway site within 3% accuracy. WimCal would still require the four sets of passes by a rigid type vehicle for determining sensitivity and power factors accurately. Most rural sites would not see many R11 vehicles of this type with a varying assortment of loads, so it would be necessary to hire this vehicle. A number of articulated semi trailers could be selected from the live traffic stream for the remainder of passes.

10.0 Interpretation of Results

Although WimCal has removed one of the most difficult tasks of analysing all the calibration data in order to derive a set of calibration factors, an amount of experience is still required to assess the quality and the consistency of the site. WimCal produces a number of reports, which help determine this. Our main objective in all calibrations is to derive a set of suitable calibration factors that reflect the physical and dynamic characteristics of the site. Our second objective is to determine that the site meets a defined functional performance requirement as stated in ASTM E 1318-94.

Function	Tolerance for 95% Probability of Conformity				
	Type 1	Type 2	Type 3	Type 4 Value > Kg	Type 4 ± Kg
Wheel Load	± 25%	n/a	± 20%	2,300	100
Axle Load	± 20%	± 30%	± 15%	5,400	200
Axle-Group Load	± 15%	± 20%	± 10%	11,300	500
Gross Vehicle Weight	± 10%	± 15%	± 6%	27,200	1,100
Speed	Speed ± 2 km/h				
Axle Spacing	Axle Spacing ± 150 mm				

Table 4: Functional Performance Requirements for WIM systems

The standard states that only 95% (2 standard deviations) of the total calibration passes collected need to be part of the overall accuracy assessment.

WimCal produces a summary error statistics report that essentially tells you everything you need to know about the performance requirements of the site.

The following table relates definitions between the E1318-94 standard and the WimCal summary error report.

E 1318 -94 definitions	WimCal summary report definitions
Wheel Load	1Steer
Axle Load	Single
Axle-Group Load	Tandem
Axle-Group Load	Triaxle
Axle-Group Load	Quad
Gross Vehicle Weight	Gross

Table 5: Definition mapping

10.1 Summary error statistics

Summary statistics for each axle group

	1Steer	2Steer	Single	Tandem	Triaxle	Quad	Gross	Gross
Min Error =	-8.48%	0.00%	-11.65%	-1.26%	-8.83%	0.00%	-8.03%	-1.46t
Max Error =	17.70%	0.00%	12.86%	10.48%	14.39%	0.00%	7.59%	3.30t
Avg Error =	0.00%	0.00%	0.16%	4.01%	-0.10%	0.00%	-0.01%	0.17t
Std Error =	6.76%	0.00%	5.73%	3.57%	6.21%	0.00%	4.15%	0.90t
No. =	59	0	35	24	24	0	59	

Table 6: Sample summary statistics error report

- Min Error (The minimum error calculated for the particular axle group).
- Max Error (The maximum error calculated for the particular axle group).
- Avg Error (Arithmetic mean of all errors for the particular axle group).
- Standard deviation for the particular axle group.
- Total axle count for the particular axle group.

By comparing the results obtained from the WimCal report against the functional performance requirements of E-1318-94 you can access whether the site meets a Type 1 classification.

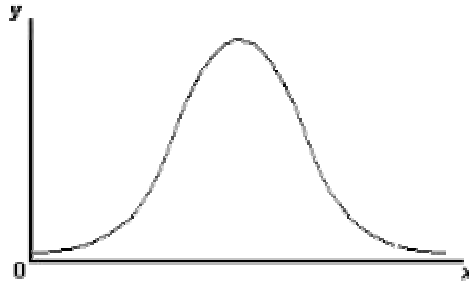
10.2 Standard Error

Otherwise referred to as the standard deviation, is a measure of how widely values are dispersed from the average value (the mean).

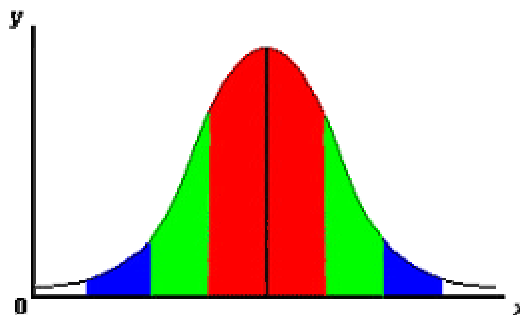
$$\sqrt{\frac{n \sum x^2 - (\sum x)^2}{n^2}}$$

The standard deviation is kind of the "mean of the mean," and often can help you find the story behind the data.

A normal distribution of data means that most of the examples in a set of data are close to the "average," while relatively few examples tend to one extreme or the other. If you looked at normally distributed data on a graph, it would look something like this:



The **standard deviation** is a statistic that tells you how tightly all the various examples are clustered around the mean in a set of data. When the examples are pretty tightly bunched together and the bell-shaped curve is steep, the standard deviation is small. When the examples are spread apart and the bell curve is relatively flat, that tells you have a relatively large standard deviation. Computing the value of a standard deviation is complicated. But let me show you graphically what a standard deviation represents...



One standard deviation away from the mean in either direction on the horizontal axis (the red area on the above graph) accounts for somewhere around 68 percent of the people in this group. Two standard deviations away from the mean (the red and green areas) account for roughly 95 percent of the people. And three standard deviations (the red, green and blue areas) account for about 99 percent of the people. If this curve were flatter and more spread out, the standard deviation would have to be larger in order to account for those 68 percent or so of the people. So that's why the standard deviation can tell you how spread out the examples in a set are from the mean.

11.0 WimCal Reports

During the automated analysis WimCal produces two files as part of the reporting phase. These files have *.cal extension and a *.crp extension.

The file with the *.cal extension contains all data about the static weight data which was entered into WimCal during the course of the calibration. The file also contains all logged calibration data that has been translated from Culway vehicle record form into a format that WimCal uses for data analysis

11.1 Sample *.cal file

*CULWAY CALIBRATION DATA

*Site - B,L

*Generated at 04:07:02 pm on Thursday February 28, 2002.

*Calibration Vehicle Data

*ID Conf Type	Grp1Wt	Grp2Wt	Grp3Wt	Grp4Wt	Grp5Wt
# 1 0202 11	3.66	4.26			
# 2 0202 11	3.94	6.04			
# 3 0202 11	4.44	8.56			
# 4 0202 11	5.44	10.50			
# 5 0603 123	4.44	17.44	23.56		
# 6 0603 123	4.56	11.72	14.28		
# 7 0603 123	4.66	6.72	6.98		

Static vehicle weight detail with corresponding vehicle ID tags.

*Calibration Vehicle Records

*Date	Time	ID Conf	Type										
\$020228	0930:05	1 0202 11	124	6.06	207								
\$020228	0933:41	1 0202 11	138	6.11	198								
\$020228	0943:38	1 0202 11	127	6.11	176								
\$020228	1018:00	1 0202 11	129	6.02	197								
\$020228	1023:25	1 0202 11	123	6.04	207								
\$020228	1029:06	1 0202 11	127	6.10	171								
\$020228	1143:52	2 0202 11	129	6.10	241								
\$020228	1149:32	2 0202 11	133	6.10	261								
\$020228	1155:05	2 0202 11	128	6.08	251								
\$020228	1200:21	2 0202 11	132	6.05	247								
\$020228	1319:26	3 0202 11	143	6.10	310								
\$020228	1325:49	3 0202 11	145	6.06	316								
\$020228	1331:44	3 0202 11	144	6.11	312								
\$020228	1404:36	3 0202 11	146	6.10	315								
\$020228	1411:56	3 0202 11	143	6.06	302								
\$020228	1420:23	3 0202 11	145	6.15	319								
\$020228	1457:34	4 0202 11	173	6.09	398								
\$020228	1537:00	4 0202 11	184	6.06	391								
\$020228	1520:03	4 0202 11	184	6.05	402								
\$020228	1528:59	4 0202 11	185	6.06	386								
\$020228	0922:28	5 0603 123	154	4.38	342	1.29	344	7.31	351	1.24	328	1.24	264
\$020228	0932:13	5 0603 123	156	4.39	346	1.28	347	7.35	369	1.22	332	1.22	273
\$020228	1029:35	5 0603 123	154	4.37	342	1.30	350	7.32	397	1.21	330	1.26	271
\$020228	1224:08	6 0603 123	159	4.34	255	1.33	260	7.30	263	1.24	224	1.24	170
\$020228	1327:47	7 0603 123	154	4.35	165	1.30	166	7.31	135	1.23	115	1.26	100
\$020228	1357:38	7 0603 123	159	4.40	179	1.29	165	7.32	170	1.24	123	1.24	098
\$020228	1405:39	7 0603 123	171	4.36	174	1.26	158	7.31	154	1.22	122	1.26	112
\$020228	1414:24	7 0603 123	147	4.40	165	1.29	153	7.32	164	1.24	127	1.24	104

Rigid axle calibration records
Date, Time, VehicleID, Axle configuration,
Steer strain count reading, axle spacing (m),
drive strain count reading.

Semi trailer calibration records

Date, Time, VehicleID, Axle configuration

Steer strain count reading, axle spacing (m), 1st tandem strain count reading, Axle spacing, 2nd tandem strain reading, Axle spacing, 1st tri-axle strain reading etc.

11.2 Sample *.crp file

Site - B

Generated at
08:40:18 pm on
Monday April 01,
2002.

Calibration Vehicle
Data

ID	Conf	Type	Grp1Wt	Grp2Wt	Grp3Wt
1	202	11	3.66	4.26	
2	202	11	3.94	6.04	
3	202	11	4.44	8.56	
4	202	11	5.44	10.5	
5	603	123	4.44	17.44	23.56
6	603	123	4.56	11.72	14.28
7	603	123	4.66	6.72	6.98

Vehicle Static Weights

Calibration Factors

Sensitivity = 0.005181
Power Factor = 1.281313
Unit Influence = 2.623069
Steer Constant = 1.386332
R Squared = 0.973434

Calibration Factors

Error Statistics

	1Steer	2Steer	Single	Tandem	Triaxle	Quad	Gross	Gross
Min Error =	-8.63%	0.00%	-11.65%	-7.03%	-16.87%	0.00%	-9.19%	-2.81t
Max Error =	17.52%	0.00%	12.86%	11.07%	15.09%	0.00%	8.03%	3.56t
Avg Error =	0.00%	0.00%	0.16%	4.10%	-0.17%	0.00%	0.00%	0.18t
Std Error =	6.80%	0.00%	5.73%	4.22%	7.04%	0.00%	4.39%	1.02t
No. =	60	0	35	25	25	0	60	

Summary Error Statistics

Date	Time	ID	Culway Weight	Static Weight	Error	Culway Weight	Static Weight	Error	Culway Weight	Static Weight	Error	Err(t)
20228	930:05:00	1	3.46	3.66	-5.56%	4.81	4.26	12.86%	8.26	7.92	4.35%	0.34
20228	933:41:00	1	3.96	3.66	8.32%	4.54	4.26	6.61%	8.51	7.92	7.40%	0.59
20228	943:38:00	1	3.56	3.66	-2.62%	3.91	4.26	-8.33%	7.47	7.92	-5.69%	-0.45
20228	948:50:00	1	3.42	3.66	-6.53%	4.34	4.26	1.80%	7.76	7.92	-2.05%	-0.16
20228	954:41:00	1	3.35	3.66	-8.48%	4.19	4.26	-1.60%	7.54	7.92	-4.78%	-0.38
20228	1000:00:00	1	3.42	3.66	-6.53%	4.57	4.26	7.30%	7.99	7.92	0.91%	0.07
20228	1006:03:00	1	3.42	3.66	-6.53%	4.25	4.26	-0.24%	7.67	7.92	-3.15%	-0.25
20228	1011:44:00	1	3.39	3.66	-7.51%	4.16	4.26	-2.28%	7.55	7.92	-4.69%	-0.37
20228	1018:00:00	1	3.64	3.66	-0.65%	4.51	4.26	5.92%	8.15	7.92	2.88%	0.23
20228	1023:25:00	1	3.42	3.66	-6.53%	4.81	4.26	12.86%	8.23	7.92	3.90%	0.31
20228	1029:06:00	1	3.56	3.66	-2.62%	3.76	4.26	-11.65%	7.33	7.92	-7.48%	-0.59
20228	1143:52:00	2	3.64	3.94	-7.71%	5.84	6.04	-3.28%	9.48	9.98	-5.03%	-0.5
20228	1149:32:00	2	3.78	3.94	-4.03%	6.47	6.04	7.12%	10.25	9.98	2.72%	0.27
20228	1155:05:00	2	3.6	3.94	-8.63%	6.15	6.04	1.89%	9.75	9.98	-2.26%	-0.23
20228	1200:21:00	2	3.74	3.94	-4.95%	6.03	6.04	-0.18%	9.77	9.98	-2.07%	-0.21
20228	1205:44:00	2	3.64	3.94	-7.71%	5.94	6.04	-1.73%	9.57	9.98	-4.09%	-0.41
20228	1211:57:00	2	3.89	3.94	-1.25%	5.69	6.04	-5.84%	9.58	9.98	-4.03%	-0.4
20228	1217:11:00	2	3.64	3.94	-7.71%	5.97	6.04	-1.22%	9.6	9.98	-3.78%	-0.38
20228	1222:38:00	2	3.89	3.94	-1.25%	6.25	6.04	3.46%	10.14	9.98	1.60%	0.16
20228	1319:26:00	3	4.15	4.44	-6.55%	8.07	8.56	-5.77%	12.22	13	-6.03%	-0.78
20228	1325:49:00	3	4.22	4.44	-4.87%	8.27	8.56	-3.43%	12.49	13	-3.92%	-0.51
20228	1331:44:00	3	4.19	4.44	-5.71%	8.13	8.56	-4.99%	12.32	13	-5.24%	-0.68
20228	1337:48:00	3	4.11	4.44	-7.38%	8.74	8.56	2.09%	12.85	13	-1.15%	-0.15
20228	1343:32:00	3	4.41	4.44	-0.65%	8.3	8.56	-3.03%	12.71	13	-2.22%	-0.29
20228	1350:32:00	3	4.41	4.44	-0.65%	8.67	8.56	1.30%	13.08	13	0.63%	0.08
20228	1357:22:00	3	4.3	4.44	-3.18%	8.27	8.56	-3.43%	12.57	13	-3.34%	-0.43
20228	1404:36:00	3	4.26	4.44	-4.03%	8.23	8.56	-3.82%	12.49	13	-3.89%	-0.51
20228	1411:56:00	3	4.15	4.44	-6.55%	7.8	8.56	-8.87%	11.95	13	-8.08%	-1.05
20228	1420:23:00	3	4.22	4.44	-4.87%	8.37	8.56	-2.25%	12.59	13	-3.14%	-0.41
20228	1457:34:00	4	5.3	5.44	-2.65%	11.11	10.5	5.81%	16.41	15.94	2.92%	0.47
20228	1505:26:00	4	5.53	5.44	1.70%	9.98	10.5	-4.97%	15.51	15.94	-2.69%	-0.43
20228	1512:45:00	4	5.37	5.44	-1.20%	10.61	10.5	1.06%	15.99	15.94	0.29%	0.05
20228	1520:03:00	4	5.73	5.44	5.36%	11.25	10.5	7.17%	16.98	15.94	6.55%	1.04
20228	1528:59:00	4	5.77	5.44	6.09%	10.68	10.5	1.74%	16.45	15.94	3.22%	0.51
20228	1537:00:00	4	5.73	5.44	5.36%	10.86	10.5	3.43%	16.59	15.94	4.09%	0.65

20228	922:28:00	5	4.56	4.44	2.76%	18.07	17.44	3.60%	23.01	23.56	-2.33%	45.64	45.44	0.45%	0.2
20228	932:13:00	5	4.64	4.44	4.48%	18.17	17.44	4.18%	23.56	23.56	0.01%	46.37	45.44	2.05%	0.93
20228	943:11:00	5	4.91	4.44	10.52%	17.94	17.44	2.84%	23.24	23.56	-1.35%	46.09	45.44	1.42%	0.65
20228	952:56:00	5	5.18	4.44	16.64%	18.75	17.44	7.51%	23.53	23.56	-0.15%	47.45	45.44	4.43%	2.01
20228	1001:20:00	5	4.79	4.44	7.92%	17.83	17.44	2.25%	23.65	23.56	0.39%	46.28	45.44	1.84%	0.84
20228	1009:15:00	5	5.22	4.44	17.52%	18.91	17.44	8.40%	24.12	23.56	2.36%	48.24	45.44	6.16%	2.8
20228	1021:05:00	5	4.91	4.44	10.52%	18.31	17.44	4.98%	23.73	23.56	0.71%	46.94	45.44	3.31%	1.5
20228	1029:35:00	5	4.56	4.44	2.76%	18.41	17.44	5.56%	24.64	23.56	4.59%	47.61	45.44	4.78%	2.17
20228	1038:56:00	5	4.83	4.44	8.79%	18.93	17.44	8.57%	25.23	23.56	7.09%	49	45.44	7.82%	3.56
20228	1149:26:00	6	4.49	4.56	-1.60%	11.64	11.72	-0.71%	13.81	14.28	-3.32%	29.93	30.56	-2.07%	-0.63
20228	1157:28:00	6	4.34	4.56	-4.91%	11.8	11.72	0.67%	13.1	14.28	-8.25%	29.24	30.56	-4.33%	-1.32
20228	1204:24:00	6	4.72	4.56	3.40%	11.67	11.72	-0.46%	13.52	14.28	-5.29%	29.91	30.56	-2.14%	-0.65
20228	1212:29:00	6	4.98	4.56	9.31%	10.9	11.72	-7.03%	11.87	14.28	-16.87%	27.75	30.56	-9.19%	-2.81
20228	1218:45:00	6	4.68	4.56	2.56%	11.66	11.72	-0.49%	13.14	14.28	-7.98%	29.48	30.56	-3.54%	-1.08
20228	1224:08:00	6	4.75	4.56	4.24%	12.9	11.72	10.07%	14.53	14.28	1.78%	32.19	30.56	5.33%	1.63
20228	1231:26:00	6	4.83	4.56	5.92%	11.81	11.72	0.80%	13.8	14.28	-3.39%	30.44	30.56	-0.40%	-0.12
20228	1238:41:00	6	5.14	4.56	12.71%	12.89	11.72	10.02%	13.73	14.28	-3.82%	31.77	30.56	3.95%	1.21
20228	1244:14:00	6	4.91	4.56	7.61%	12.01	11.72	2.50%	13.29	14.28	-6.94%	30.21	30.56	-1.15%	-0.35
20228	1327:47:00	7	4.56	4.66	-2.09%	7.16	6.72	6.48%	6.49	6.98	-6.95%	18.21	18.36	-0.80%	-0.15
20228	1334:01:00	7	4.41	4.66	-5.34%	7.18	6.72	6.90%	7.74	6.98	10.87%	19.33	18.36	5.30%	0.97
20228	1339:40:00	7	4.83	4.66	3.65%	6.97	6.72	3.72%	8.03	6.98	15.09%	19.83	18.36	8.03%	1.47
20228	1346:26:00	7	4.41	4.66	-5.34%	7.18	6.72	6.90%	6.79	6.98	-2.77%	18.38	18.36	0.12%	0.02
20228	1357:38:00	7	4.75	4.66	2.00%	7.46	6.72	11.07%	7.52	6.98	7.72%	19.74	18.36	7.49%	1.38
20228	1405:39:00	7	5.22	4.66	11.97%	6.98	6.72	3.80%	7.39	6.98	5.82%	19.58	18.36	6.64%	1.22
20228	1414:24:00	7	4.3	4.66	-7.75%	6.75	6.72	0.42%	7.59	6.98	8.74%	18.64	18.36	1.51%	0.28

The *.crp file contains all the individual error statistics for all logged calibration passes. The analyst can use this information to determine if a particular event or group of vehicle events are reporting a higher than average error.

12.0 WimCal calibration Plots

12.1 Strain count Vs static axle weight plot

WimCal has employed a very useful feature that allows the analyst to remove any outliers from the data which they may feel is biasing the results. Outliers can sometimes result from calibration vehicles having to brake excessively across the site or a large vehicle may have been in the adjacent lane at the same time one of the calibration vehicles were being weighed. If these types of events can be identified as isolated and occurred due to some external influences other than site characteristics they should be removed from the data set.

The program has an inbuilt facility where the analyst can select the particular outlier record directly from the strain count Vs static axle weight plot. This is achieved by simply clicking on the record directly from the graph. The application changes the appearance of the record from a red to a blue dot and at the same time reanalyse the data with the revised set of data records to produce a new set of calibration factors and summary error statistics report. This procedure allows you to see what the effects are of this change instantaneously. If the change made the results worse the record can be reselected as part of the data set by simply clicking on it again.

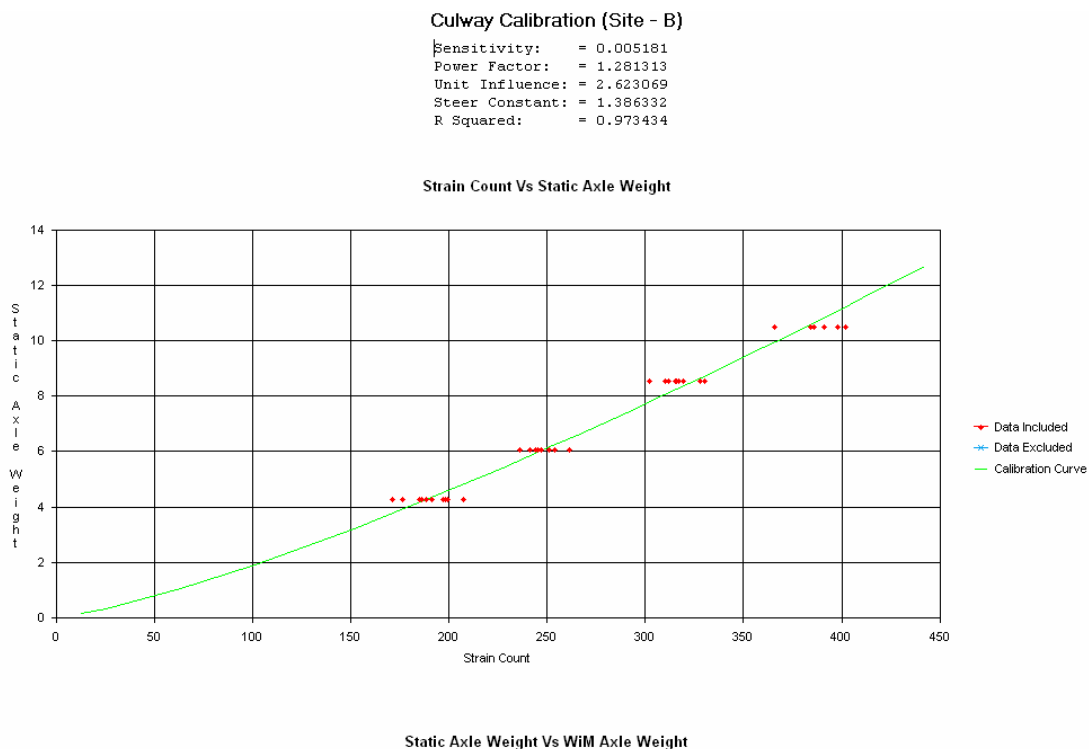


Figure 20: The first plot displays strain count Vs static axle weight. Only rigid vehicle drive axle strain readings are displayed on this chart.

12.2 Static axle weight Vs WIM axle weight plot

The second graph plots Static Weight against WIM axle weight to illustrate the standard error between both measurements. Again only single drive axles are represented in this plot.

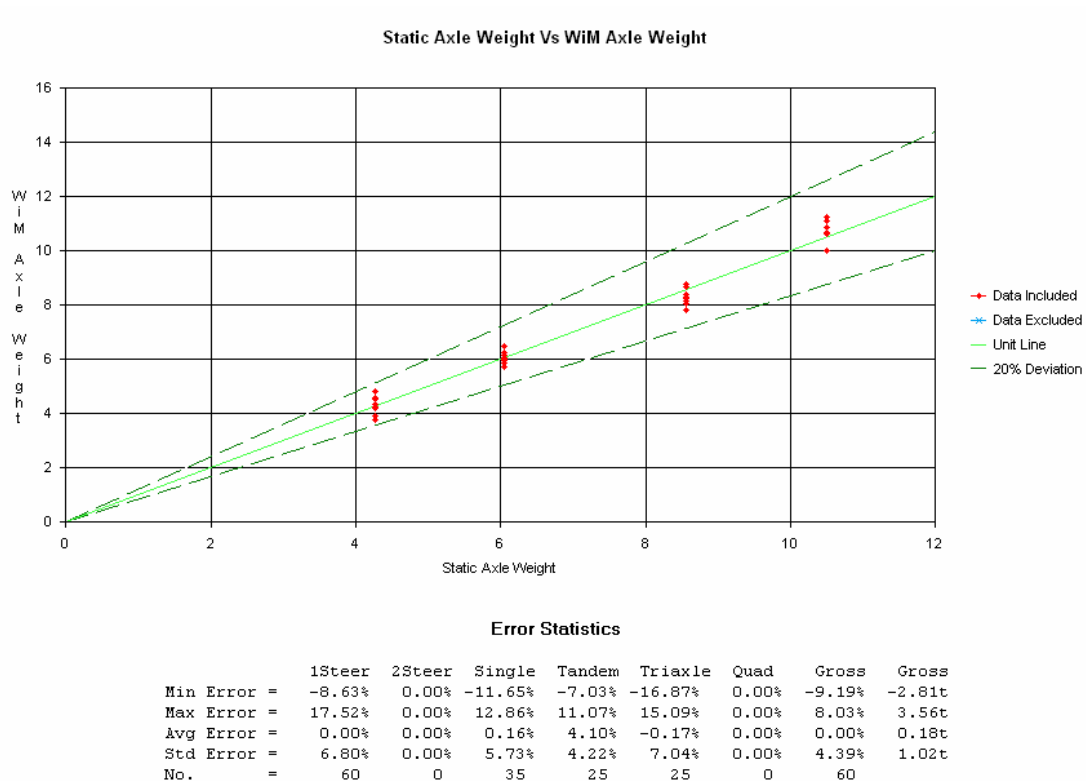


Figure 21: Static weight Vs WIM axle weight plot

Note:

It is very important that all calibration factors are entered to their full 6 decimal places in any post processing Culway software. The rounding of these values will have a significant impact on the accuracy of any post-processed data.

13.0 Strain Dumps

The generation of strain dumps is one of the most important tools you can use to check the operation and accuracy of the WIM site. Dumps should be performed on all Culway sites on a regular basis including calibration day as they can reveal a number of potential problems that can affect the site. The generation of strain dumps can help identify the following symptoms;

- Faulty MSA
- Faulty Buffer box or associated cabling
- Faulty Culway logger
- Faulty piezo interface (axles don't line up with peeks)
- Poor MSA placement
- Loose MSA
- Structural faults with culvert
- Unsuitable design characteristic of culvert
- Excessive culvert vibration
- Culvert movement
- Complex UIL influences

The use of strain dumps as a maintenance tool for detecting equipment and installation faults fall outside the scope of this document. Refer to manufacturer's service manual for details.

The detection of faults associated with the culvert condition or design characteristic should have been identified well before the calibration so that the appropriate action can take place to correct the site faults if possible or discard the site altogether.

Calibration day should include dumps from all the calibration vehicles especially some from the single drive rigid when it is fully loaded. These dumps may be required if the site exhibits a complex UIL characteristic. (See section about Complex UIL).

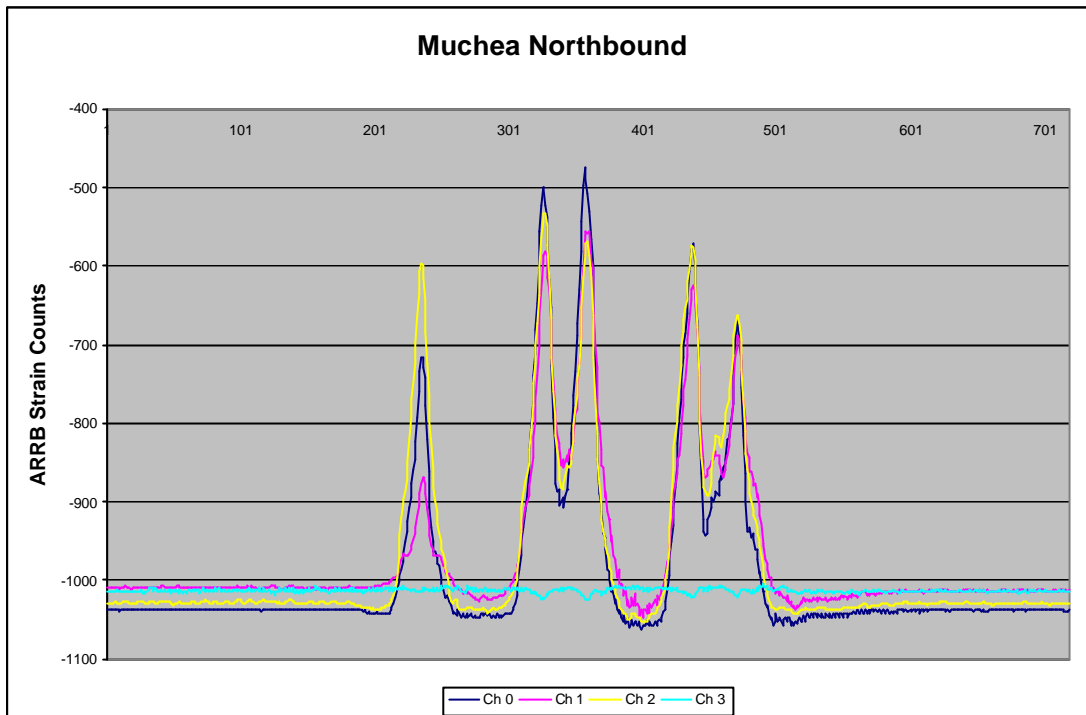


Figure 22: Sample dump showing individual channel outputs

14.0 Fine Tuning calibration factors after calibration

This method of calibrating WIM sites does have some downsides as it only uses a small selected set of calibration vehicles to derive an optimised calibration factor. The other problem is the calibration takes place for only a few hours where conditions usually remain fairly stable so again our factors have been optimised for those conditions.

Therefore the factors, which have been derived for the calibration, are fine for the ideal world where conditions are controlled. Culway in the real world is a different story as it has to weigh an almost unlimited assortment of vehicle types, size, weight, axle configurations, axle spacings, suspension types, length and changing weather and site conditions.

Although the factors which have been derived are the most accurate we can obtain with the resources we have available adjustments from time to time may be required to offset changing conditions. Spot checks using live traffic can reassure you that the factors are still appropriate.

It is known fact that steer axle weights for type A123 semi-trailers remain fairly constant irrespective if the vehicle is loaded or unloaded. There are tools available in Culway post processing software which produces steer axle averages for the period of data processed. This information can be used to adjust and correct for steer axle drifts.

Appendix A

Material to be added (left blank)

Appendix B

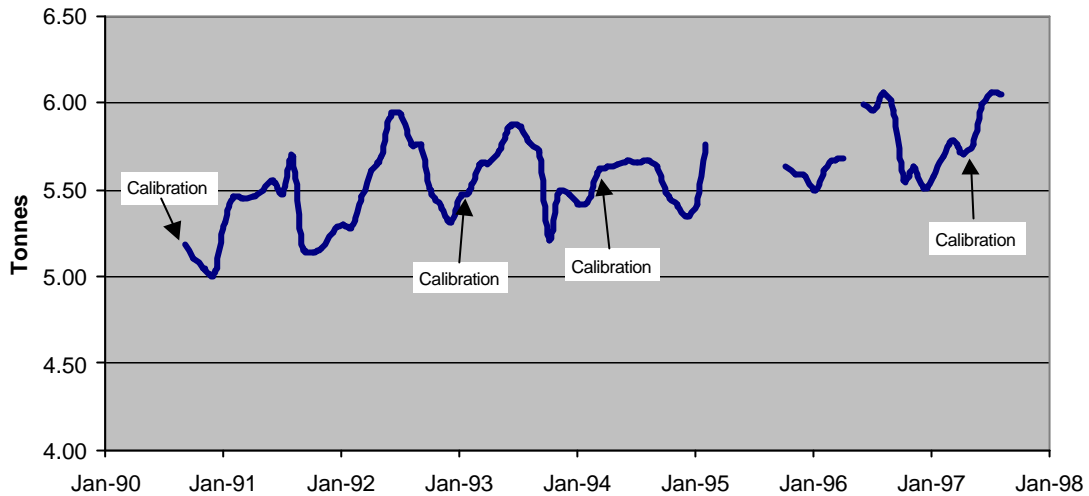
Improving the Accuracy of Culway Data by Allowing For Seasonal Calibration Variation

I have had cause in recent times to have a look at Culway data and in so doing have given some thought to how the data accuracy can be considerably improved. There have also been some other key drivers:

- Knowing that calibration drift is a problem with most WIM systems, but also knowing that managing calibration drift is expensive if undertaken by frequently recalibrating sites with test vehicles;
- Findings in the United States that recalibration without test trucks, using statistically valid measures such as average steer mass results in significantly improved data accuracy;
- A recent draft ARRB report indicating that there is gross overloading in WA, when I am not convinced of some of the numbers; and
- Data prepared by John Murphy for me on the long term trends in overloading – data that I was using as the basis for some performance indicators. Some of the data looked questionable.

The long term Culway data now available has convinced me that there can be a seasonal variation in calibration and consequently **accuracy**. This is no better illustrated than at the Esperance Culway site in Western Australia. The chart below shows the month by month average mass of the steer axle of A12323 vehicles (Double Road Trains).

Steer Mass - Esperance - A12323



(Calibration is when the site was calibrated with a truck of known mass)

I don't believe the variation is real.

It clearly shows that the average steer mass as measured with Culway is highest in late winter and lowest in mid summer. Knowing the way that Culway works makes these findings eminently possible, but not believable. From a structural perspective it is quite likely the case that the pavement is less stiff in late winter than in the summer, due to some moisture penetration and softening, probably from the unsealed shoulder. It should be remembered that Culway determines the mass of axles on the basis of the amount a culvert roof bends during the passage of the axle. A softer pavement results in more culvert roof bending and an apparently greater axle mass. At the Esperance site it would seem that the combined pavement and culvert stiffness is about 10% lower in late winter than in summer.

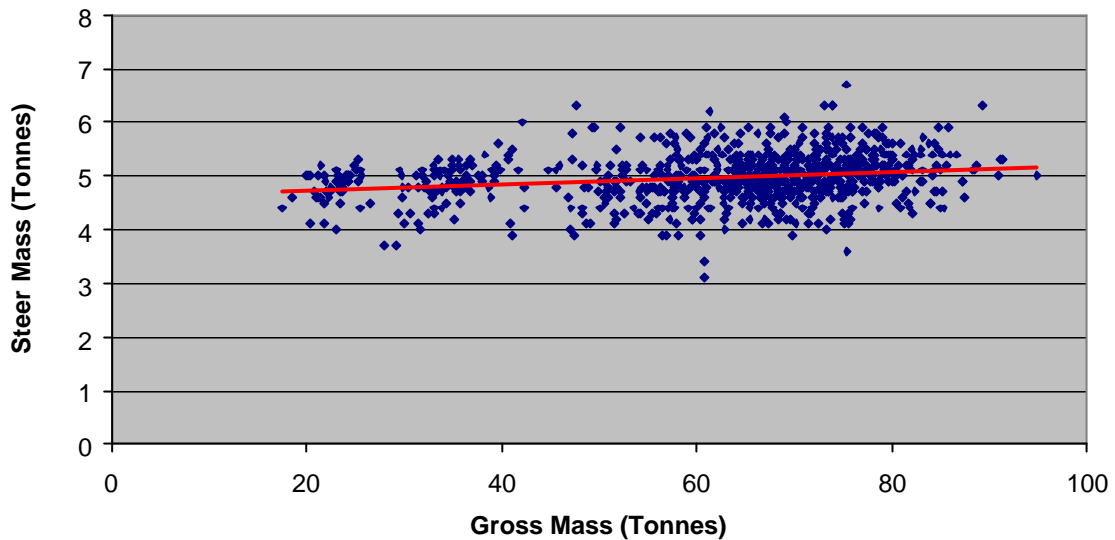
It is also interesting to note that over the long term at this site the average steer mass is increasing. This is not surprising as the legal limit for steer axles increased from 5.4 tonnes to 6.0 tonnes in the late 1980s, and in recent times concessional loading has allowed some steers to go out to 6.5 tonnes.

There is however the question as to whether the seasonal calibration thesis is reasonable. Could the variation actually be simply due to steer axle mass being higher in the winter?

After examining weighing records for road trains the evidence is quite clear that the variation in steer mass is remarkably small. This is due to the fact that the vehicles have heavy engines, chassis and fuel tanks which result in the steer axle being fully laden prior to attaching the semi trailer and dog trailer.

The following chart shows that the mass of the steer axle on this type of vehicle vary little, regardless of the overall mass of the vehicle combination. A line of best fit has been added to show the variation.

**Steer and Gross Mass
A12323 - Geraldton - February 1993**



Further evidence will need to be gained to prove beyond reasonable doubt the thesis, but the evidence so far is quite compelling.

So what should be done?

Regular site recalibration with test trucks, perhaps monthly, would keep the problem in check, but would be very expensive. I am as a consequence suggesting that we overcome the problem in the office environment by preparing an additional set of Culway 'recalibrated' records with the seasonal variation removed.

I have asked John Murphy (Rod Hood is on leave) to determine the monthly correction factors that would be required to eliminate the variation for each site. The task is quite large (some weeks) but thanks to excellent data management by Rod and John should be relatively straight forward. The more detailed advice that I am giving to John is at the end of this memo.

The impact of the changes could be considerable. Weighing too heavy by up to 10%, which seems quite likely in some months, could give rise to an over estimation of:

- 50% in ESAs;
- 15% on freight tonnages; and
- 40% on the number of overloaded vehicles.

After the data has been corrected, I propose looking into having a report prepared on the first ten years of Culway operation in Western Australia. The report would concentrate on trends in loading, pavement loading, freight and so on for each of the sites. I would like to think it might form the basis for future Culway Annual Reports.

Culway Monthly Calibration Procedure

Adjusting the data held in DCD files

1. Following each site calibration ascertain the average steer axle mass for the dominant articulated vehicle for the following month. The vehicle will usually be an A123 (six axle articulated) or A12323 (double road train).

Eg: Calibration - April 1993
Average Steer Mass in May 1993 5.37 tonnes

2. For each subsequent month determine the average steer mass for that vehicle type.

Eg Average Steer Mass in June 1993 5.61 tonnes

3. Determine the calibration factor needed to adjust it to the average steer mass measured in the month after calibration.

Calibration factor of $0.957 (5.37/5.61)$

4. Use this factor to adjust all the mass figures measured in that month.

Eg: Adjust down all June mass figures by multiplying them by 0.957.

5. Continue this process until the site is once again recalibrated with a test truck/s. Then start the process again. *Site calibration should be undertaken when there has been an obvious change in site performance, or 'drift' of more than 15% has taken place.*

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