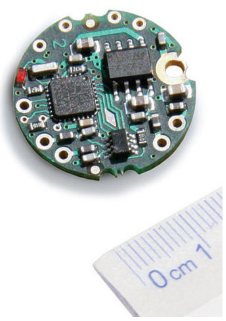
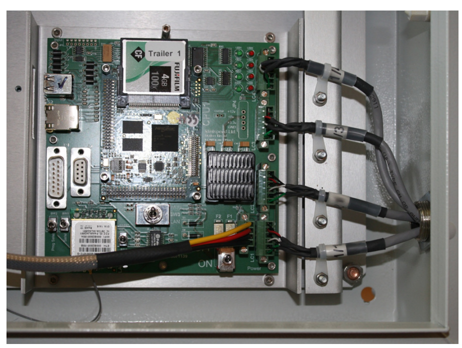
This document describes how load cells work and explores the concepts involved in calibration…..

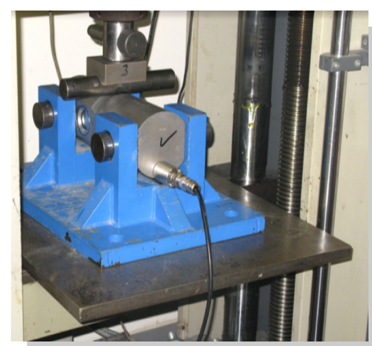
Double Shear Beam Load Cell

Introduction: contemporary weighing systems use ***load cells*** to measure force, these are billets of s/s alloy machined in such a way as to deliberately include a weak area that is intended to deform when the load cell is subjected to a mechanical load. The area of deformation has a small electronic circuit called a ***strain gauge*** bonded to it and this device has a small excitation voltage applied to it; there are two other terminals on the gauge for ***sensing***. The voltage between the sense terminals changes with respect to the load applied to the load cell and in direct proportion. In theory, a voltmeter could be used to measure load but it would be necessary to convert the voltage reading (expressed in mV) into lbs, grams, Kg or Tonnes. However, usually this function is accomplished with the use of external amplifiers, computers or instrumentation.



The load cells used in Seacom trailers are effectively ***digital***. They include all of the features mentioned above but in addition also include a small but powerful microcomputer (see left) to convert the minute voltage changes into meaningful ***Engineering Units*** (lbs, grams, Kg, Tonnes etc.). This microcomputer is actually fitted inside a s/s housing at the end of the load cell itself (see below left) and the load data is transmitted in RS485 format to the central embedded PC on the trailer (below centre).





This design philosophy allows *pre-calibration* in a test laboratory where the highest standards of accuracy can be obtained. The load cell is loaded to a test rig (above right) and using some specialist software on a PC connected to the microcomputer, the values of ***ZERO*** load and ***Full Scale Deflection (Span)*** are set with the appropriate numeric value as the test load is applied. With no mechanical load a numeric value of ***0*** is entered and with rated maximum load (e.g. 100.00 Tonnes) a numeric value of ***100,000*** (Kg) is entered. These values define ***the slope of the graph*** of ***physical load*** against ***load value*** transmitted (see page 5) and are stored in non-volatile memory within the load cell microcomputer; these values remain indefinitely unless deliberately changed and this action would only normally be done in a test laboratory with suitable facilities to those used in the initial calibration.

It is important to bear in mind that due to the very large test weights required and the challenging environment of the Steelworks, it would be virtually impossible to replicate or duplicate this standard of accuracy in the Scrap Yard.

All the load cells are all wired back to the embedded PC (above centre) which consolidates the individual readings by sequentially and constantly polling all four cells and ***adding*** the individual readings to provide a ***total weight***. There are other features in the software for smoothing and damping the load but in essence, the central trailer computer adds the individual load cell readings and organises the transmission to an external host system via WiFi.

Potential Sources of error

Aside from a load cell failure which is usually quite obvious and necessitates replacement, there are several possible sources of minor weighing errors;

1) Build-up of Debris (a)

Debris can build up around the load cell and this can affect the performance. The most usual place is under the centre strut of the upper part of the load cell cradle as shown in the picture on the right. Under full rated load, **the load cell can deflect by up to 2mm (1/8th inch**) and anything that inhibits that deflection will also seriously affect the apparent accuracy. Debris can either be solid (scrap items) or a build-up of lime dust which can form a concretion if allowed to get wet and then subsequently solidify.

2) Build-up of Debris (b)

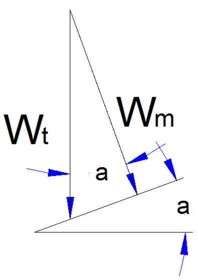
Another source of problem is the build-up of debris (scrap) on the weighing platform due to ***spillage*** when loading; it must be remembered that if scrap is on the weighing platform **IT WILL BE WEIGHED**. The same is true of scrap that is caught on the scrap basket, it will all be weighed and reported back to the host system. Nevertheless, this scrap **WILL NOT GET LOADED TO THE FURNACE** There is no way the trailer computer or the host computer system can account for this; it requires visual inspection and physical intervention to handle.

Depending on how the external software adds the material weights in the host system this ***apparent loss*** may affect the ***apparent yield***. The shortage is only ***apparent*** since the material hasn't been lost—its still on the trailer or if its fallen off, its still in the scrap yard.

By remote monitoring of the weighing system using the web browser, debris on the platform has been observed to weigh up to 2 or 3 Tonnes. This is deduced by a comparison of ***TARE Weights*** for a particular scrap basket whose empty (TARE) weight seems to ***grow*** each time the empty basket is put back on the trailer. Clearly this doesn't happen but if the platform is cleaned off, the TARE weight of the basket reverts to what it should be.

3) Uneven Terrain

If the trailer is sloping or parked on uneven terrain sufficient to induce a chassis twist, errors can be introduced due to the alignment of the load cells plane of operation (normally at right-angles to the plane of the chassis) with respect to the vertical force of gravity. A 5° slope can introduce an error of 0.4%; a 10° tilt, although very unlikely, would introduce an error of 1.5% in all cases, the weighing system would **under-read**. At 10° slope the trailer would need 101.50T loaded to display 100.00T. In the load vector diagram on the left, the ***Measured Weight*** (***W_m***) is reduced because the load cell is at an angle; the formula to calculate that measured load is; ***$W_m = W_t$ x Cosine a***
where ***W_t*** is the ***True Weight*** and ***a*** is the Angle of tilt.



This potential problem is <u>exacerbated</u> if the trailer is sloping <u>during</u> the calibration procedure since the initial error will be included in the calibration and replicated indefinitely; this is why <u>any</u> calibration MUST be done on near-perfect, flat and level ground.

e.g. A precise dead weight of 100.00T would, at 5° be measured at 99.62T, if during calibration the full scale deflection was then set at 100.00T, <u>all subsequent measurements would be out by 0.</u>4% (unless measured on the same slope). This means that all loads would need an extra 0.4% of material to reach a specified target thus using more stock.

It should be noted that a *mobile* weighing system can **never** be as accurate as a *static* one; load cells in a static weighbridge are purely compression cells and **only** have to support weight, they are not required to be a component of the chassis and be able to withstand bumps and jolts. Also, all the structural steelwork in a weighbridge is securely mounted on a concrete foundation which is, or at least should be, perfectly flat and level.

Weight Checking and Calibration

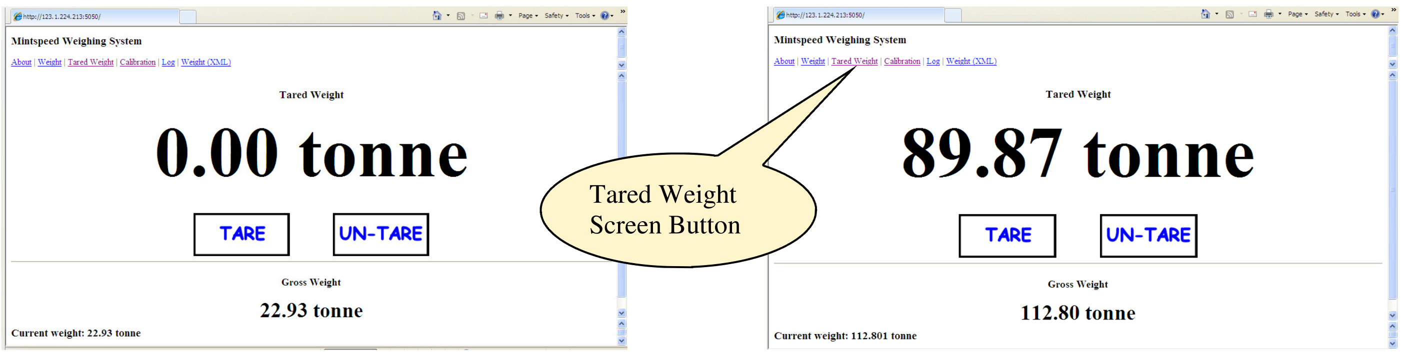
It may be a requirement to carry out regular ***Weight CHECKS*** on each trailer using test weights in conjunction with the Web Browser software in each trailer but;

DO NOT use the *Calibration* function to check weight accuracy; use the *Tared Weight* screen.

This is accessible from the Weighing System Home Page

If the calibration procedure is used without having a clear understanding of what's involved, there is a risk of introducing significant errors, much larger than those you're attempting to eliminate. Some are covered on Page 4

Zero Load 90,000 Kg Load



In the above example, with an empty platform, the ***TARE*** button was pressed with a Gross Weight of 22.93T; a 90T (90,000Kg) test weight was loaded and the weight recorded. This example has a small error of 130Kg; this equates to 0.14% with respect to the Net Load and 0.11% with respect to Gross Load; this trailer **SHOULD NOT** be calibrated.

We strongly advise using the PlayStation to experiment with the calibration procedure to gain experience.

Test Weights

It is very important to remember that the empty scrap basket uses about a 1/4 or 1/3 of the total capacity of the weighing system, consequently, the ***area of interest*** therefore is in the **upper** 3/4 or 2/3 - checking and calibration in the lower 1/3 of the system span is actually pointless.

It is therefore counter productive to use a small set of weights that barely ***tickle*** the weighing system. For example; setting ***zero*** with no load and then using a single, 10T test weight to set ***span*** at 10,000 Kg. This method relies on *extrapolation* for weights greater than 10T and is notoriously inaccurate; for a 150 Tonne trailer, this is only 6% of the rated load and any errors at this level will be significantly ***amplified*** as load is increased (see graph 1 on Page 5)

The correct way is to have test weights equal-to or close-to the rated load of the trailer. For example, setting zero with no load and then using test weights totalling 130T (for a 130T trailer) to set span at 130,000Kg. Having set these lower and upper limits, intermediate weights can be reliably *interpolated* to get weight (see graph 2 on page 5)

In the same way that the ONLY reliable way to calibrate a temperature measurement system is to boil fresh water at Sea Level to set the value of 100° C, there is no substitute for using accurate test weights to check and calibrate weighing systems and unfortunately, these need to be LARGE. Unfortunately, the use of lots of small weights is fraught with problems, these are…….

1) They take a lot of time to load / unload
2) They are potentially dangerous if stacked up
3) Individual errors on each weight will stack-up and introduce inaccuracies
4) The test weights need to be symmetrically positioned close to the Centre of Gravity of the scrap basket and lots of small weights make this difficult to achieve.

Principles of calibration procedure

The ScrapMan weighing computer arithmetically adds the weight readings from the individual load cells; as already described, these are already *digitised* and *scaled* in *engineering units* of Kg at the load cell itself and this calibration was done in a test laboratory using specialist equipment and to a standard that would be impossible to achieve in the scrap yard. The calibrated values within each load cell **cannot** be changed on site, only in a test lab with suitable equipment and software. ***However***, the trailer computer ***does*** include some software to permit the resultant total weight to be ***tweaked*** up or down if, with the passage of time, weighing errors are observed. This is accomplished by adjusting the *Weight **GAIN*** factor in one of the text files residing in the C/F card; the file is called *CalibrationSettings.xml* and typically looks like…..

```
<?xml version="1.0" encoding="utf-8"?>
<Settings>
  <Weight>
    <Gain>1.0</Gain>
    <UseOffset>false</UseOffset>
    <Offset>0</Offset>
    <!-- Cal weight in Kg -->
    <CalWeight>90000</CalWeight>
  </Weight>
  <Battery>
    <Gain>1.0</Gain>
  </Battery>
</Settings>
```

*Weight **GAIN*** Value for fine tuning.

Calibration Test Weight; this can be adjusted to suit the actual Test Weights

Battery **GAIN,** do not change this value, it is related to the battery voltage measurement. It can be adjusted up or down if the voltage measurement has been found to have drifted.

The *Weight **GAIN*** shown in **RED** is by default set to **1.0** This means that if the arithmetical sum of all four load cells is 11,382Kg then the weight transmitted to the host system when requested is also 11,382Kg. With the same weight, if the Gain was changed to 1.1 the transmitted load would be 12,520Kg (11,382 x 1.1) or conversely, if the Gain was set to 0.9 the transmitted load would be 10,243Kg 11,382 x 0.9). The Gain therefore is simply a number by which the measured weight is multiplied-by. This ***Weight GAIN*** can be set by editing the *CalibrationSettings.xml* with a text editor (e.g. Microsoft Notepad) or, more usually, using the calibration procedure described in the manual. In essence, this is done by setting ***zero*** (with no load) and setting ***Span*** or Full Scale Deflection with a known weight applied.

However, this should only ever be attempted if the following conditions can be met;

1) The trailer **MUST** be on flat and level ground
2) The test weights **MUST** be close to the rated maximum load of the trailer (see following page)
3) Using lots of small weights is potentially dangerous; a small number of BIG weights is better
4) Suitable lifting gear MUST be available (melt-shop crane)
5) The weights need to be loaded to the platform symmetrically and close to the C of G of the scrap basket

The **CalWeight** figure in **GREEN** is simply the default test weight value; in this case, 90T (90,000 Kg). If you have a test weight of 124,371 Kg, this value can be typed into the text file as the default value.

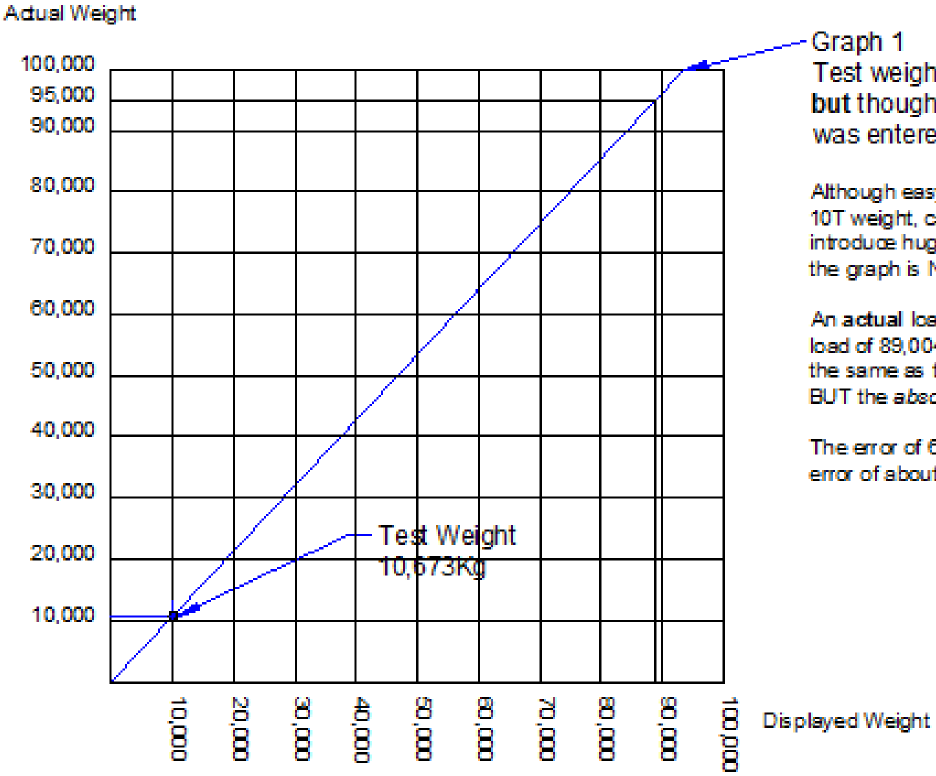
Examples of how errors can be introduced are as follows;

1) If a test weight *believed* to be 90,000Kg (but was in actuality 90,500Kg) was loaded to the platform and the span set to 90,000 then an inherent error of 500Kg (about 0.5%) has been introduced and the ***Weight GAIN*** would be set to 1.005. All subsequent readings would be multiplied by 1.005 and hence wrong.
2) An even bigger error can be introduced if the test weight is (for example) 100,000 **lbs**; if the engineer inputs a span calibration numerical value of 100,000, the weighing system (which is expecting Kg) will be out by a factor of 2.20462 (the ratio of lbs—Kg). The gain factor would therefore be 2.20462 and all subsequent load readings would be 2.20462 times as big as they actually are.

If this ever happens, the easiest solution is to edit the CalibrationSettings.xml file and set the gain back to 1.0

Graphs showing the different effects of calibration weights;
Example 1 is to be avoided, Example 2 is OK

Example 1
Calibrating with a small test weight and ***extrapolating*** for higher loads



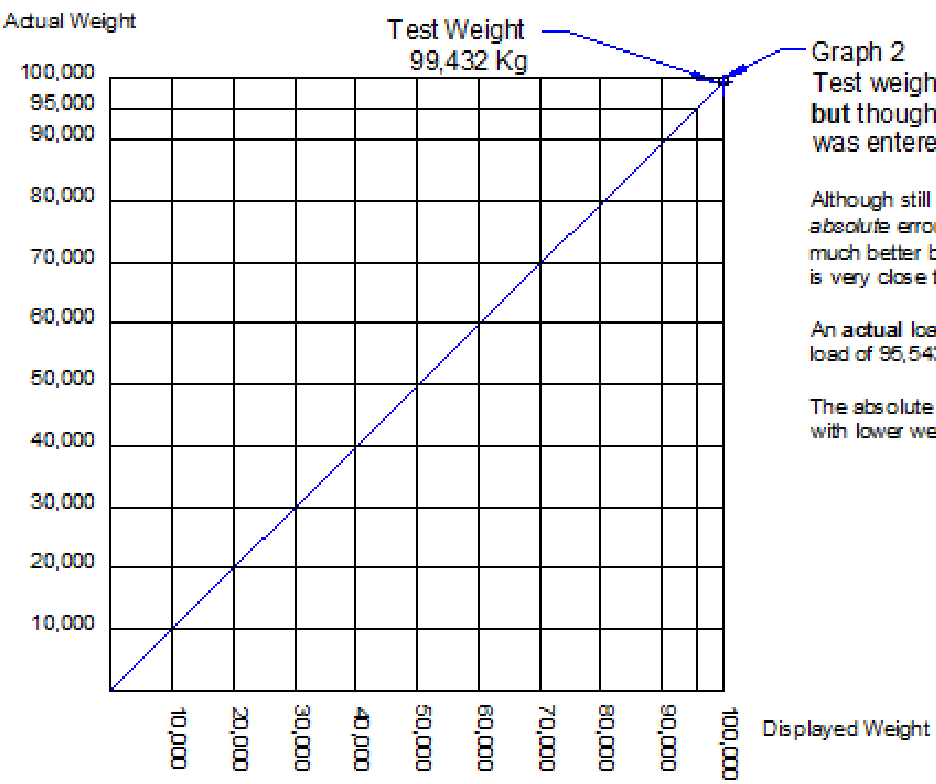
Graph 1
Test weight was actually 10,673Kg **but** thought to be 10,000Kg and this was entered as the calibration value

Although easy because of using only one 10T weight, calibrating like this could introduce huge errors because the slope of the graph is NOT correct

An **actual** load of 95,000Kg would **display** a load of 89,004Kg. The *percentage* error is the same as that introduced in calibration BUT the *absolute* error is magnified.

The error of 673Kg in Calibration is now an error of about 6,000Kg at full load.

Example 2
Calibrating with a large test weight and ***interpolating*** for lower loads



Graph 2
Test weight was actually 99,432 Kg **but** thought to be 100,000Kg and this was entered as the calibration value

Although still not correct (there is a similar *absolute* error of about 600Kg) this is overall much better because the slope of the graph is very close to the ideal.

An **actual** load of 95,000Kg would **display** a load of 95,543Kg.

The absolute error will of course get smaller with lower weights.

Calibration by statistical analysis

There is a method of calibration that may be appropriate for some steelworks operations; it would be based on the ***Yield*** from the furnace with comparison to the weight of material ***Supplied*** to the furnace and would rely on long-term statistical analysis. As a method of calibration, although not strictly speaking very accurate, it is substantially simpler, easier, quicker and less expensive than loading very large test weights.

This was alluded-to on Page 2 under *potential sources of error…..*

> Another source of problem is the build-up of debris (scrap) on the weighing platform due to ***spillage*** when loading; it must be remembered that if scrap is on the weighing platform **IT WILL BE WEIGHED**. The same is true of scrap that is caught on the scrap basket, it will all be weighed and reported back to the host system. Nevertheless, this scrap **WILL NOT GET LOADED TO THE FURNACE** There is no way the trailer computer or the host computer system can account for this; it requires visual inspection and physical intervention to handle.
>
> Depending on how the external software adds the material weights in the host system this ***apparent loss*** may affect the ***apparent yield***. The shortage is only ***apparent*** since the material hasn't been lost—its still on the trailer or if its fallen off, its still in the scrap yard.
>
> By remote monitoring of the weighing system using the web browser, debris on the platform has been observed to weigh up to 2 or 3 Tonnes. This is deduced by a comparison of ***TARE Weights*** for a particular scrap basket whose empty (TARE) weight seems to ***grow*** each time the empty basket is put back on the trailer. Clearly this doesn't happen but if the platform is cleaned off, the TARE weight of the basket reverts to what it should be.

If over a period of time there was deemed to be an ***apparent*** loss of ***material in*** compared to ***material out*** and this was statistically consistent over time and across all trailers; it is reasonable to assume that this discrepancy is due to material being weighed but **NOT** being loaded to the furnace. As already stated, this is an ***apparent*** loss in that the material is still in the yard somewhere.

This situation could be handled by changing the *Weight **GAIN*** factor by the amount of the yield error; for example if the yield was deemed to be 98%, the *Weight **GAIN*** could be changed to 0.98. This would theoretically force an extra 2% of material to be loaded to the scrap basket but since that material is statistically unlikely to get loaded to the furnace anyway, overall it is quite correct.

In the above example, the CalibrationSettings.xml file would look like…….

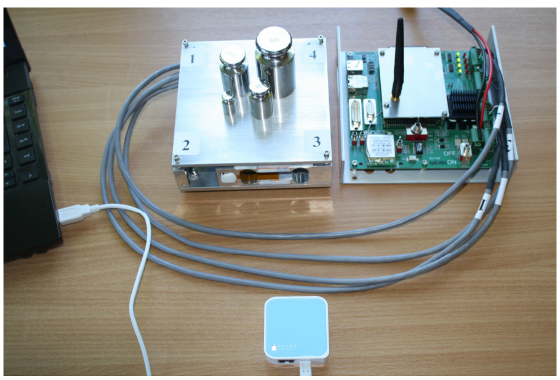
```
<?xml version="1.0" encoding="utf-8"?>
<Settings>
  <Weight>
    <Gain>0.98</Gain>
    <UseOffset>false</UseOffset>
    <Offset>0</Offset>
    <!-- Cal weight in Kg -->
    <CalWeight>90000</CalWeight>
  </Weight>
  <Battery>
    <Gain>1.0</Gain>
  </Battery>
</Settings>
```

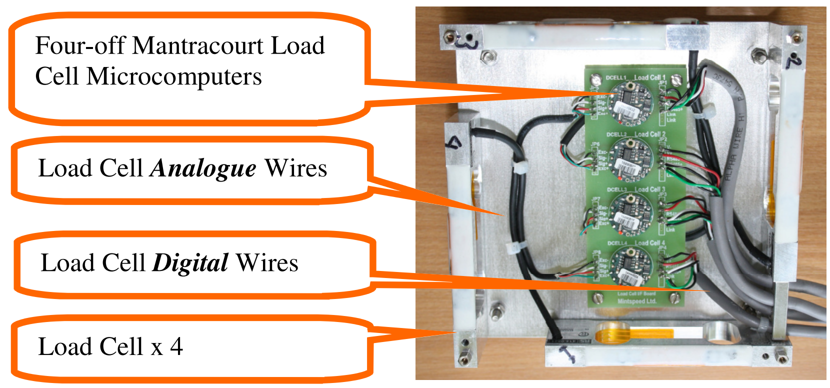
PlayStation experimentation

It is a good idea to practice and experiment with the calibration procedures using the PlayStation and spare computer but ensure the ***Weight GAIN*** value is set back to **1.0** before using the computer or Compact Flash card in the scrap yard; this is the variable programmed into the ***CalibrationSettings.xml*** file (shown below).

The typical set-up is shown below with PlayStation (weighing platform) set of test weights, spare computer, wireless router and a PC. The weighing platform has four load cells and like the actual trailer, each has a Mantracourt Micro-controller included for the ***digitising*** of the weight measurement. These load cells have been artificially scaled to measure in Tonnes instead of grams.

Each has a nominal capacity of 300 gram , these were loaded with test weights to 300.00 gram but the microcomputer in each cell was ***scaled*** with test software to *apparently* read 30,000 Kg (30Tonnes) to add some realism to software (100,000:1 scale). This means that with a load on each cell of say 125gm, the load coming back from the load cell microcomputer was 12,500 Kg. This 100,000:1 scaling was set during manufacture and cannot be changed without specialist software.





The PlayStation should be used for experimental purposes and efforts made to deliberately introduce errors such as calibrating on a slope or entering the wrong numeric value of actual test weights. This will allow experience to be gained at spotting problems and the subsequent rectification. After every experimentation session, remove the C/F card and using Notepad, inspect the ***CalibrationSettings.xml*** file and look at the **GAIN**…..

```
<?xml version="1.0" encoding="utf-8"?>
<Settings>
  <Weight>
    <Gain>1.0</Gain>
    <UseOffset>false</UseOffset>
    <Offset>0</Offset>
    <!-- Cal weight in Kg -->
    <CalWeight>90000</CalWeight>
  </Weight>
  <Battery>
    <Gain>1.0</Gain>
  </Battery>
</Settings>
```

N.B.
The *Weight GAIN* is the number that ALL reported weights are multiplied by…..

When finished experiments, ensure that the *Weight GAIN* value is RESET to 1.0

A ***successful calibration*** should end up with a ***Weight GAIN*** of ***about*** **1**. It should **never** be less than 0.9 or greater than 1.1; either condition would indicate a mistake or a faulty load cell.

After calibration, a typical ***CalibrationSettings.xml*** file may look like…..

```
<?xml version="1.0" encoding="utf-8"?>
<Settings>
  <Weight>
    <Gain>1.00361300682457</Gain>
    <UseOffset>false</UseOffset>
    <Offset>0</Offset>
    <!-- Cal weight in Kg -->
    <CalWeight>90000</CalWeight>
  </Weight>
  <Battery>
    <Gain>1.0</Gain>
  </Battery>
</Settings>
```