LOW COST CALIBRATION MANAGEMENT

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Abstract
The dominant highway speed Weigh In Motion (WIM) System in Australia is Culway, as system that uses concrete culverts as the load sensors. It has been known for some time that its weighing accuracy can change with time. This paper reports on the seven years of weighing records from one site which has exhibited a consistent seasonal variation in weighing accuracy. The paper demonstrates that the variation is not due to changes in vehicle characteristics, but rather due to natural causes. It finally presents a recommendation on how the variation can best be managed.
Keywords: Accuracy, Variation, Vehicle, Highway, Weigh in Motion

Résumé
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Mots-clés:

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1. Introduction

Culway (1, 2) is a highway speed WIM system. It was developed in Australia in the mid 1980's and dominates the Australian WIM market with over 100 installations. It uses existing concrete culverts as the load sensing elements.(See Figure 1) Strains, measured on the underside of the lids of the box culverts, are converted to axle mass with a simple unit influence line algorithm. Culway has been very successful because it is low in cost to install and maintain, and is accurate. Samuels (3) showed that the accuracy of Culway was comparable to bending plate WIM systems.

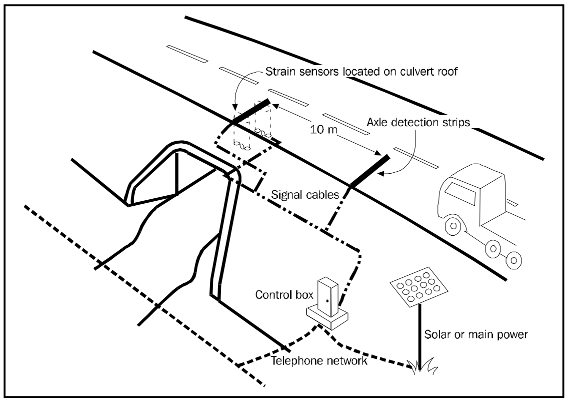

Figure 1
Typical Culway Installation

The main advantage of Culway comes with having the load sensor well away from the road surface. It is not 'battered' by traffic or exposed to the weather. In addition there is no culvert dynamic influence, as the surrounding soil stops the culvert from vibrating. Culway, like all WIM systems, is at its most accurate when the road surface is very smooth. And maintaining the smooth surface with Culway is simple and low cost, as the sensor does not form part of the road surface. It does not have the pavement stiffness discontinuity problems encountered by surface mounted WIM systems.

All of the WIM data referred to in this paper has been collected in Western Australia with Culway. About ten systems are used to cover the 2.5 million square kilometres which has a population of about 2 million people and about 17 000 kilometres of state and federal roads.

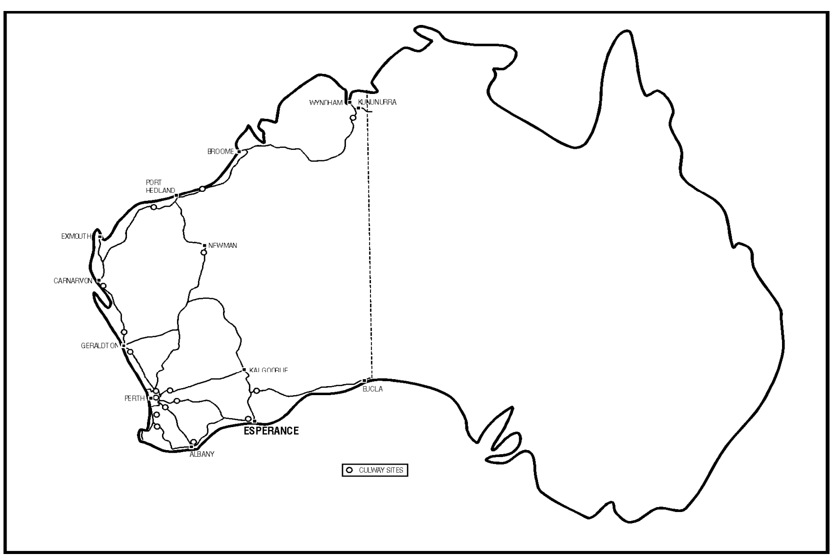

Figure 2
Culway sites in Western Australia

Much of the road system is lightly trafficked, and this in combination with good road building conditions and a forgiving topography means the freight vehicles are large. Some 80% of the road freight is carried on vehicles with gross masses ranging from 60 tonnes to 200 tonnes. See Figure 3.

2. Background

It became apparent early in the use of Culway that the weighing records from some sites exhibited a seasonal variation in mass, a variation that could not be simply explained. This paper investigates in detail one site that has exhibited this variation and concluded that the variation is due to climatic factors. It also concludes that the variation can be removed with the application of a relatively simple correction algorithm.

3. Site

In this paper the records from the Culway site near Esperance (Fig 2) are examined. Most of the other sites have also been examined, but have not been reported. Some demonstrate similar seasonal variations, but others do not. The only common denominator seems to be the depth of material over the culvert. Esperance has about 35cm. Culverts with much larger cover exhibit less seasonal variation. The most obvious effect of this small cover is the size of the live loading experienced by the Esperance culvert. A 10 tonne single axle results in 45 microstain on the soffit of the box culvert's lid at Esperance. The Esperance site is in a Mediterranean climate. It has a hot and dry summer and a cool and damp winter. Annual temperature variation is from a cold night of about 0°C to a hot summers day of about 45°C. Annual rainfall is about 600mm. See Figure 10.

4. Dominant Vehicles

The dominant vehicle at the Esperance site is the 11 axle double bottom road train – configuration 12323. See Figure 3. The allowable gross mass is now typically 85 tonnes, and the allowable steer mass is 6 tonnes. The gross mass limit was 75 tonnes in 1987 and the steer mass limit was 5.4 tonnes. The new limits have been phased in over the past 10 years.

These vehicles are mainly hauling grain from farms and inland grain receival facilities to the Port of Esperance. The task is virtually all year round – from farms during the harvesting season and from the grain receival facilities during the rest of the year. There is however no reason why there should be any significant variation in the mass during the year.

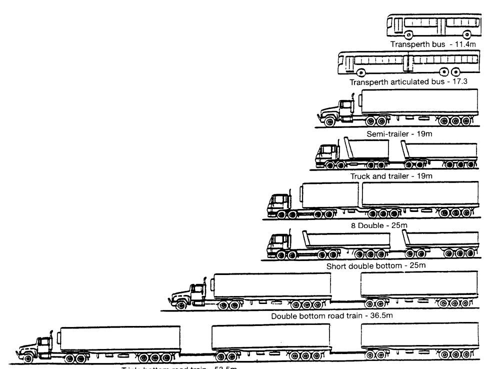

Figure 3
Selected Vehicles in use in
Western Australia

5. Esperance Data

The following charts summarise the data recorded over 7 years at Esperance. In order to make the data manageable measured mass values have been averaged on a monthly basis. The first data presented (Figure 4) is that of the average steer mass of 35,000 road trains. The monthly average varied from a low of 5.01 tonnes to a high of 6.06 tonnes, and the variation in the standard deviation was from 0.48 to 0.77 tonnes. It clearly shows some long term growth – as expected, but it also shows a consistent seasonal variation. It is always at its lowest in January and at its highest in July. Being the southern hemisphere this means low in summer and high in winter.

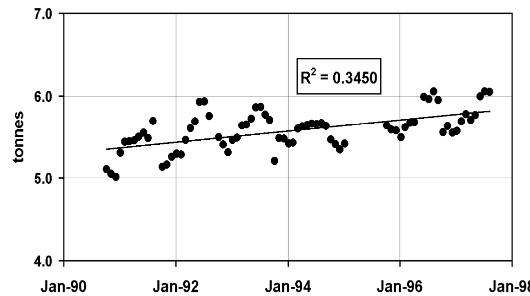

Figure 4
Monthly Average Steer Mass
Road Trains at Esperance

No unequivocal reason for the variation in steer mass has been established, but much has been done to eliminate possible causes. Figure 5 shows that the monthly vehicle count did not vary on a seasonal basis.

There was also some suggestion that the variation in steer mass may have been taking place on an hourly basis, with the variation somehow being related to the time of day. The long term records were aggregated on an hourly basis and showed that there was no significant difference with time of day. See Figure 6.

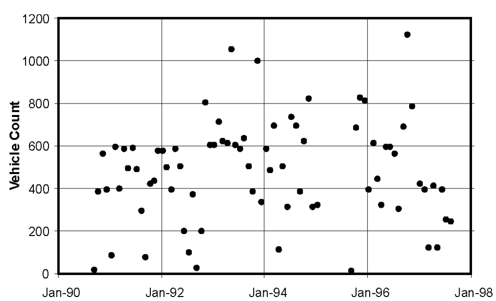

Figure 5
Monthly Vehicle Count – Road Trains at Esperance

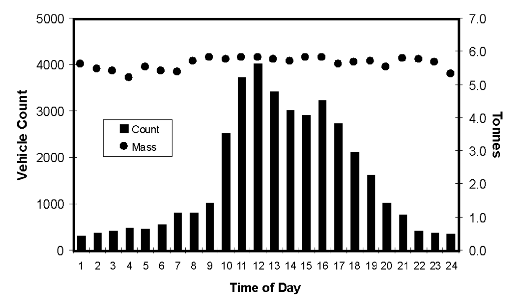

Figure 6
Steer Mass and Vehicle Count by Time of Day – Road Trains at Esperance

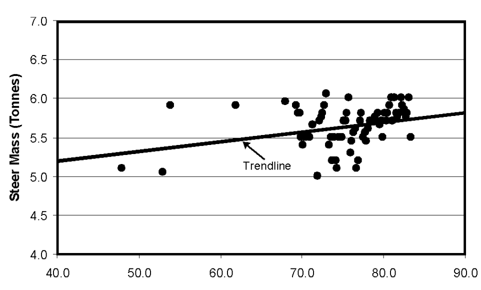

Figure 7
Steer Mass and Gross Mass for each Month
Road Trains at Esperance

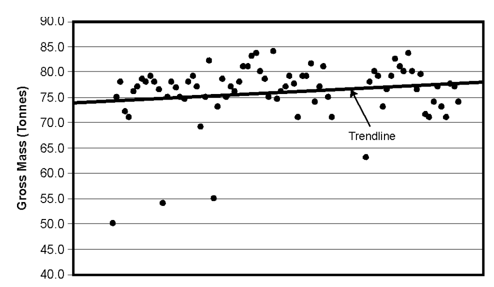

Figure 8
Gross Mass by Month
Road Trains at Esperance

Finally there was the suggestion that the steer mass variation may have been as a result of gross mass variations. This also seems improbable when the relationship between gross mass and steer mass is plotted, as shown in Figure 7. Steer mass shows little variation with mass. This is quite reasonable to expect as with most road trains the steer mass is virtually all coming from the engine, chassis and fuel tanks. The steer axle of the 'tractor' is at the maximum allowable prior to the semi trailer being attached. The turntable on the tractor is usually centrally placed over the drive axles.

The variation by month in gross mass (Fig 8) follows the same pattern as that of steer mass, and is of a seasonal nature. It would appear to be at a maximum of about 4 tonnes in excess of that 'expected' in winter, and about 4 tonnes light in summer, or about 5%.

6. Correcting for Seasonal Variation at Esperance

On the assumption that a seasonal variation is taking place, for reasons unrelated to vehicle loading, a correction algorithm was designed. The variation was tested against rainfall – remembering that being a Mediterranean climate there is a wet and cool winter and a hot and dry summer – a cycle that matched the variation. The correlation was good with an R^2 of 0.8. But the best fit came when the variation was tested against the sinusoidal function shown in Figure 9, at 0.87.

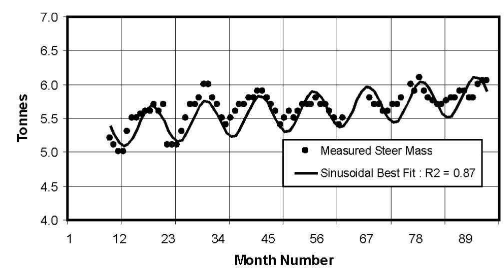

Figure 9
Model Steer Mass Seasonal Variation – Road Trains at Esperance

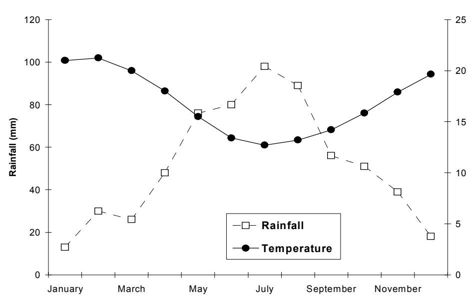

Figure 10
Rainfall and Temperature at Esperance

The sinusoidal function is:

Anticipated Steer Mass

$= 5.29 + 0.0059M + 0.28L$

where

M = month number; and

$L = \mathrm{SIN}(((M - 1.3) * (\pi /6)) - (\pi /2))$

This relationship indicated that in January road train steer axles were underweighed by 0.28 tonnes and in July they were overweighed by 0.28 tonnes, or about 5%. This figure is about the same as that observed for gross mass. It would seem to be clear that at the Esperance site there is a seasonal variation of +/- 5%.

7. Correcting Data for Seasonal Variation

This is yet to take place, but it is proposed to apply the correction factors shown in Table 1 to all mass data collected at Esperance.

The effect of making these corrections is shown in Figure 11. Quite clearly the variation from month to month has been reduced, as can be seen by comparing Figures 4 and 11. The standard deviation from the line of best fit has been reduced from 0.035t to 0.022t and the R^2 value has been improved from 0.3450 to 0.5307.

Table 1
Recommended Monthly Correction Factors For Esperance

Month	*Correction*
January	Add 5.0%
February	Add 4.7%
March	Add 3.2%
April	Add 0.8%
May	Subtract 1.8%
June	Subtract 3.9%
July	Subtract 5.0%
August	Subtract 4.7%
September	Subtract 3.2%
October	Subtract 0.8%
November	Add 1.8%
December	Add 3.9%

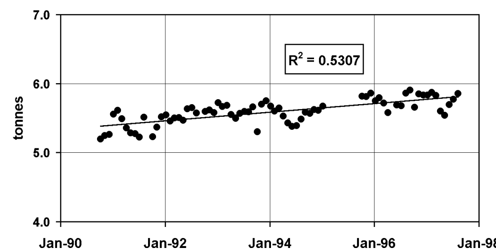

Figure 11
Steer Mass Corrected for Seasonal Variation – Road Trains at Esperance

8. Impact Of The Corrections

Some analysis has been undertaken to model the impact that the corrections to the data will have. As far as long term aggregate data is concerned the impact is small provided site calibration has taken place at the times when seasonal variation is at a minimum. The value of the WIM data in the short term, particularly from the mass enforcement perspective is compromised during the middle of winter and summer if the corrections are not made. The data cannot realistically be used to assist in axle mass limit enforcement at these times unless corrections are made.

9. Why Is There A Seasonal Variation?

The reasons for the seasonal variation can only be conjecture. For some reason the concrete roof of the culvert bends more in winter than in summer, and if it is assumed that the concrete properties do not change with the seasons, it could be assumed that those of the pavement have. It would seem that the pavement becomes less stiff in winter and more stiff in summer. The pavements are made of well graded compacted natural materials, with no added binder. There is no asphalt or concrete in the pavement, and the surface treatment of bitumen and stone chips is only 1cm thick. The surface treatment is enough to water proof the pavement and adhere the wearing surface to the pavement. The pavement has probably never been inundated.

It would nevertheless appear that the pavement stiffness is lower in winter, probably as a result of a marginally higher moisture content. Other culverts used for Culway purposes, but with very deep cover, exhibit less seasonal variation, suggesting that the moisture contents of these thicker pavements on average change less during the year, a supposition that seems likely.

10. Conclusion

The analysis of the data from the Esperance site has shown that there can be a seasonal variation in the accuracy of a WIM System that uses existing concrete culverts as load sensors. The cause of the variation has not been found, but it has been proved beyond reasonable doubt to be seasonal. The causal factor is probably temperature or moisture, or a combination of both. The variation correlates well with both – or for that matter the hours of daylight!

The analysis has shown that the observed variation is 'real', and not as a result of seasonally different loading patterns. The analysis has also shown the variation to be consistent from year to year, and that it can be simply allowed for with a monthly percentage correction made to all measured mass values. It has also demonstrated how long term data can be used to maintain the calibration of WIM sites, at a far lower cost than would be the case with regular site re-calibration.

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