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ON-BOARD TRUCK SCALES

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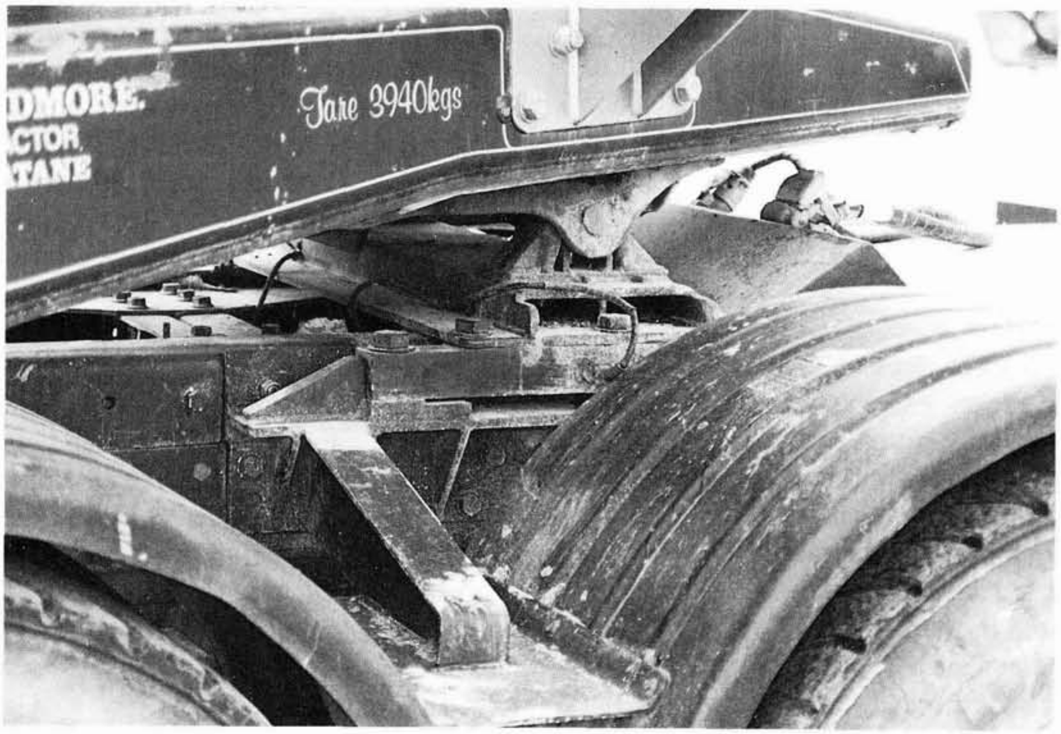

Figure 1 - Loadcells fitted under fifth wheel of Logging B-train

ABSTRACT

A case study of eleven on-board truck scale systems was conducted to evaluate their accuracy and reliability. The payload variation of trucks fitted with scales was compared to that of trucks without scales.

Results showed the accuracy of the truck scales varies widely, from an average error of ±0.19 tonnes up to ±0.68 tonnes. The reliability was also highly variable, with repair and maintenance costs ranging from zero to over $3,500 in the year of the study. The payload variation of the trucks with scales was approximately half that of trucks without scales.

The accuracy of six Loadrite systems was also measured and found to be much less than that of the truck scale systems.

INTRODUCTION

To maximise profitability, it is important for truck contractors to carry maximum payloads, while staying within the legal weight limits to avoid overloading fines. The Ministry of Transport have increased the number of portable weight scales they operate, and they are expected to increase activity in the weighing of heavy vehicles (N.Z. Trucking, February, 1992). Due to varying log length, diameters, and densities, it is difficult to judge accurately the weight of a load of logs. On-board truck scales allow truck drivers to check the payload weight as it is being loaded to achieve the greatest allowable payload. Increasing numbers of logging trucks are being fitted with scales, and forestry companies in some regions are making on-board scales mandatory for their contractors.

This report presents a case study conducted on eleven trucks of various configurations fitted with the common types of loadcell on-board truck scales. The scales were evaluated for accuracy and reliability, and the variation in payload of the trucks equipped with scales was compared to trucks without scales. Repair and maintenance (R & M) requirements were also recorded, and this allowed a costing to be calculated as input to a cost-benefit analysis. The accuracy of Loadrite scales fitted on six loaders was also measured.

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STUDY PROCEDURE

Data Collection

Three different brands of scales were involved in the study: three trucks with Vulcan systems, five with SI and three with Lodec or a mixture of Lodec and SI components. Table 1 shows the truck configurations, the location of the loadcells, and the age of the system at the start of the study.

The truck drivers recorded the weight displayed by the on-board scales at the completion of loading at the skid. Also recorded were: fuel level, docket number, weighbridge weight, weather conditions, and in some cases, skid site conditions. For the Loadrites, the loader driver recorded the weight displayed by the Loadrite at the completion of loading. The truck scales and Loadrite weights were measured against the weights recorded at several weighbridges around the central North Island, which are assumed to record actual weight. Weighbridge printouts were obtained from the forestry companies to cross-check the recorded weights, and to compare the highway payload variation between trucks with scales, and those without scales.

Data Analysis

The data for each truck and loader were analysed to find the average error, the average of the absolute error, and variation of the error as measured by the standard deviation. The average error indicates how accurately the scales are calibrated, and not how precise they are. With well calibrated scales, over a large sample, positive and negative errors will balance out to give an average error of close to zero. Taking the absolute number of the individual errors, and averaging these, gives the average difference per load (either above or below weighbridge

Table 1 - Truck configurations and loadcell location

	Configuration	Location of Loadcells	Age (yrs)
Vulcan Scales:			
Truck 1	Folding Bailey Bridge	2 cells under fifth wheel, and four cells under suspension equalisers	1
Truck 2	B-Train	as above	0.5 - 2
Truck 3	Truck and Trailer, shorts	8 cells under bolsters	cells 4, new electronics
SI Scales:			
Truck 1	Truck and Trailer, shorts	8 cells under bolsters	3
Truck 2	Truck and Trailer, shorts	8 cells under bolsters	1.5
Truck 3	Truck and Trailer, shorts	8 cells under bolsters	½ cells 5, ½ 2.5
Truck 4	Truck and Trailer, longs	4 cells under bolsters	1.5
Truck 5	Truck and Trailer, shorts	8 cells under bolsters	1.5
Lodec/SI Scales:			
Truck 1	Bailey Bridge	8 cells under bolsters (all Lodec)	1.5
Truck 2	Truck and Trailer, convertible	4 cells (Lodec) under bolsters on truck, 4 cells (SI) under suspension on trailer	1.5
Truck 3	Truck and Trailer, convertible	as above	1.5

weight) between the truck scales and the weighbridge during the collection period.

The real measure of the precision of the scales is how variable the error is. This can be measured by the standard deviation of the error. For example, if the average error was +100 kg, and the standard deviation of the error was 200 kg, then 95% of the errors would be between -300 kg and +500 kg (the average ± 2 std. dev.). However, if the standard deviation of the error was only 50 kg, then 95% of the errors would lie between 0 and +200 kg, a much smaller range and more consistent performance.

Variability of the scales was also calculated following a procedure used by FERIC in their truck scale study (Phillips, 1989). A linear regression was calculated between the weighbridge weights and the scales weights, as shown in Figure 2. Ideally, with no variation in performance, the weights recorded by the scales would fall on this one line, irrespective of the calibration of the scales. Also if the calibration of the scales was correct, the line would pass through the origin and have a slope of 1.0.

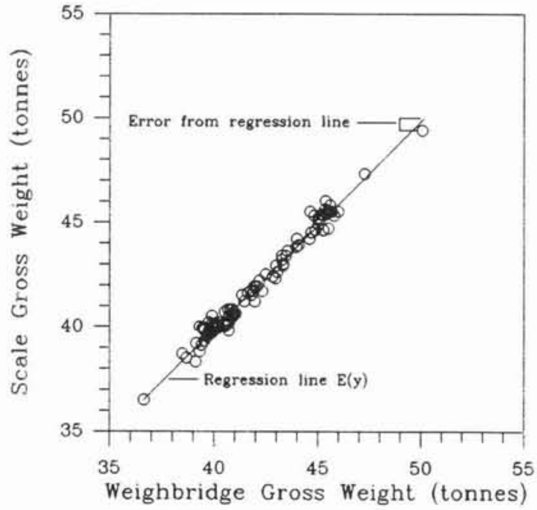

Figure 2 - Typical weighbridge versus scales graph, with best fit regression line

A new data set was calculated as the difference between the recorded scale weight, and the scale weight predicted by the linear regression. This is shown on Figure 2 as the distance of the data points from the regression line. The standard deviation of this data set, expressed as a percentage of the average gross weight

Table 2 - Summary of results from truck scales

Truck	No. of Loads	Average Error (tonnes)	Std Dev. of Error (tonnes)	Range of Error (Min,Max)	Average Absolute Error (tonnes)	Av. Abs. Error as % of Av. Gross	Coeff. of Variation
Vulcan Scales:							
Truck 1	96	-0.15*	0.49	-1.28,1.28	± 0.39	0.85%	1.00%
Truck 2	144	-0.25*	0.82	-4.4,1.34	± 0.57	1.08%	1.49%
	81	0.17	0.89	-2.38,3.16	± 0.68	1.33%	1.61%
Truck 3	191	-0.14*	0.44	-1.8,0.97	± 0.35	0.71%	0.88%
SI Scales:							
Truck 1	82	0.17*	0.29	-0.4,0.96	± 0.28	0.61%	0.62%
	27	-0.52*	0.24	-0.98,0.06	± 0.53	1.14%	0.49%
Truck 2	87	0.04	0.66	-1.62,2.32	± 0.48	1.04%	1.42%
Truck 3	85	-0.09	0.68	-1.76,2.32	± 0.49	1.07%	1.33%
	102	-0.13*	0.22	-1.06,0.4	± 0.19	0.42%	0.47%
Truck 4	180	-0.09*	0.56	-2.1,1.6	± 0.43	0.99%	1.25%
Truck 5	48	0.04	0.68	-2.3,1.6	± 0.50	1.14%	1.37%
Lodec/SI Scales:							
Truck 1 (All Lodec)	104	-0.14*	0.33	-0.92,0.86	± 0.27	0.65%	0.78%
Truck 2 (Lodec/SI)	84	-0.15*	0.47	-1.1,1.26	± 0.38	0.84%	1.02%
Truck 3 (Lodec/SI)	52	0.27*	0.69	-1.02,2.42	± 0.58	1.25%	1.44%
	34	-0.28	1.19	-3.78,1.58	± 0.93	1.96%	2.51%

* indicates the average error is significantly different from zero ($P<0.05$)

has been termed the Coefficient of Variation of the estimate (COV) and is used as a measure of the precision of the scales.

RESULTS AND DISCUSSION

The results of the data analysis for the truck scales are shown in Table 2. For most trucks, the average error was small, indicating good calibration.

Two sets of data were collected from Vulcan Truck 2, as a suspension modification was made after the first set of data was collected. The operator felt that this had improved the performance of the scales and offered to collect more data. However, although there is a significant difference in the average error, indicating changed calibration, there is no significant difference between the two data sets in terms of variability.

The scales on SI Truck 1 were recalibrated by the driver after 82 loads, due to what he considered a larger than normal error being recorded. This resulted in a markedly different average error for the second data set, although the variability, as shown by the standard deviation, is similar to that before recalibration. This shows the effect that calibration has, it does not affect the precision (consistency) of the scales, only the absolute accuracy.

The scales on SI Truck 3 were fitted with all new cables after the first 85 loads, as the operator was unhappy with the accuracy he was getting, although the scale performance was not significantly worse than many of the other trucks. The effect of the new cables can be seen in significantly better performance in the second set of data collected, and is in fact the best performance of any of the scales. The scales installation on this truck was approximately three years old, and the improved performance shown after the maintenance illustrates the need to maintain the scale system for best performance.

The data for Lodec/SI Truck 3 are divided into two sets due to a fault developing with the scales during the data collection. The fault was traced to a defective load cell. The data before the fault occurred, and after it was fixed, is grouped together in the first data summary, and the second data is that collected while the fault was present. It can be seen that the data collected while the fault was present represents significantly poorer performance compared to the other data set.

The precision of the scales, as measured by the COV, ranges from 0.47% to 1.61% (disregarding the data collected from the faulty system). Figures 3 and 4 show the variation in the recorded error for the most precise, and for the least precise scales respectively. The difference in the performance of the scales is easily seen by comparing these two graphs, with much smaller errors for the scales shown in Figure 3 (COV = 0.47%), compared to the frequent large errors in Figure 4 (COV = 1.61%).

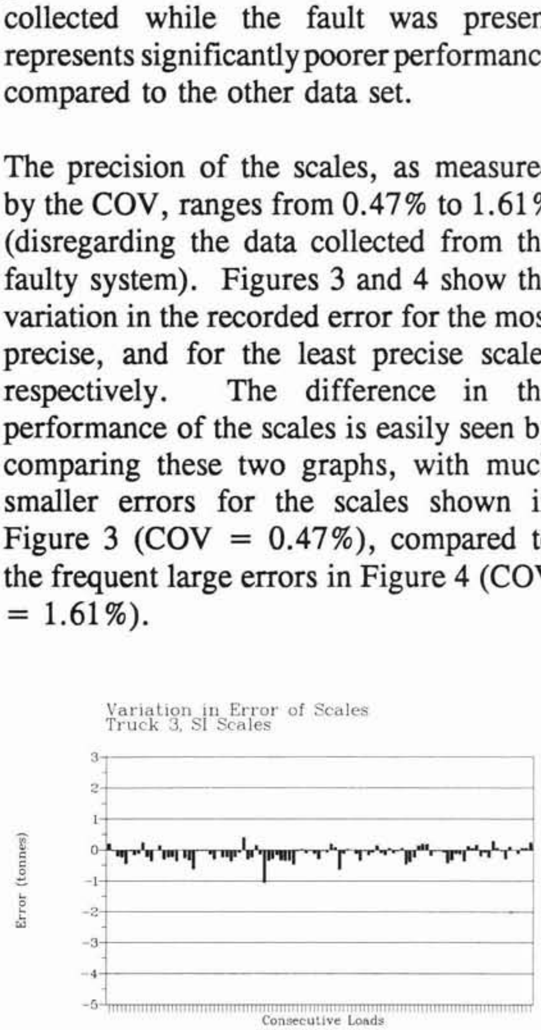

Figure 3 - Variation of error (scales - weighbridge) from most precise scales

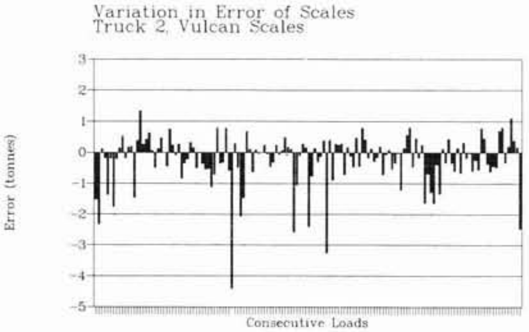

Figure 4 - Variation of error for least precise scales

For comparison, the COVs measured by FERIC during their study, involving scales from the same three manufacturers as in this study, ranged from approximately 0.35% to 2.20%. FERIC results compare well with those recorded in this study.

Effect of Fuel Level

The fuel level will affect the precision due to the change in truck tare weight. An analysis on the most precise scales in this study (SI Truck 3) showed that although the fuel level was a significant factor in the trend of the error, the effect tends to be overshadowed by the variation caused by other factors. For this reason, no correction for the effect of fuel level was undertaken.

Effect of Skid Terrain

Two of the data sets collected in the study included information on the terrain of the skid site. This was subjectively recorded by the truck drivers into categories of flat, slope (side or longitudinal), and uneven.

For Vulcan Truck 2, there is a significant difference (95% level) between the errors measured on the flat, and those measured on a sloping or uneven skid. A trend of increasing error and variability is observed as the skid terrain departs from flat and smooth (Table 3).

Vulcan Truck 3 showed no significant differences between the terrain classes, although the same trend is evident. Truck 2 has the loadcells located under the suspension equaliser brackets on the trailer, while Truck 3 has all loadcells under the bolsters.

For Vulcan Truck 2, in addition to classifying the skid conditions, the weight indicated by the truck scales (for 16 loads) was recorded on flat ground at the weighbridge. This was generally done for loads which had shown a large error

Table 3 - Comparison of errors by skid terrain class. Different letters indicate a significant difference (P<0.05) between performance on the different terrain classes

Slope Class	Flat		Slope		Uneven	
	Average Error	Std. Dev.	Average Error	Std. Dev.	Average Error	Std. Dev.
Vulcan Truck 2	0.07[a]	0.70	-0.35[b]	0.73	-0.86[b]	1.48
Vulcan Truck 3	-0.07[c]	0.35	-0.19[c]	0.49	-0.26[c]	0.55

between the weight measured at the skid, and the weighbridge weight. Table 4 compares the performance of the truck scales on the flat ground at the weighbridge, to the same loads recorded at the skid. It is seen that the performance on the flat ground is very much improved over that at the skid. This again illustrates the susceptibility of some scale installations to uneven ground conditions.

Effect of Scale Installation Type

The type of scale installation can be divided into two categories: those with the loadcells all under the bolsters, and those with some loadcells under the suspension mounts. It has been speculated that the scales are not as precise with the loadcells located under the suspension. A T-test conducted between the COVs for the trucks in these two groups revealed no significant difference at the 95% confidence level. However, as discussed in the previous section, there is some evidence to suggest that under suspension installations may be more vulnerable to uneven ground conditions.

Use of Truck Scales for Log Payment

There has been some interest in recent times in using truck scales as an alternative to a weighbridge for log sales and payment of contractors. The results from this study indicate that with careful calibration, this should be a fair and equitable practice. The results from Vulcan Truck 2 when weighing at the weighbridge illustrated the improvement in accuracy achieved when weighing on level ground, as would be the case when weighing at a mill yard on delivery. As these were the least precise scales in this study, most scale systems would be expected to achieve better performance than this on flat ground. Totalled over a number of loads, individual errors should approximately cancel out if calibration is correct. It will be necessary however, to regularly check the calibration of the truck scales on a certified weighbridge, or in some other manner.

Variation by Brand

There is no significant difference in performance between the different brands of scales in the study. Rather, it appears that the method of installation, the level of upkeep, and good calibration are the important factors that determine scale performance.

Comparison of Highway Payload Variation

Payload data was collected from five trucks without scales, operating on-highway, and is compared to data from five of the scale trucks for average weight and variability (Table 5). The figures in brackets are the average weights as percentages of the allowable highway legal maximum weights, including weighing tolerances.

Table 4 - Comparison of truck scale performance at skid versus at weighbridge

	Average Error	Standard Deviation	Average Absolute Error	Standard Deviation
Truck Scales at Skid	-1.31	1.28	1.45	1.12
Truck Scales at Weighbridge	-0.10	0.52	0.35	0.37

Table 5 - Comparison of average weights and weight variation between scales equipped trucks and those without scales

	Scales Fitted		No Scales	
	Average Gross Weight (tonnes)	Standard Deviation	Average Gross Weight (tonnes)	Standard Deviation
1	40.5 (100%)	1.23	41.2 (95%)	2.01
2	45.1 (99%)	1.12	41.2 (95%)	1.69
3	45.7 (100%)	1.00	42.3 (97%)	2.42
4	45.9 (101%)	0.96	42.3 (97%)	2.13
5	45.7 (100%)	1.11	42.4 (97%)	2.06
Averages	100%	1.08	96%	2.06

The variation of the gross weights for the trucks with scales, measured by the standard deviation, is significantly lower ($P=0.0001$) than the variation for the trucks without scales. The average weights for the trucks with scales are tightly grouped around their respective maximum allowable, while the averages for the non-scales trucks are lower than the allowable maximums. While there may be some effect in this data of the different loading policies of the individual operators and drivers with respect to attaining maximum loads, it is clear that with the intention of avoiding overloading, scales will help achieve higher average payloads while lowering the incidence and severity of overloading.

Scales Repair and Maintenance

Data on the repair and maintenance required by the scale systems over a twelve month period were recorded by the truck contractors (Table 6).

From Table 6, it can be seen that many of the trucks had loadcell failures during the study period. In addition, damage to plugs and wiring was fairly common, requiring regular attention. There were, however, several trucks whose scales were more or less maintenance free during the period.

ECONOMIC ANALYSIS OF ON-BOARD SCALES

A cost-benefit analysis was conducted to assess the economics of fitting on-board scales to a logging truck. A costing for the scales was calculated based on the Annual Average Investment method, depreciating a typical shorts or convertible scale system costing $12,000 to 35% of purchase value over five years, and allowing for an average R&M figure of $1020/year from the data collected. The total owning and operating cost for a typical scale system works out to $3650/year.

The weight data from one truck with scales, and one truck without scales was analysed to predict an expected total fines per year (both over-weight and over RUC license weight), based on random enforcement weighings of 1 load in 40. The probability of a random load being in an overweight category was calculated assuming a normal distribution of the weight data. On the benefit side of the analysis is the higher average payload shown to be achievable using scales. This analysis is summarised in Table 7.

The analysis shows that the truck with scales can achieve extra payload into the

Table 6 - Scale repairs summary

Truck	Problem/Repair	Approx. Cost
Vulcan Truck 1	Display on meter repaired under warranty Loadcell plug socket broken - repaired free of charge	- -
Vulcan Truck 2	Meter replaced under warranty Wiring repairs - fix connector	- $35
Vulcan Truck 3	No repairs during 12 month period	-
SI Truck 1	No repairs during 12 month period	-
SI Truck 2	One loadcell replaced due to broken plug fitting and moisture ingress Wiring problems, and attempted cell repair	$1571 $300
SI Truck 3	New cables fitted. No other problems in six years	$180
SI Truck 4	Replaced 1 loadcell (4 yrs old), loose connection caused moisture ingress Wiring problems, pinched wired on pole etc	$1420 $300
SI Truck 5	Replaced two loadcells, cracked due to incorrect mounting (2 more cells replaced free over 2 yr period) Trouble shooting cells, wiring problems	$3230 $400
Lodec Truck 1	Replaced 1 cracked loadcell (4 cracked & replaced free in 1 yr period) Wiring problems	$1474 $300
Lodec Truck 2	Replaced loadcell, plug knocked off - unrepairable Wiring problems, junction box repairs	$1500 $300
Lodec Truck 3	One loadcell replaced free Wiring repairs	- $200
	Average	$1020

Table 7 - Economic analysis of on-board truck scales

	Scales Truck		Non-Scales Truck	
	Cost	Benefit	Cost	Benefit
Annual Expected fines	$2547		$3672	
Extra income per year (payload above an average weight of maximum allowable)		$11100 (1.05 tonne)		$2850 (0.27 Tonne)
Scales Owning & Operating Cost	$3650		-	
		$4903	$822	

Table 8 - Summary of results from Loadrite scales

Loader	No. of Loads	Average Error (tonnes)	Std.Dev. of Error (tonnes)	Range of Error (Min,Max)	Average Absolute Error (tonnes)	Av. Abs. Error as % Av. Gross	Coeff. of Variation
1	96	0.82	1.29	-1.96,7.72	± 1.04	2.26%	4.18%
2	110	-0.56	1.31	-5.86,8.98	± 0.93	2.12%	4.53%
3	100	1.52	1.07	-2.6,4.16	± 1.64	3.57%	3.18%
4	52	0.49	1.57	-2.8,4.49	± 1.23	2.58%	4.55%
5	26	-0.34	0.42	-1.02,0.86	± 0.45	0.86%	1.06%
6	88	0.17	1.59	-6.5,6.9	± 1.09	2.56%	5.8%

weighing tolerances, with less risk of fines than the truck without scales. The overall benefit shows a pay back period for the scales of 2.5 years. An increase in frequency of enforcement weighing will obviously favour the use of on-board scales even further.

LOADRITE SCALES

Table 8 presents the results for the Loadrites studied.

The results showed that in general the Loadrites are less accurate, and less consistent than the truck scales. Only loader 5 approached the performance of the truck scales. Most of the Loadrites had a large range of error, with numerous errors sufficient to cause overloading fines of several thousand dollars.

No attempt is made to explain the causes of the errors for the Loadrites, as it is only intended to illustrate typical operational accuracy. However, past studies on Loadrites have indicated several factors which can introduce error into the measured weights (Ellis, 1986). These include improper operating techniques (engine rpm too fast), sloping ground, and neglecting calibration maintenance. New versions of the Loadrite reportedly compensate for engine speed and other factors.

CONCLUSIONS

The measured accuracy of on-board truck scales varied significantly, ranging from average absolute errors of ± 0.19 tonnes to ± 0.68 tonnes. The magnitude of the average error was not dependent on brand or whether the loadcells were located under the suspension or under the bolsters. Probable factors influencing scale precision are quality of maintenance, degree of care in the use of the scales, and engineering aspects of the selection and installation of the loadcells.

Uneven ground conditions were found to deteriorate scale performance. In flat ground however, truck scales are probably accurate enough for payment and sale of wood.

The payload variation of trucks without scales was found to be twice that of trucks equipped with on-board scales.

Like the accuracy, the reliability of the scales varied significantly over the 12 month period they were monitored, from no maintenance at all to replacement of several loadcells.

An economic analysis based on several simplifying assumptions, indicated a likely pay back period of 2.5 years on truck scales.

The performance of Loadrite scales was found to be significantly inferior to the truck scales in general.

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