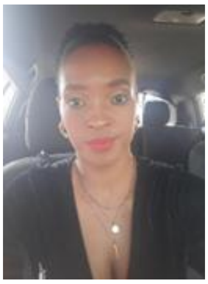
A COMPARISON OF AXLE WEIGHT MASSES FROM A LOW-SPEED WEIGH-IN-MOTION SCALE AND A STATIC WEIGHBRIDGE SCALE FOR THE PURPOSE OF BROADENING LAW ENFORCEMENT EFFORTS



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Abstract

In South Africa, one of the primary uses of the low-speed weigh-in-motion scale involves the detection of overloaded heavy vehicles and the automatic alerting of traffic officials or the automatic rerouting of heavy vehicles to the static weigh bridges. This study analysed data from two static weighbridges and four low speed weigh-in-motion scales in order to determine how the WIM weighting can be applied even though it does not achieve a 100% weighing precision compared to the static scale weighing, so as to expand law enforcement efforts. The accuracy rates of the weigh-in-motion weights to the static weights of all the heavy vehicles which had the same weigh results from both the static and weigh-in-motion scale were analysed to check accuracy difference in percentages. The weigh-in-motion weights of Axle1 and Axle2 from the weigh-in-motion scale showed that more than 90% of the heavy vehicles weighed were found along the +-15% accuracy of the 100%.

Keywords: Static Scale, Heavy Vehicles, Weigh-in-Motion (WIM) Scale.

1. Introduction

Very little research has been done in South Africa regarding the application of WIM for studies on law enforcement in comparison to other countries. Given that WIM has been used in South Africa for the past 70 years (Slavik, 2007), this is a significant disadvantage, especially with the high rate at which the South African road infrastructure is deteriorating. Screening potentially overloaded heavy vehicles and alerting authorities or automatically directing suspected vehicles to static weigh bridges to determine whether the heavy vehicles in question are overloaded is one of the key applications of low-speed WIM in South Africa.

Numerous studies have demonstrated how the use of WIM weights for law enforcement is constrained by the lack of precision when compared to static scale weights. This study acknowledges the lack of accuracy caused by the dynamic nature of the WIM Scale. As a result, it might not be reasonable to assume that the weight of a vehicle in motion will be the same as when that same vehicle is stationary, especially given that even static scales cannot operate as intended when a heavy vehicle is in motion. Therefore, the goal of this study is to ascertain whether low speed WIM can be used for law enforcement by examining the range or percentages in which the WIM weights change from the static weights while giving the same weigh results in terms of the heavy vehicle being legal, on a warning, or overloaded. The analysis of the data focuses on the axle weights and the speed at which the heavy vehicle was moving on the low-speed WIM.

2. Background to Weigh in Motion

According to (Slavik, 2007), a WIM scale is "a technique for the measurement of axle loads without stopping vehicles" and "a scale that measures dynamic forces applied to the road surface by passing wheels." Then vice versa, a static weighbridge scale is a scale that assesses the static forces imposed on the road by stationary heavy vehicles. In contrast to static weighbridge scales, which are primarily used for law enforcement purposes to reduce overloading of heavy vehicles along South African routes, WIM is used to monitor traffic load for tracking suspect overloaded vehicles for accurate static weigh and potential fine when the heavy vehicle is found overloaded, estimate the life span of pavements, assist traffic officials on where overloading tends to occur most frequently, maintenance and pavement design. (Slavik, 2007).

There are several reasons why the Weigh-in-Motion scales cannot be used, including their mediocre weighing accuracy (Gajda, Burnos and Sroka, 2006). However, because vehicles are weighed in two different states and because WIM has always been a dynamic scale, and it is difficult to evaluate a dynamic scale's weighing accuracy using a comparison to a static scale.

This study's main goal is to look at the rate at which specific axle weight masses vary from the WIM scale to the static weigh scale. In the investigation, the masses of heavy vehicles that were weighed using weigh-in motion scales and static weigh-bridge scales were compared in order to determine whether weigh in motion scales may be used to broaden the scope of law enforcement operations.

3. Application of WIM

3.1 WIM

3.1.1 Previous work on the use of WIM for law enforcement.

Research was once conducted at the Montana Department of Transportation in the US to try and maintain infrastructure through the use of WIM data (Stephens *et al.*, 2003). The information was utilized to point traffic officials to highways where there is a lot of overloading during the hours when this overloading is the most common. By using this information, overloading was reduced by 20% in all the monitored sites. The use of WIM for prosecuting of overweight heavy vehicles in France was examined by (Jacob and Cottineau, 2016). The precision of the WIM equipment for prosecution of vehicles in Poland was evaluated by (Gajda, Burnos and Sroka, 2018).

3.1.2 WIM In South Africa

South Africa has a current WIM history of 70 years, and there were around fifty six (56) permanent WIM stations on South African provincial & national routes in 2007(Slavik, 2007). The 2018 SANRAl report shows that there has been another increase in the number of the permanent WIM sites in South Africa as displayed on Figure 1. The permanent WIM sites are run by SANRAL and others by the provinces (CSIR, 2010). The CSIR report further higlited that in 2010 South Africa had 122 static weigh bridges across its 9 provinces.

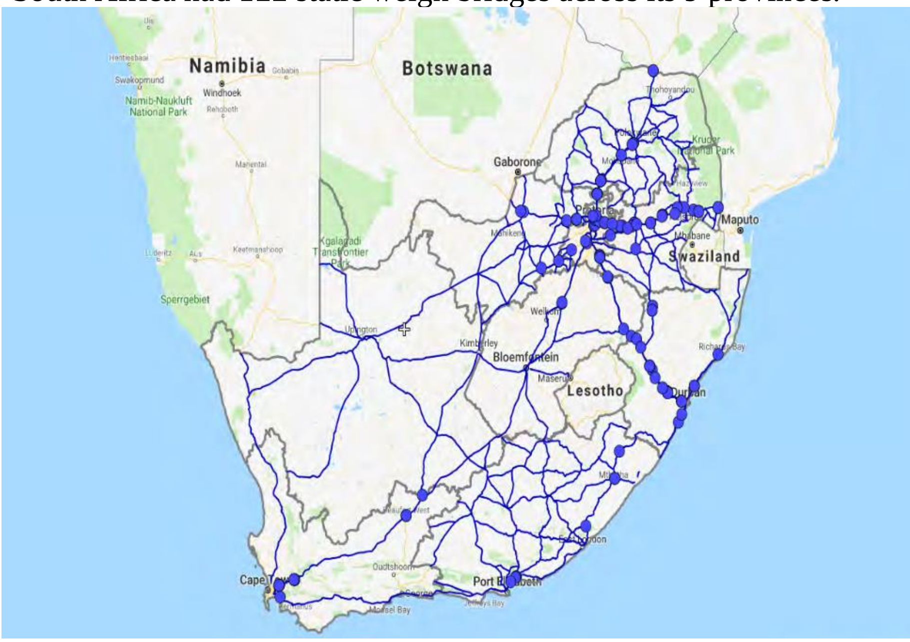

Figure 1: Permanent WIM Stations across South Africa(Kannemeyer, 2018)

4. Methodology

Information was collected at a location with two weighbridges that are static two-waist bridge located on a portion of the South African national road which targets vehicles travelling in both directions. The two automated weigh-in-motion scales are located right outside the static weighbridge sites. These scales weigh the vehicles and, through the use of a boom gate, only those that are legal are allowed to proceed. To assess whether the vehicles are overloaded or not, any suspected overloads are nonetheless directed to the static weighbridge scale.

A data set collected over three months was provided, covering November 2022 to January 2023. The weigh-in motion data set required a lot of data cleaning and pre-processing. Variables including the time, date, and vehicle registration were useful in linking and comparing the WIM scale and the static scale data sets. Observations without vehicle registration numbers had to be removed as they could not be linked to the static data. It was also necessary to eliminate data points with empty or zero-weight readings. Only vehicles with a difference of 06 seconds up to 59 minutes between the time the vehicle was weighed on the static scale & WIM scale were included in the data set that was used to compare the axle weights on the static scale & the WIM scale. The final data set that was used contained heavy vehicles which the WIM scale flagged as "suspects" for potential overload, which is how all these heavy vehicles ended up on the static weighbridge scale.

The following table highlights the 31 717 Heavy Vehicles from the used data set that have 2, 3, and 4 axle units using three distinct colors. There are 3 744 heavy trucks with 2 axle units, 9 585 with 3 axle units, and 18 388 with 4 axle units. The following table lists the heavy vehicle configurations that were found in the data collection.

Table 1: Heavy Vehicle Configurations in the Sample Data Set

	Heavy Vehicle Configuration	**Number of Heavy Vehicles**
2 Axle unit's heavy vehicles		
	11	2 046
	12	1 650
	22	48
Subtotal	**3**	**3 744**
3Axle units' heavy vehicles		
	111	136
	112	431
	113	84
	121	26
	122	384
	123	8 446
	222	3
	223	75
Subtotal	**8**	**9 585**
4 Axle units' heavy vehicles		
	1111	148

	1112	69
	1121	8
	1122	15
	1211	760
	1212	37
	1221	9
	1222	16 989
	1223	97
	1231	93
	1232	134
	1233	2
	2211	3
	2212	2
	2222	22
Subtotal	**15**	**18 388**
Grand Total	**26**	**31 717**

5. Data Analysis and Results

The first step was to look at all the heavy vehicles weigh results from the entire data set to check if the WIM could be used to flag overloaded heavy vehicles or not. Table 2 shows that 17 851of the heavy vehicles from the entire data set was not supposed to be directed into the static weighbridge as the heavy vehicle's weights were legal according to the WIM scale. This could mean that besides the weights alone on the WIM scale there might be other things the WIM system could be considering before letting the heavy vehicles of the hook.

Table 2 All Vehicles Loading Status

	Static Legal HV, s	Static Overload HV, s	Static Warning HV, s	**Totals**
WIM Legal	17 851(81%)	230 (24%)	3 966 (46%)	**22 047**
WIM Overload	932 (4%)	435 (46%)	1 352 (16%)	**2 719**
WIM Warning	3 269 (15%)	280 (30%)	3 402 (39%)	**6 951**
Total	**22 052 (100%)**	**945 (100%)**	**8 720 (100%)**	**31 717**

Table 2 shows that, when comparing the weigh results from the static scale and the WIM scale, 81% of all the legal heavy vehicles were appropriately weighed as legal, 46% of all the overloaded vehicles were correctly weighed as overloaded, and 39% of all the heavy vehicles on a warning were correctly weighed as on a warning. Table 2 indicates that only 30% ((2 719+6 951)/31 717 * 100) of the heavy vehicles were required to weigh on the static weighbridge, and that 70% (22 047/31 717*100) of the heavy vehicles were not supposed to end up there because all these heavy vehicles weights were all determined to be legal by the WIM scale.

Furthermore, the weight of the axles from the WIM scale were divided by the axle weight from the static scale and multiplied by 100 to obtain the percentage of accuracy from the static weigh bridge scale as it is already in use for law enforcement. The tables below provide the accuracy results as percentages according to the axle units.

$$Acc(Accuracy) = \frac{WIM\ Weights}{Static\ Weights} * 100$$

Table 3: Axles which have an accuracy rate of 100% and +-15%.

Axle. No	85% <= Acc < 100%	Acc=100%	100% < Acc <= 115%	Total Percentage
Axle1	42%	8%	46%	96%
Axle2	21%	7%	63%	91%
Axle3	36%	8%	36%	80%
Axle4	21%	5%	26%	52%

As (Slavik, 2007) stated, "The fact is that WIM cannot supply static loads; it is, and always has been, a dynamic scale." This statement is automatically supported by the fact that, of the entire data set across all axles, only 5% to 8% of the axle weights were 100% accurate. The accuracy rates are also showing that if in South Africa we were to follow the American standard (ASTM E 1318, 2002), which calls for a +-15% accuracy tolerance when utilizing static loads as a reference, then on Axle1, Axle2 & Axle3 the WIM would have covered more that 80% of the weighed vehicles unlike on Axle4 only, 52% of the vehicles would have been covered.

Figure 2, Figure 3, Figure 4 & Figure 5show the average speed of the heavy vehicles within the accuracy range of +-15% around 100%. Axle1, Axle2 & Axle 3 show the same pattern when it comes to the 100% accuracy rate. The average speed of all vehicles which had a 100% accuracy ranges from 20 to 25 km/h. The same speed range on Axle1, Axle2, Axle3 & Axle4 was found in the +15% accuracy weight range. Therefore, speed is not the only contributing factor. As (Slavik, 2007), (Swanlund, 2016) and (Sujon and Dai, 2021) also mentioned that WIM measurements are susceptible to many influences including the condition and suspension characteristics of individual vehicles, the road's quality and firmness, and the humidity and temperature that can affect the WIM sensor.

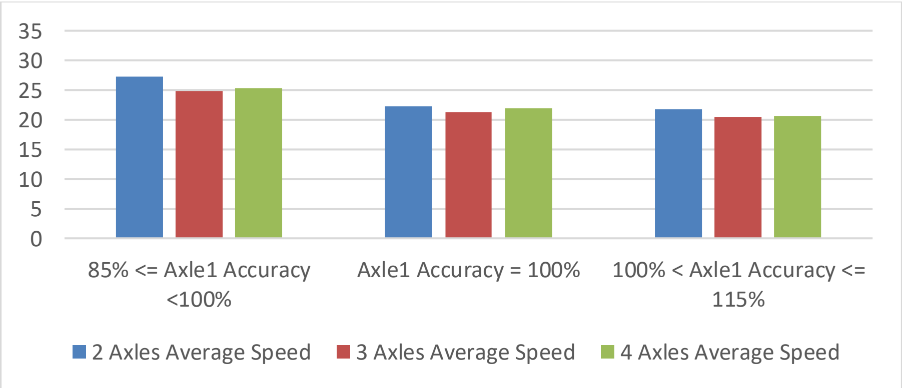

Figure 2: Axle1 Average Spped on +-15% accuracy of 100%

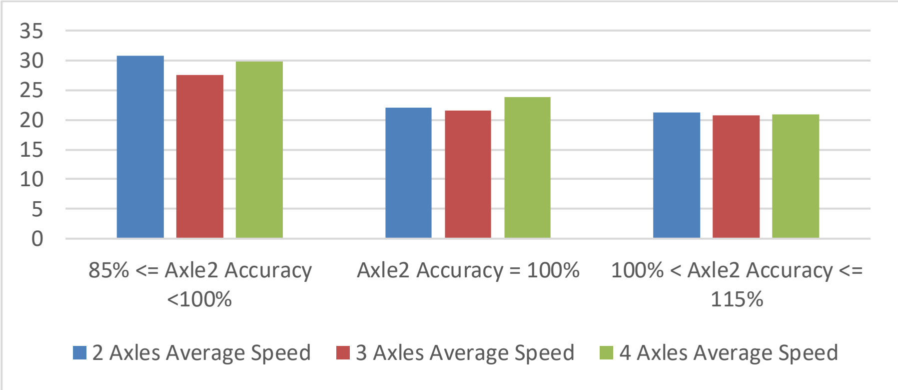

Figure 3: Axle2 Average speed with +-15% accuracy of 100%

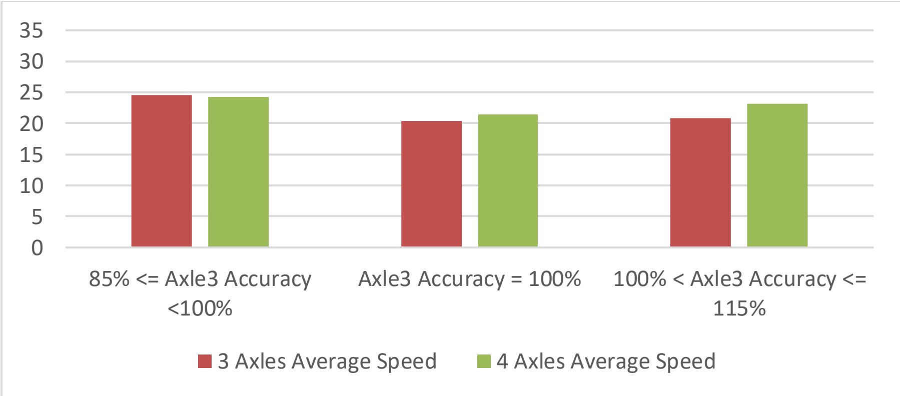

Figure 4: Axle3 Average Speed on +-15% accuracy of 100%

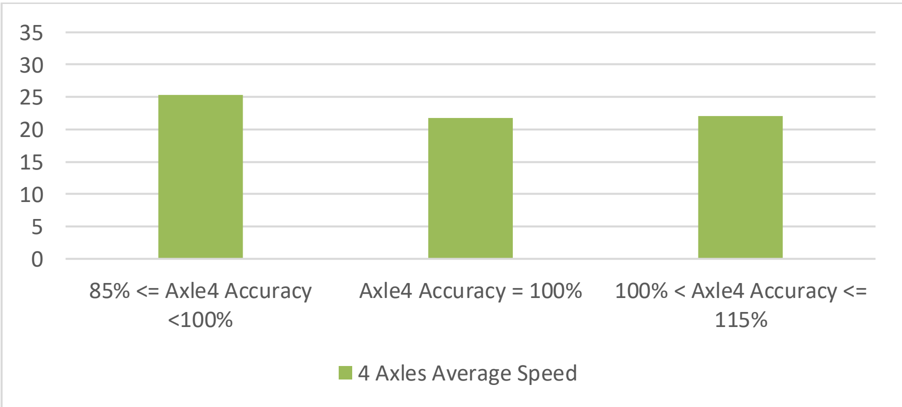

Figure 5: Axle 4 Average speed on +-15% accuracy of 100%

Table 4, Table 5, & Table 6 display the percentage of weights of all heavy vehicles that were determined to be lawful, on warning, or overloaded using both the static and WIM scales. These are the heavy vehicles highlighted in Table 2. These tables highlight the possibility that, despite potential differences in weighting, the conclusions could still be the same.

Table 4: Axle Accuracy Rate of Legal Vehicles

Axle No.	85% <= Acc < 100%	Acc=100%	100% < Acc <= 115%	Total Percentage
Axle1	41%	8%	45%	94%
Axle2	21%	7%	65%	93%
Axle3	35%	8%	36%	79%
Axle4	24%	6%	29%	59%

Table 5: Axle Accuracy Rate of Warning Vehicles

Axle No.	85% <= Acc < 100%	Acc=100%	100% < Acc <= 115%	Total Percentage
Axle1	43%	10%	45%	98%
Axle2	25%	13%	59%	97%
Axle3	39%	13%	37%	89%
Axle4	11%	4%	21%	36%

Table 6: Axle Accuracy Rate of Overload Vehicles

Axle No.	85% <= Acc < 100%	Acc=100%	100% < Acc <= 115%	Total Percentage
Axle1	43%	7%	48%	98%
Axle2	31%	9%	56%	96%
Axle3	25%	6%	21%	52%
Axle4	4%	1%	11%	16%

All the accuracy tables from Table 3, Table 4, Table 5, & Table 6 indicate that the Axle 4 weights are the least trustworthy, which may indicate that there is a technical problem. Axles 1 and 2 demonstrate that practically all weightings can deviate by up to 15% from the correctness of 100% weights.

Discussion/ Conclusion

The data analysis process proved that the WIM scale is and will always be a dynamic and therefore should not be expected to produce static weights. The ability to use the WIM for law enforcement will not totally solve the overloading problem, which is one of the primary causes of the rapid deterioration of the road infrastructure, but it can reduce it. The majority of the WIM's weightings already match the American standards for accuracy rates for Axle1 and Axle2, where the majority of accurate weighing results are produced within +-15% of the actual value of 100%. Furthermore, the Axle4 deck of the WIM scale could have technical issues hence the number of heavy vehicles found on the +-15% accuracy of 100% was very low.

Regardless of how many axles in the heavy vehicle were discovered to be overweight, the weighing findings were done for the entire vehicle regardless of how many axles were overloaded. This indicates that further research into individual axle weight results is still necessary, and if the results on Axles 1 and Axle 2 remain the same, it presents an opportunity to determine how the WIM weights can be formulated using speed as a parameter to approach or come as close enough to the static weights. This could also open an opportunity to introduce fines based on axle1 and axle2 and using the scientific formulas will then certify whether the vehicle was overloaded or not without the need of a static weighbridge to ascertain that.

Bibliography

ASTM E 1318 (2002) 'Standard Specification for Highway Weigh-In-Motion (WIM) Systems with User Requirements and Test Methods', *ASTM Standard E 1318*, 04(June), pp. 1–16.
CSIR (2010) *DoT-OvstatsLT_Report_20100707*.
Gajda, J., Burnos, P. and Sroka, R. (2006) 'Accuracy Assessment of Weigh-in-Motion Systems for Vehicle's Direct Enforcement', *IEEE Intelligent Transportation Systems Magazine*. IEEE, 10(1), pp. 88–94. doi: 10.1109/MITS.2017.2776111.
Gajda, J., Burnos, P. and Sroka, R. (2018) 'Accuracy Assessment of Weigh-in-Motion Systems for Vehicle's Direct Enforcement', *IEEE Intelligent Transportation Systems Magazine*. IEEE, 10(1), pp. 88–94. doi: 10.1109/MITS.2017.2776111.
Jacob, B. and Cottineau, L. M. (2016) 'Weigh-in-motion for Direct Enforcement of Overloaded Commercial Vehicles', *Transportation Research Procedia*. Elsevier B.V., 14(0), pp. 1413–1422. doi: 10.1016/j.trpro.2016.05.214.
Kannemeyer, L. (2018) 'USE OF WIM IN SOUTHERN AFRICA Current / Future'.
Slavik, M. (2007) 'Weigh-in-motion: Years of South African experience', *Journal of the South African Institution of Civil Engineering*, 49(1), pp. 11–16.
Stephens, J. *et al.* (2003) 'Preservation of Infrastructure by Using Weigh-in-Motion Coordinated Weight Enforcement', *Transportation Research Record*, (1855), pp. 143–150. doi: 10.3141/1855-18.
Sujon, M. and Dai, F. (2021) 'Application of weigh-in-motion technologies for pavement and bridge response monitoring: State-of-the-art review', *Automation in Construction*. Elsevier B.V., 130(August), p. 103844. doi: 10.1016/j.autcon.2021.103844.
Swanlund, M. (2016) 'LTBP Program ' s Literature Review on Weigh-in-Motion Systems', (June).