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Oregon DOT Slow-Speed Weigh-in-Motion (SWIM) Project: Analysis of Initial Weight Data

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This report presents the results of a preliminary analysis of axle weights from the Oregon DOT Slow-Speed Weigh in Motion (SWIM) scale at the Wyeth weigh station.* This report includes an analysis of methodology and variables used in the study; estimates of accuracy and precision of the WIM readings; and a regression analysis of the WIM and static scale weighings. Axles weights were collected from the traffic stream.

Methodology

Weighings for this analysis were collected by a Oregon Department of Motor Vehicles weighmaster with the assistance of a Graduate Research Assistant from the Center for Urban Studies at Portland State University. Data were collected when weighings did not interfere with enforcement duties* at the weigh station and when a clean reading was obtained from the WIM scale. Although this approach does not ensure randomness, it is not expected to bias the sampling process.

The large volume of trucks on I-84 at the site precludes scientific sampling. Even with the conventional weighing process allowing a slow roll across the static scale, trucks are often queued back to the interstate (at which point they are permitted to bypass the scale). While early sampling design called for the random selection of trucks from traffic stream, this has proven impossible to implement due to the setup of traffic control at the site and the need for enforcement.

WIM readings are recorded manually from the WIM monitor, which displays WIM weights for each axle as well as the vehicle speed. As the truck reaches the static scale it is ordered to a full stop by the weighmaster and the weight for the steering axle is recorded. Successive axles are weighed individually or by splitting axles. Care must be taken to ensure the truck comes to a complete stop with only certain axles on the scale. For this reason it was

* The Wyeth station is located at milepost 54 on the Westbound lane of I-84.

* Enforcement of axle weights, vehicle weights, vehicle lengths, safety violations, and tracking of permit tags, takes the majority of the weighmaster's time while on site. As data-collection is secondary task to enforcement it is not uncommon for an hours time to pass between opportunities for sampling.

necessary for the weighmaster to direct the truck from outside while the scale readings were recorded from inside the building.

Splitting Axles

Splitting axles is a process by which individual axles within axle groupings are weighed. The process requires two people and requires time and concentration, raising issues of measurement error.

There are several types of truck which do not require splitting and can be weighed by a single individual from within the weigh shed. “5-5’s”, “3-3’s”, and “6-7’s” have no axle groups. Although this offers convenience for data collection (axles can be fairly easily weighed by a single weighmaster), it raises issues of sampling bias due to predisposition to select only those trucks without grouped axles.

Rounding Error

Axle weights are recorded manually from the scale display inside the weigh shed. Static weights can be rounded downward to the nearest 50 pounds, but are rounded down to the nearest 100 pounds for this study. WIM weights are displayed to the nearest 100 pounds and it is uncertain what type of rounding takes place.

Analysis of Variables

Weighings from the WIM and static scales were collected over a period of three days (June 6, June 9, and June 18), yielding data on 45 trucks and 223 axles. Data was also collected for vehicle type, number of axles, vehicle speed, and axle weight for each axle.

Vehicle Type

Oregon DOT classifies trucks into 8 vehicle types which are listed below along with the number of each type used for the study and the number of axles for which data is recorded. Sixty percent of the sample are type 3 - tractor-trailer semi’s.

Vehicle Type

V-TYPE	vehicle samples #	%	axle samples #	%
1 - truck	2	4.4.	5	2.2
2 - log-truck	4	8.9	20	9.0
3 - t-t semi	28	62.2	135	60.5
4 - truck w/ trailer	1	2.2	5	2.2
5 - double	7	15.6	39	17.5
6 - triple trailer	1	2.2	7	3.1
7 - dromedary	1	2.2	5	2.2
8 - other	1	2.2	7	3.1
Total	45	100	223	100.0

Axles

Number of operating axles on each truck are recorded as they pass through the weigh station. Non-operating axles, such as retracted auxiliary axles are not counted. Each axle is numbered from front of the truck. Axle 1 is always the steering axle. Although axles 2 and 3 are often the drive axles, this is not always the case, especially in trucks with auxiliary axles forward of the drive axles. Five axle and 7 axle trucks are the most common and make up 74 percent and 12 percent of the sample, respectfully.

Speed

Vehicle speed is recorded by sensors within the WIM system and is displayed on the WIM monitor. The speeds of the vehicles in the sample ranged from 1 mph to 11 mph. Vehicle speed is an important variable as it appears to effect the dynamic forces instrumental to the WIM system. Previous use of the WIM system required a vehicle speed of no more than 4 mph and an optimum speed of 2 mph. It is hoped that this analysis will quantify the effect of vehicle speed on the WIM readings.

# of Axles on Vehicle

VAXL	Frequency	Percent	Cumulative Percent
2	2	.9	.9
3	11	4.9	5.8
4	4	1.8	7.6
5	166	74.4	82.1
6	12	5.4	87.4
7	28	12.6	100.0
Total	223	100.0	

Vehicle Speeds

	SPEED
# Trucks	45
Minimum	1
Maximum	11
Mean	5.33
Std. Deviation	2.76

Average vehicle speed for the 45 trucks used thus far in the study was 5.3 mph, with only one truck traveling at a speed greater than 10 mph. WIM analysis assumes a constant and steady speed across the WIM sensors. In fact, field conditions make consistency difficult. Most trucks are decelerating or, at times, accelerating when they cross the WIM sensors. Previous studies and the calibration analysis controlled for acceleration and deceleration across the WIM sensors. No efforts towards such control was used in this study. Recorded vehicle speed (1mph - 11mph) was obtained as a result of the narrowing corridor and approach to the scale. Given their high volume and associated queuing, trucks oftentimes came to a complete stop on the WIM scale.

Axle Weights

Axles were weighed on the static scale to determine the "true" axle weight. Weights ranged from 4.5 thousand to 21 thousand pounds, averaging 13.5 thousand with a standard deviation of 3.9 thousand pounds.

Descriptive Statistic for axle weights

	STAT
N	223
Minimum	4.50
Maximum	21.00
Mean	13.4804
Std. Deviation	3.9440

Weather and Temperature

Information on temperature and weather conditions are recorded for each measurement session. However, lack of variability in weather conditions and temperature prevents an analysis of these variables. Temperature data includes bivariate indicators for conditions below freezing or above 100 degrees Fahrenheit. Weather includes bivariate indicators for rain, freezing rain, or snow. Although the WIM system collects information on scale plate temperature, this data is not displayed on the WIM monitor and is not being recorded at this time. Because plate temperature is thought to affect WIM readings more directly, it would be preferable to have this data displayed in the monitor in the future.

Accuracy and Precision of WIM Weights

The accuracy of the WIM weights is determined by testing the difference between WIM readings and static weight. This is derived for each axle and for gross vehicle weight according to the following formula:

Accuracy = [(Wd-Ws)/Ws] * 100**,** where

Wd = axle or vehicle weight measured by a WIM scale;

Ws = axle or vehicle weight measured by a WIM scale

Analysis of the three data groups (all axles, steering axles, and GVW) reveals a mean difference in WIM readings and static weights that are well within the 2 percent error target of this study (see the table and figure below). A comparison of steering axle error to non-steering axle error reveals a much greater range of errors in non-steering axles (38%) than for steering axles (19%). Gross vehicle weight has the least variation in error with all WIM readings coming within ± 5.6% of the static weight.

SWIM Scale Accuracy for Three Data Groups

	N	Min Error	Max Error	Mean Error	Confidence Interval (95%)	
All axles	223	-15.38	22.73	-0.54	-1.14	0.07
Steering Axles	45	-5.69	13.08	-0.26	- 1.22	0.70
Non-steer Axles	178	-15.38	22.73	-0.60	-1.32	0.11
GVW	45	-5.60	5.59	-0.74	-1.46	-0.03

Axles

Among the 223 axles the difference between SWIM and static weights ranges from -15.38 % to 17.73 %. The mean difference is -0.54 %, with a standard deviation of 4.56 %.

One-Sample Test on axle readings

		ACC
t		-1.754
df		222
Sig. (2-tailed)		.081
Mean Difference		-.535445
95% Confidence Interval of the Difference	Lower	-1.137079
	Upper	6.62E-02

Steering Axles

A t-test on steering axles reveals no significant reduction in accuracy compared to the full sample. The 95 % confidence interval reveals a mean difference of readings to be between -1.22 % and 0.7%.

One-Sample Test on Steering Axles

		ACC
t		-.551
df		44
Sig. (2-tailed)		.584
Mean Difference		-.263062
95% Confidence Interval of the Difference	Lower	-1.224523
	Upper	.698400

Non-Steering Axles

Accuracy for non-steering axles is similar to that of steering axles, with a mean difference between SWIM and static scale weights of -.60% and a 95% confidence interval of -1.32% to .11%.

One-Sample Test on Non-Steering Axles

		ACC
t		-1.663
df		177
Sig. (2-tailed)		.098
Mean Difference		-.604306
95% Confidence Interval of the Difference	Lower	-1.321333
	Upper	.112720

Gross Vehicle Weight

Analysis of gross vehicle weight (gvw) reveals accuracy similar to that found with the axle level data. One-sample t-test indicates mean error of -.74% and a 95% confidence interval of -1.45 % to -.028 %. This is the only confidence interval which does not encompass zero, and it indicates the presence of systematic error

One-Sample Test on GVW

		ACC
t		-2.093
df		44
Sig. (2-tailed)		.042
Mean Difference		-.7436
95% Confidence Interval of the Difference	Lower	-1.4596
	Upper	-2.75E-02

The table below present the cumulative frequencies of SWIM errors within one, two and three percentage points for axles and GVW. For twenty-eight percent of the 223 axles the SWIM weight was within +/- one percent of the static scale weight, while slightly more than half the axles had SWIM-measured weights within two percent of the static scale weight. In contrast with our previous experience, errors are somewhat smaller for steering axles. Consistent with previous experience, however, GVW errors were smaller than axle-level errors, indicating off-setting effects.

Cumulative Distribution of SWIM Error

	Error Level		
	1%	2%	3%
All Axles	28	51	64
Steering Axles	29	58	69
Non-Steering Axles	26	51	62
Gross Vehicle Weight	31	56	76

Regression Analysis

The use of regression helps to determine whether various factors affect the precision of SWIM weights.

The regression analysis examines four sets of data - WIM weights for individual axles, steering axles, non-steering axles, and gross vehicle weight. Three exogenous variables which are thought to influence SWIM precision were specified: vehicle speed, number of axles on the vehicle, and axle number.

The table reports the results of the regression and lists the coefficient and t-value for each variable. Steering axles returned the least biased readings with a SWIM reading that was .999 that of the static weight.

Vehicle speed is estimated to have a significant effect on individual axle weights and on non-steering axles, yet is not significant when calculating steering axles or gross vehicle weights. Neither axle position nor number of axles on vehicle is found to significantly affect the SWIM weight.

Inverse Regression Parameter Estimates
Dependent Variable = WIM weight

	VARIABLES						
	Intercept	Static Weight	Vehicle Speed	Axles on Vehicle	Axle #	R2	SEE
All Axles	.555*	0.964*	-0.034*	-0.004	-0.022	.991	0.517
(t-value)	(3.86)	(109.49)	(-2.71)	(-.105)	(-.921)		
Steering Axles	-0.059	.999*	-0.022	.008	N/A.	.935	0.378
	(0.108)	(23.34)	(-0.29)	(.127)			
Non-Steer Axles	0.756*	0.962*	-0.037*	-0.013	-0.040	.982	0.549
	(2.62)	(95.26)	(-2.45)	(-.027)	(-1.185)		
G.V. Weight	1.145	0.967*	-0.165	0.270	N/A.	.996	1.50
	(.915)	(67.32)	(-2.01)	(.848)			

* indicates significance at .05 level

Conclusions

Several conclusions can be drawn from this analysis. First, the SWIM system offers a potentially accurate means of recovering axle and gross vehicle weights at slow speeds (below 10 mph).

Also, this study found a need for teams to minimize procedural contributions to measurement error in collecting the SWIM and static weights. Field conditions are such that two people are required to ensure consistency in data collection. Along these same lines is the need to maintain consistency in personnel. It is recommended that a designated weighmaster and a PSU student be assigned responsibility for data recovery for the duration of the study.

Summary of Recommendations

Change SWIM reporting so plate temperature is displayed on SWIM monitor

Designate a single weighmaster at Wyeth Scale for data collection, assisted by a PSU student