CONCURRENT SESSION 2C - WIM CALIBRATION AND RELATED ISSUES

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DEVELOPING ALTERNATIVE WIM SYSTEM EVALUATION/CALIBRATION METHODS

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ABSTRACT

This paper explores the feasibility of two methods for evaluating/calibrating weigh-in-motion (WIM) systems. The first method uses a combination of test trucks and vehicle simulation models. The computer model VESYM was used for the simulations. The models for the test trucks were calibrated using acceleration measurements on-board the vehicles. Although, this approach does not allow calculation of the discrete value of the dynamic axle load over WIM sensors, it can be used effectively in establishing the extent of variation at a particular WIM site. This information leads to an effective WIM system calibration method. The second method for calibrating WIM systems is by comparing static and dynamic axle loads of vehicles through automatic vehicle identification (AVI). The AVI facilities developed for the Heavy Vehicle Electronic License Plate (HELP) project on the I-5 corridor was used for this purpose. The static axle load of AVI-equipped vehicles was obtained from the Oregon DOT for two sites, namely Woodburn south-bound and Ashland north-bound. The WIM load data was obtained from Lockheed IMS for all the AI&equipped WIM systems on the I-S corridor. The data was analyzed to match AVI numbers, dates and times of weighing. Time limits for traveling between sites were established to ensure that trucks had no time to stop and load/unload cargo between sites. Errors were calculated as the percent difference between WIM and static loads for individual axles/axle groups. Calibration factors were derived to minimize the residual sum of squares of the errors.

ACKNOWLEDGMENT

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PROBLEM STATEMENT

Traditionally, weigh-in-motion (WM) system accuracy has been evaluated with reference to static axle loads or static gross vehicle weights (GVW), (Ref. 1). The issue is complicated, however, by the fact that in-motion axle loads can be substantially different than static axle loads at any particular road location due to pavement roughness-induced vehicle dynamics. This dynamic load variation has been the subject of a number of theoretical and experimental studies, as summarized in (Ref. 2). As a result, two WIM error components are perceived:

- the difference between the dynamic load applied to a WIM sensor the instant an axle is directly over it and the static load of this axle and,
- the inherent error of the WIM system in measuring the dynamic load applied.

To-date, there has been no widely accepted method for effectively separating these two sources of error and incorporating the analysis into a comprehensive procedure for evaluating/calibrating WIM systems. This paper addresses this need and proposes procedures that can be used by field personnel for effectively calibrating WIM systems. The study examines the feasibility of two WIM evaluation/calibration methods, one using a combination of test trucks and vehicle simulation models and another involving traffic stream vehicles equipped with automatic vehicle identification (AVI).

TEST TRUCK -VEHICLE SIMULATION APPROACH

Approach

The basic property utilized for separating these two sources of error in WIM measurements is the spatial repeatability of the dynamic axle loads resulting from replicate vehicle passes (i.e., same axle running at the same speed generates dynamic load waveforms repetitive in space). This was observed by a number of experimental studies (e.g., Figure 1). The other source of error was quantified through a modified version of the vehicle simulation model VESYM (Ref. 4), named VESYMF. The axle dynamic behavior of the test trucks was simulated through VESYMF for the pavement roughness conditions at particular WIM sites.

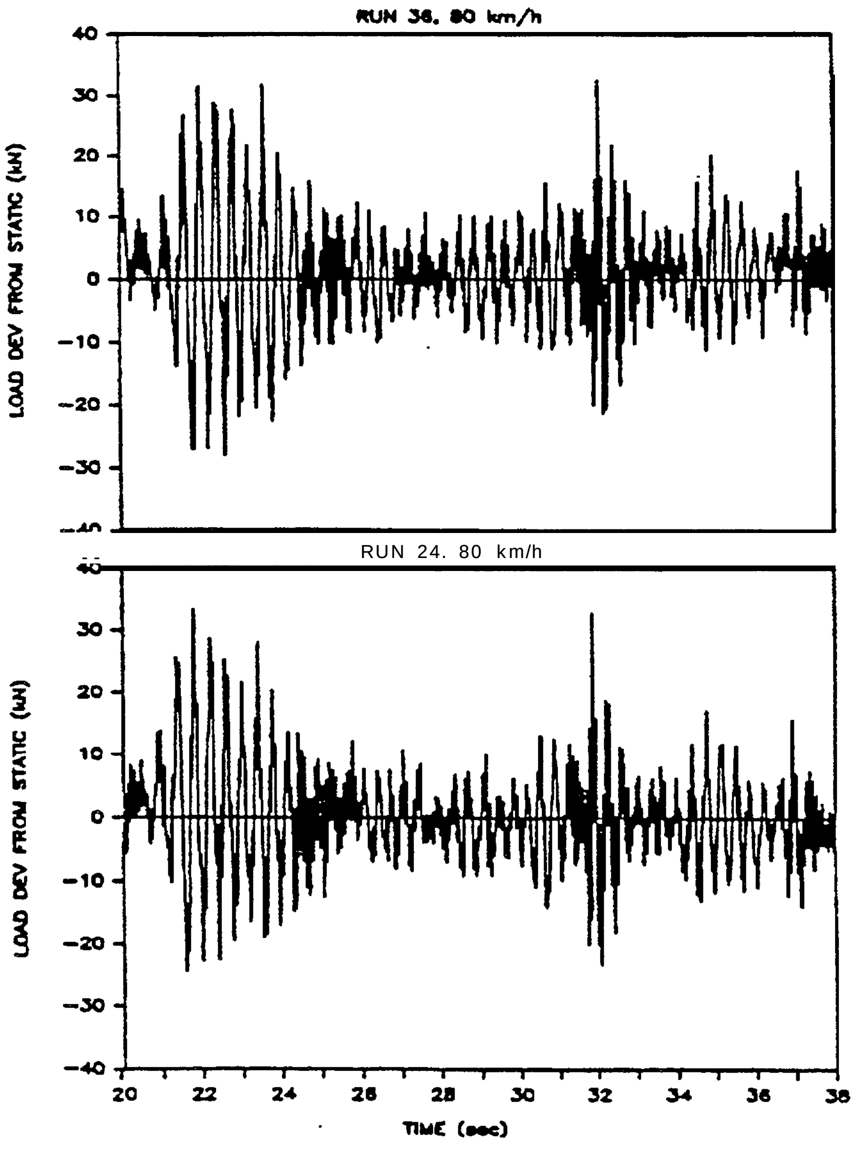


Figure 1: Repetitiveness of Dynamic Axle Loads from Replicate Runs Measured with the NRCC Instrumented Vehicle, (After Ref. 3).

Field Testing

The field experimentation involved three types of WIM sensors, namely a pressure-cell, a piezoelectric and a bending plate WIM system. Three test trucks were used, namely a Z-axle single unit, a 3-axle tandem-drive axle single unit and a 5-axle semi-trailer truck. They were all equipped with leaf-spring suspensions in all their axles for modeling simplicity. In each WIM site, ten replicate runs were conducted with each of the three test vehicles at each of four speeds (i.e., 50, 70, 90 and 110 km/h). Since there were unavoidable speed variations from these nominal values, the speed output of the WIM system was recorded and used as the reference for analysis. The WIM measurements were plotted for each truck axle as a function of speed. An example of the results obtained from the pressure-cell WIM and the 3-axle truck is shown in Figure 2.

At a given speed, the WTM measurements of a particular axle exhibit significant clustering. This is a direct result of the spatial repeatability of the dynamic loads applied by replicate axle passes, as pointed out earlier. Also, for the particular system, there seems to be no consistent relationship between vehicle speed and WIM error. This is due to the random location of the part of the dynamic load waveform, which is over the WIM sensor at various vehicle speeds. The precision of the three WIM systems tested is indicated by the coefficient of variation of the measurements from replicate axle passes, (Table 1). These mean precision values offer conservative estimates of the error in measuring the dynamic axle load being applied to a WIM sensor by an in-motion axle. This is because there would be some inherent variation in the magnitude of the dynamic loads being applied by replicate axle passes, due to unavoidable weaving of the vehicle within the lane, changes in air resistance-generated forces and so on. Hence, this approach isolates one of the sources of error in WIM measurements.

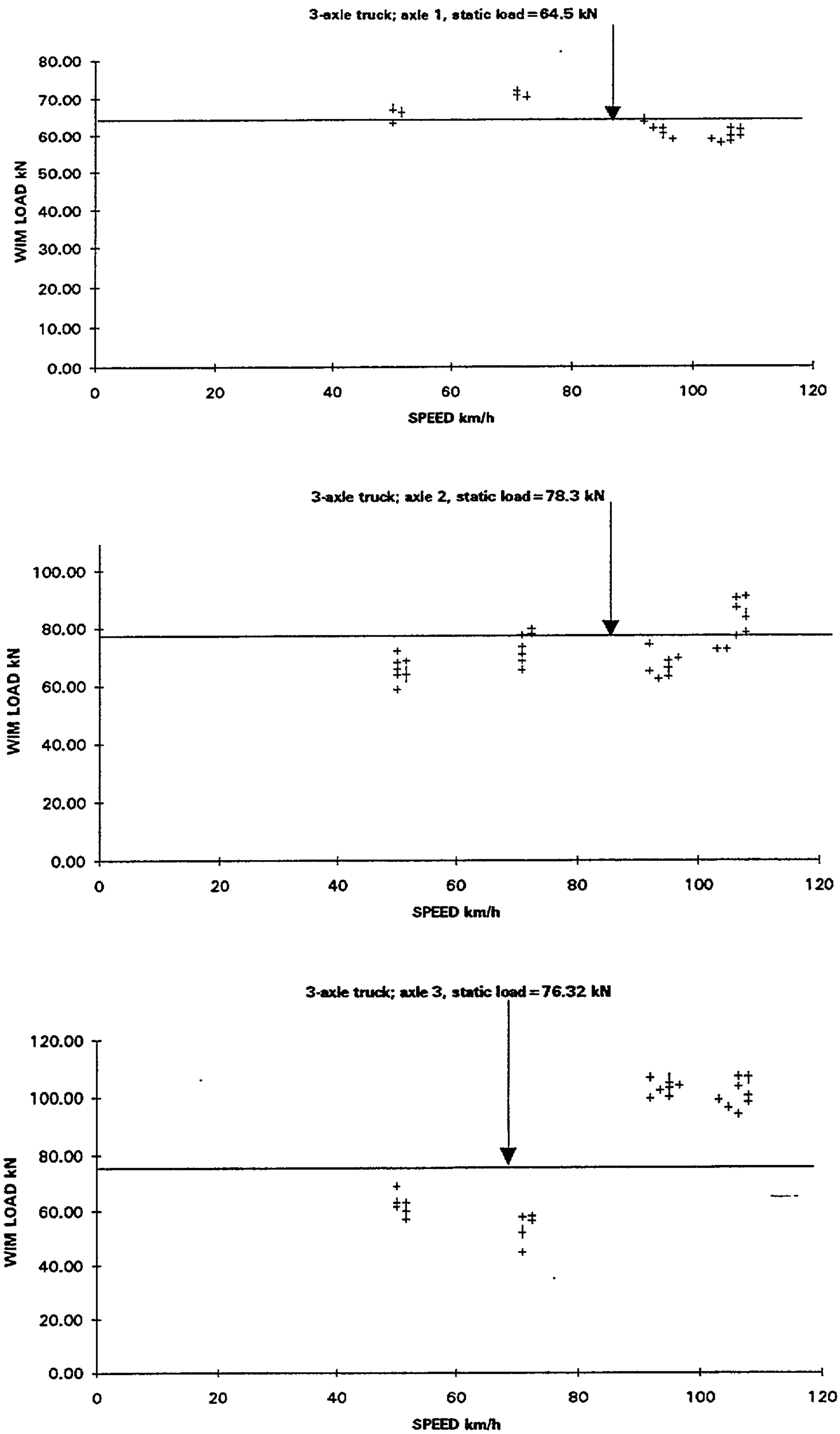


Figure 2: Examples of Pressure-Cell WIM Measurements Obtained with a 3-axle Truck

Table 1:
Summary of WIM System Precision Performance

WIMTYPE	MEAN PRECISION	PRECISION RANGE
Pressure-Cell System	3.81%	1.94 % to 5.61%
Piezoelectric System	5.67%	3.08% to 9.83%
Bending-Plate System	3.87%	2.15% to 5.21%

Dynamic Simulations of the Test Trucks

The pavement roughness profile, which was input to the VESYMF vehicle simulations, was measured with a South Dakota Profilometer at a sampling interval of 0.33 m. A substantial effort was put into calibrating the VESYM simulation models for the three trucks used in testing the WIM systems. This was carried out by comparing the vertical accelerations predicted by the models to those measured at selected body and axle locations using accelerometers placed on-board the test trucks. This approach was selected, instead of a conventional shaker table-based calibration of the simulation models (e.g., Ref. 5), to circumvent the problems associated with handling the pavement elevation profile input. The comparisons were made in terms of the power spectral densities (PSD), (Figure 3). Model calibration was effected by changing model mechanical constants one at a time, in attempting to improve the fit of the simulated accelerations to the measured accelerations. ‘This task was facilitated by an extensive sensitivity study of the vehicle simulations with respect to their mechanical properties, which was undertaken prior to the-actual calibration of the simulation models.

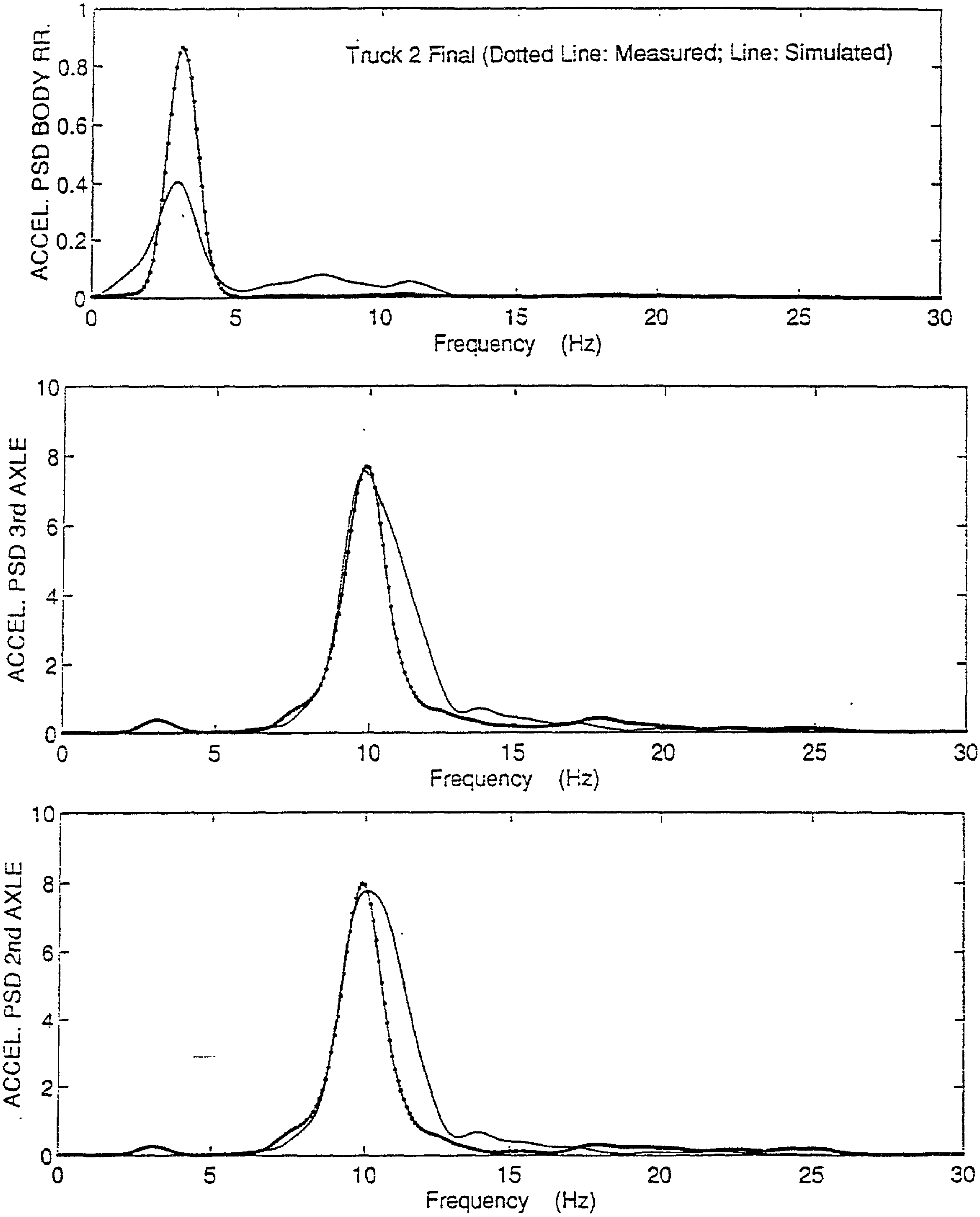


Figure 3: Comparisons of PSD's of Measured versus Estimated Acceleration; 3-Axle Test Truck.

WIM Error Analvsis

The calibrated VESYM simulation models for the three test trucks were used in analyzing the errors from the on-site WIM testing. Early in the analysis, it was realized that the vehicle simulation models were not suited for predicting the discrete dynamic axle load values exerted by individual test truck axles on the WIM sensors. This was mainly the result of the unknown initial conditions of the simulations (i.e., it was assumed that static loading conditions existed when the pavement roughness profile input begun). Instead, the simulation models were used to predict the frequency distribution of the dynamics axle loads at a given WIM site. This source of variation, combined with the variation due to the inherent error of the WIM system in measuring the dynamic axle loads applied, produce the combined frequency distribution of the expected WIM error measurements at a WIM site (Figure 4). This combined error frequency distribution reflects:

- the precision characteristics of the WIM system,
- the pavement roughness at the WIM site and,
- the dynamic characteristics and speed of the test truck used.

This combined frequency distribution is used to:

- evaluate the accuracy of WIM system in measuring static axle loads by defining the anticipated range in WIM measurements, as well as their probability p_i and,
- calibrate a WIM system by providing a rational method for averaging the WIM measurements of an axle obtained at different speeds and therefore containing different levels of dynamic load variation. The expression used for calculating the weighed average IM_a from the WIM measurements IM_i obtained at speed i is:

$$IM_a = \frac{\sum_{speed=i} WIM_i \; p_i}{\sum_{speed=i} Pi} \qquad (1)$$

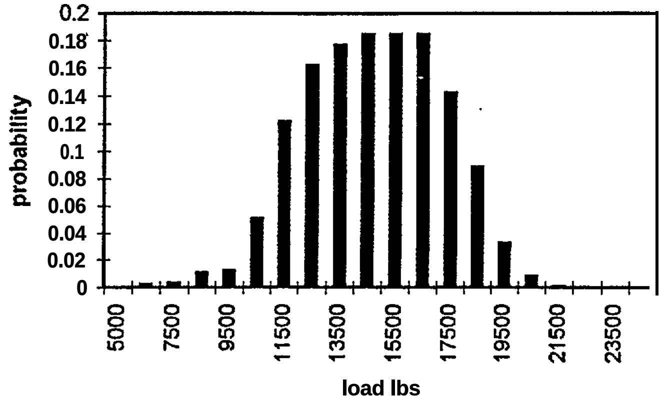


Figure 4: Example of the Expected Combined Frequency Distribution of WIM Errors; Pressure-cell WIM System on I-84 near Umatilla, Or; Steering Axle Load of 3-Axle Truck at **70 km/h.**

Recommended Procedures

The evaluation of WIM systems, involving a combination of test trucks and vehicle simulation models, requires the following steps:

1. Perform pavement roughness profile measurements with any profilometric roughness measuring device, which can output the pavement elevation in both wheel paths at a fixed distance interval (e.g., Dipstick, Surface Dynamics Profilometer, South Dakota Profilometer or equivalent). It is necessary to cover at least 200 meters upstream and 50 meters downstream from a WIM sensor. Calculate the average of the elevation in the two wheel paths to be used as input to the vehicle simulations.
2. Use a number of test trucks involving a total of at least 5 axles. They must belong to one of the FHWA classes 5, 6 or 9 (i.e., 2-axle single unit'truck, 3-axle single unit truck or 5-axle semi-trailer truck). With each truck, perform at least 5 replicate runs at each of the following nominal speeds:
   - speed limit at the site
   - speed limit -20 km/h,

- speed limit - 10 km/h and,
- speed limit + 10 km/h,

while recording the actual speed output of the WIM system for each run.

3. Group the WIM measurements obtained by axle and actual speed and retain for analysis only the exact speeds for which at least 3 WIM measurements were obtained.
4. For each axle and speed, calculate the coefficient of variation of the WIM measurements (i.e., mean over standard deviation expressed in percent). This value reflects the precision of the WIM system. The coefficient of variation calculated is used in Step 7.
5. Prepare the VESYMF input file for each test truck (i.e., file VIN5, VIN6 or VIN9, respectively). This task is facilitated by the computer program PAREST, which accepts as input the static axle loads and the axle spacing of each test truck and outputs the mechanical constants that must be modified in the input files VIN5, VTN6 and VIN9 prior to running VESYMF. Ref. 6 contains a complete manual on the use of the program VESYMF.
6. Run the VESYMF simulation for each truck and each speed analyzed and save the output files containing the dynamic axle loads of the test vehicles.
7. For each axle and speed, run the computer program HIST developed for calculating the frequency distribution due to axle dynamics (i.e., data from Step 6) and combing it with the variation due to the inherent WIM error (i.e., calculated in Step 4). The program HIST also calculates the probability P_i of particular WIM measurements.
8. If the probability of a measurement is lower than a preset value, for example 0.05 or 0.01, the measurement is unlikely with a confidence of 95% or 99%, respectively. All the axles of the test trucks must pass this test for the WIM system to successfully pass the evaluation process at the desired confidence level.

WIM system calibration involves two additional steps:

1. For each test truck and axle, calculate the weighed average, IM_a, of the WIM measurements obtained at various speeds using Equation 1.
2. Fit a straight line regression equation with zero intercept between the static axle load data and the weighed average WIM load data being considered as the dependent and independent variables, respectively. The slope of this relationship is the calibration factor (e.g., Figure 5). Finally, multiply the sensor constant of the particular WIM system by this factor to complete the calibration.

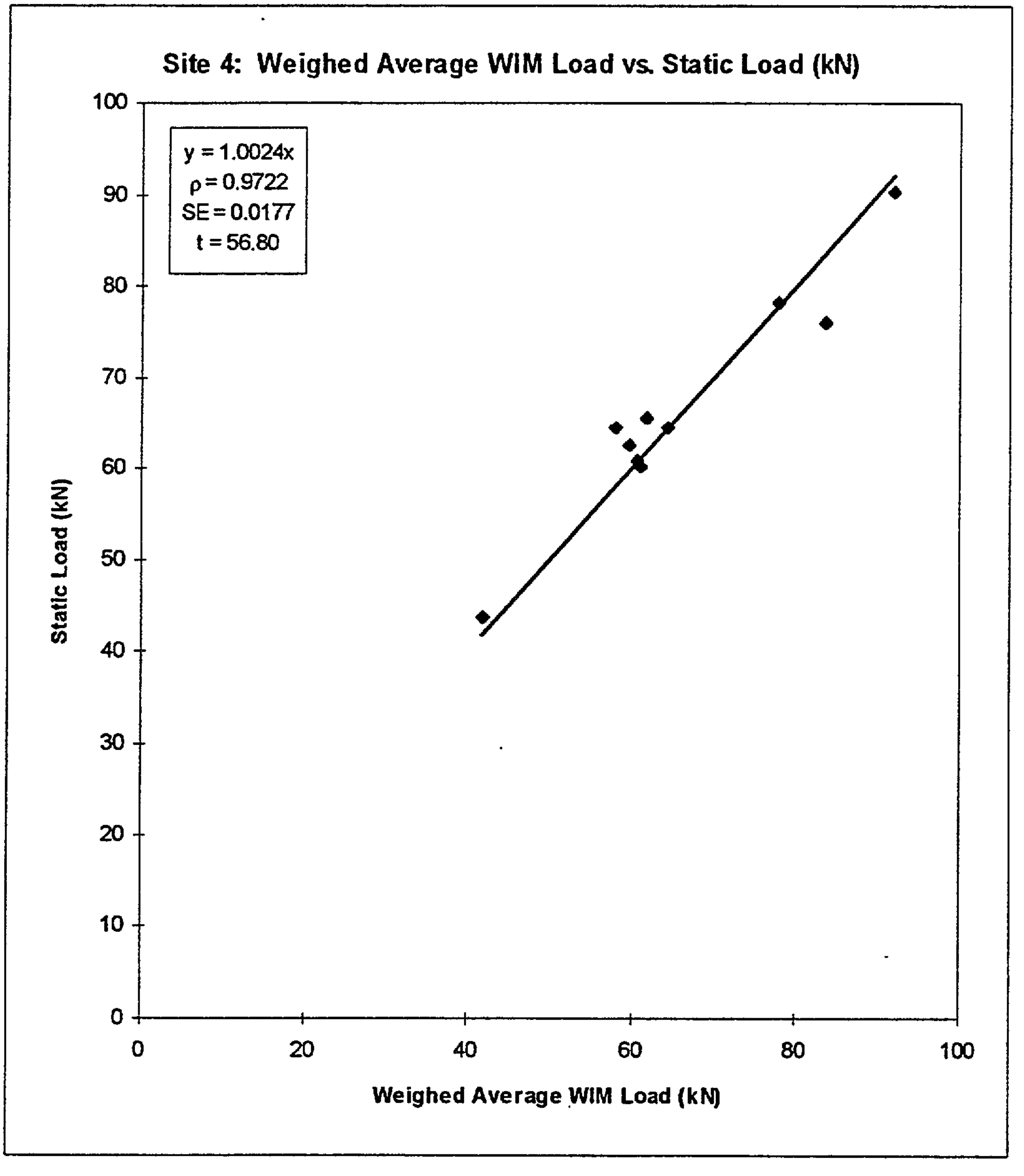


Figure 5: Calibration Curve for Pressure-Cell WIM System

AVI-BASED CALIBRATION APPROACH

Scope

The Heavy Vehicle Electronic License Plate (HELP) program combines WIM technology with automatic identification (AVI) of the vehicles being weighed. It is installed on the I-5 corridor and two adjoining corridors, one branching north into British Columbia and another east into Arizona, New Mexico and Texas. The identification of the systems on the I-5 corridor is shown in Figure 6. Approximately, 5,000 AVI transponder-equipped trucks are currently operating on this system. The scope of this part of the study is to use the AVI identification numbers as a means of comparing WIM measurements to static weight of particular vehicles by taking into account the date and the time interval between weighing locations.

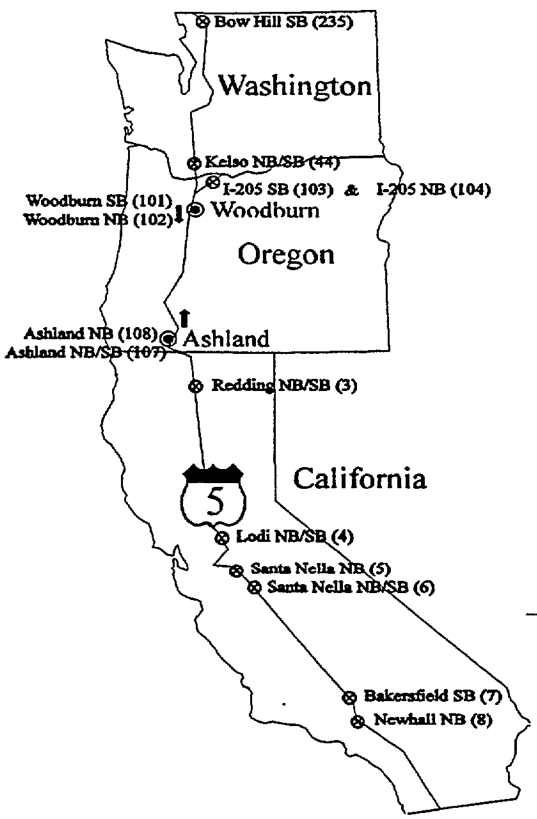


Figure 6: The WIM and Static Locations on the I-5 Corridor

Methodolow-Data

The database containing the WlM data of the HELP program is being maintained by Lockheed IMS. The data used for this study covers a period of six months (i.e., l/1/94 to 5/3 l/94) The static axle load data was extracted from a database maintained by Oregon DOT for two locations on the I-5 corridor, namely Woodburn southbound (SB) and Ashland northbound (NB). These are multi-platform load enforcement scales operating downstream from WIM sorting scales, hence most of the trucks weighed statically at these locations are likely to be heavily loaded. WIM and static data was input into two separate relational databases. Each database, contained in addition to AVI number and load, data on the date, time, vehicle class and axle spacing. The largest percentage of the AVI-equipped vehicles belonged to FHWA class 9 (i.e., 5-axle semi-trailers).

Analvsis

The accuracy of the WIM systems on the I-5 corridor was analyzed using the two databases described earlier. Direct comparisons between WIM and static axle loads were effected by matching the AVI numbers of transponder-equipped vehicles at static and WIM weighing locations and then by cross-checking the date and the driving time between them. Preliminary observation of the data indicated that the WIM load database was not complete. For some locations there was no WIM data whatsoever, as for example, Bow Hill, WA, northbound and southbound and Woodburn, OR, northbound (i.e., HELP sites 235 and 108). There were also WIM locations where WIM data was not available for particular vehicles, despite the fact that data for these vehicles was available for the same date at adjacent WIM sites. The data was screened in two stages, first to compare dates and second to compare the driving time between locations. For the latter, the relative travel time between weighing locations was sufficient for identifying vehicles that may have stopped long enough for loading/unloading.

The analysis in the first stage was carried out through a FORTRAN algorithm, which identified particular vehicles that were weighed with both a static and a WIM scale in the same day. The algorithm did not screen out data obtained in consecutive days, to allow for vehicles that drove overnight between weighing locations. Furthermore, it did not screen out data obtained in the transition between months. This was accomplished by identifying all matching AVI numbers obtained in a day of the month involving the number 1 (e.g., static weighing on l/3 l/94 and WIM weighing on 2/l/94, or static weighing on 2/28/94 and WIM weighing on 3/l/94 and so on).

The second stage of the analysis was carried out through another FORTRAN algorithm, which screened the reduced database to further eliminate data corresponding to driving times between weighing locations exceeding prescribed maximum values. For each pair of weighing locations, the maximum acceptable driving time was established on the basis of the minimum recorded time plus an allowance for stopping of half-an-hour for every four hours of driving. The minimum travel time was used instead of the actual time difference between weighing locations to eliminate possible discrepancies in the clock settings of the various systems. The time allowance was calculated from the actual distance between locations assuming a driving speed of 60 mph.

The results of the two stages of data screening are shown in Tables 2 and 3 for the northbound and the southbound vehicles, respectively. It should be noted that the number of successful comparisons with respect to date (i.e., after the first screening) may be higher than the sample size of the WIM load data in a particular location, because of multiple passes of a given vehicle over this site. For example, a particular truck was weighed statically twice on the 5th of February and subsequently, weighed by a WIM system twice on the 4th of February, three-times on the 5th of February and twice the 6th of February. The total number of possible successful static-WIM load comparisons after the first screening is 14 (i.e., 2x[2+3+2]).

Table 2:
Sample Size of Databases and of Successful Static and WIM Load Comparisons per Site; Northbound Vehicles.

Site Location	Site Number	Sample Size Static Data	Sample Size WIM Data	Min. Travel Time (min)	First Screening (Comparing Dates)	Second Screening (Comparing Times)
Bow Hill, WA	235	-	0	-	0	0
Kelso, WA	44	-	234	380	72	3
I-205, OR	104	-	930	335	159	7
Ashland, OR	107	-	640	4	953	9
Ashland , OR	108	4217	0	-	-	-
Redding, CA	3	-	345	132	406	63
Lodi, CA	4	-	1292	324	1199	82
Santa Nella, CA	5	-	1113	413	1187	49
Santa Nella, CA	6	-	626	417	741	16
Newhall, CA	8	-	321	733	316	29
Totals			5501		5033	258

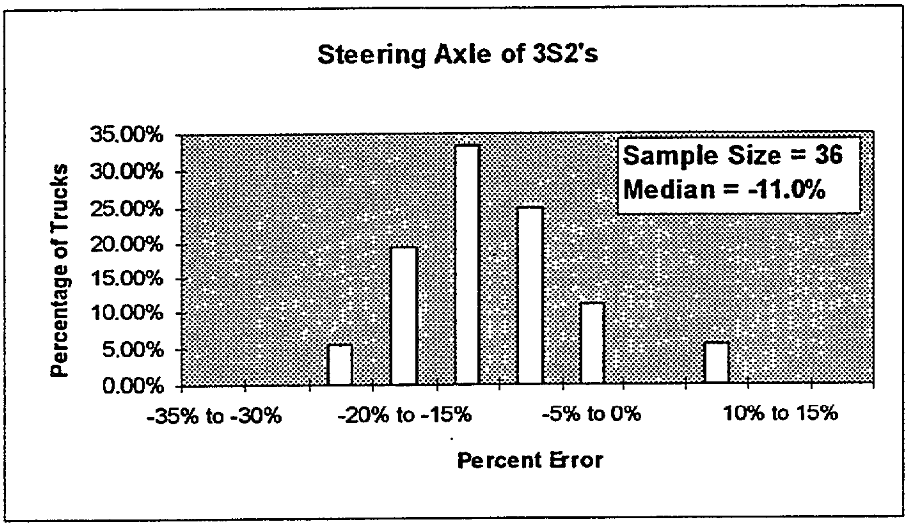
Table 3:
Sample Size of Databases and of Successful Static and WIM Load Comparisons per Site; Southbound Vehicles.

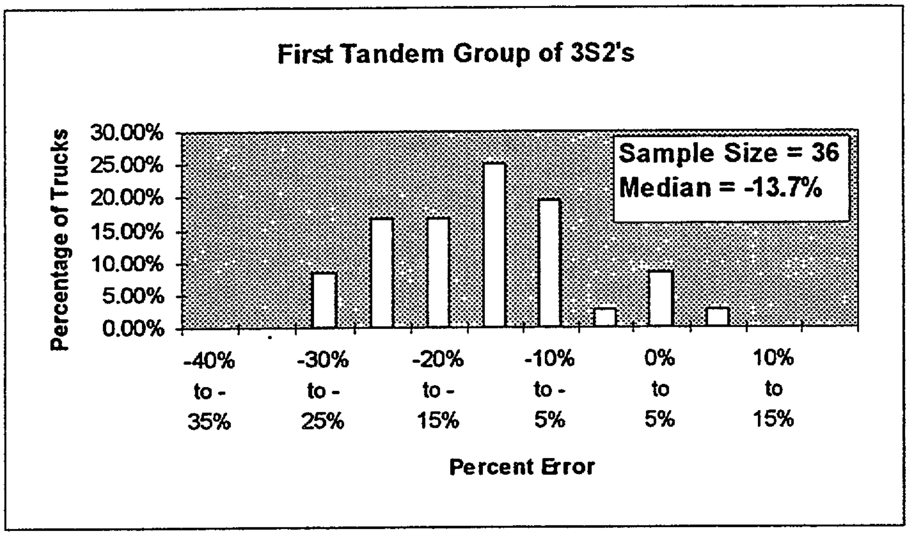
Location	Site Number	Sample Size Static Data	Sample Size WIM Data	Min. Travel Time (min)	First Screening (Comparing Dates)	Second Screening (Comparing Times)
Bow Hill, WA	235	-	0	-	0	0
Kelso, WA	44	-	855	75	207	46
I-205, OR	103	-	1040	4	223	21
Woodburn, OR	101	2083	58	-	31	4
Redding, CA	3	-	1227	279	156	3
Lodi, CA	4	-	339	686	46	2
Santa Nella, CA	6	-	449	520	37	1
Bakersfield, CA	7	-	1009	260	70	1
Totals			4977		770	78

It is also evident that the second screening with respect to the driving time between weighing locations was fairly restrictive and produced a small number of successful static and WIM load comparisons. Clearly, the further away the WIM location was from one of the two static weighing scales (i.e., Woodburn SB and Ashland NB), the smaller was the number of successful static and WIM load comparisons.

The error analysis focused on 5-axle semi-trailers only and considered errors of steering axles, first tandem axle group (i.e., drive axles) and second tandem axle group (i.e., trailer axles). WIM errors were defined as the percent of the arithmetic difference between WIM and static axle load measurements with respect to the static axle load. Frequency distributions of errors were plotted only for WIM systems, where eight or more successful comparisons were made. An example of such frequency distribution is shown in Figure 7 for HELP Site 44. A summary of the median of the WIM errors for each site is shown in Tables 4 and 5 for northbound and southbound WIM locations, respectively. It can be seen that with a few exceptions the median errors calculated were all negative and had substantial magnitudes.

Calibration factors were developed through regression, considering the static load as the dependent and the WIM load as the independent variable. Simple linear regression expressions were fitted with no intercept, so the slope of the line is the calibration factor. One expression was fitted per axle (i.e., steering, first tandem group and second tandem group) and for each WIM location. In‘addition, the data from all the axles/axle groups were grouped together and a single regression equation was fitted for each site. The results are shown in Table 6.





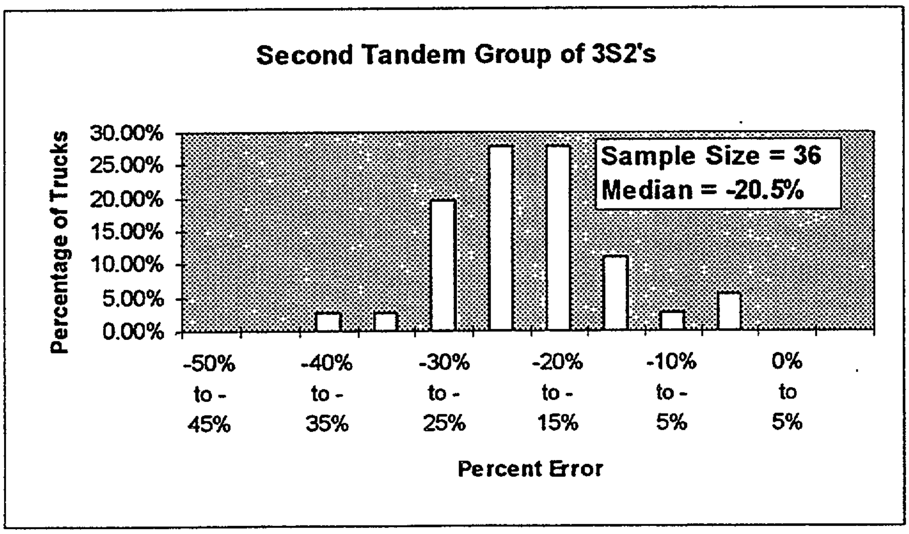


Figure 7: Percent WIM Errors for WIM Site 44 Southbound.

Table 4:
Median Arithmetic Errors for Northbound 5-Axle Semi-trailer Trucks

WIM Site Name	Site Number	Number of Successful Comparisons	Median of Axle 1	Arithmetic Group 1	Error % Group 2
Kelso, WA	44	3	-10.64	-2.98	-6.44
I-205 OR	104	5	-17.89	-21.86	-20.24
Ashland OR	107	8	-2.50	3.69	10.10
Redding, CA	3	62	-7.60	-8.98	-10.62
Lodi, CA	4	82	0.00	-1.76	-0.54
Santa Nella, CA	5	48	-1.73	1.16	-1.68
Santa Nella, CA	6	16	0.88	-6.22	2.14
Newhall, CA	8	28	-6.50	-0.75	-0.97

Table 5:
Median Arithmetic Errors for Southbound 5-Axle Semi-trailer Trucks

WIM Site Name	Site Number	Number of Successful Comparisons	Median of Axle 1	Arithmetic Group 1	Error % Group 2
Bow Hill, WA	235	None	-	-	-
Kelso, WA	44	36	-11.01	-13.70	-20.47
I-205 OR	103	8	-11.83	-20.19	-26.26
Woodburn OR	101	1*	4.20	-2.40	2.10
Redding, CA	3	3	-51.67	-49.84	-51.48
Lodi, CA	4	1*	-1.74	-0.61	-11.01
Santa Nella, CA	6	1*	12.62	-9.38	-6.29
Bakersfield, CA	7	1*	10.68	-8.21	2.10

*Error Statistics based on a Single Vehicle Comparison are not Reliable

Table 6:
WIM Calibration Relationships

Site 44 SB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 1.1062x	0.592	0.014	28.709
1st Tandem	y = 1.1320x	0.877	0.018	61.286
2nd Tandem	y = 1.2412x	0.929	0.019	66.114
All	y = 1.1751x	0.965	0.012	99.752

Site 103 SB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 1.1665x	0.609	0.063	18.488
1st Tandem	y = 1.2433x	0.838	0.052	24.124
2nd Tandem	y = 1.2889x	0.935	0.058	22.086
All	y = 1.2553x	0.955	0.031	40.060

Site 107 NB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 0.9839x	0.751	0.034	28.709
1st Tandem	y = 0.9346x	0.743	0.061	15.240
2nd Tandem	y = 0.9119x	0.701	0.087	10.514
All	y = 0.9293x	0.882	0.039	23.565

Site 3 NB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 1.1258x	0.221	0.033	34.521
1st Tandem	y = 1.1193x	0.685	0.030	37.307
2nd Tandem	y = 1.1209x	0.722	0.033	33.730
All	y = 1.1204x	0.869	0.018	61.697

Table 6 (Continues):
WIM Calibration Relationships

Site 4 NB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 1.0050x	0.370	0.012	80.912
1st Tandem	y = 1.0114x	0.937	0.009	113.775
2nd Tandem	y = 1.0116x	0.918	0.014	74.812
All	y = 1.0110x	0.967	0.007	155.264

Site 5 NB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 1.0154x	0.336	0.012	80.319
1st Tandem	y = 0.9978x	0.935	0.010	100.302
2nd Tandem	y = 1.0208x	0.936	0.014	75.419
All	y = 1.0086x	0.979	0.007	149.056

Site 6 NB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 1.0025x	0.691	0.012	84.791
1st Tandem	y = 1.0618x	0.985	0.014	73.469
2nd Tandem	y = 0.9764x	0.979	0.015	65.047
All	y = 1.0169x	0.984	0.010	100.187

Site 8 NB Axle	Equation x = WIM Load y = Static Load	Correlation (x,y)	Standard Error in y	t-value for Coeff. of x
Steering	y = 1.0766x	0.352	0.022	48.443
1st Tandem	y = 1.0323x	0.538	0.031	33.288
2nd Tandem	y = 0.9956x	0.633	0.036	27.808
All	y = 1.0201x	0.913	0.019	54.361

Development of a Portable AVI Svstem for WIM Calibration

A portable AVI system was specially developed for the purpose of WIM system calibration, where fixed AVI facilities such as those of HELP, are not available. For this purpose, two AVI readers were installed in Minnesota, one at the main-lane WIM system on I-94 in Lake Elmo, and the other at the sorting WIM system of the truck inspection station in St. Croix near the Wisconsin border. The two sites are about three miles apart and satisfy proximity to a static weigh scale, which is located at the St. Croix truck inspection station. The equipment installed has the capability to tag WIM records with the AVI number of traffic-stream vehicles. A total of 80 AVI transponders were installed on trucks passing frequently through these sites. The tagged data from each WIM site was downloaded at regular intervals through a telephone line via modem. In addition, the static axle load data of the AVI-equipped vehicles was collected at the truck inspection station. This was done by modifying the software of the sorting WIM system at the entrance to the truck inspection station to produce an audio alarm to alert the truck inspection station personnel, who had to save the data on a file by hitting a single key. These data files were also downloaded through modem. The installation of these systems was completed in May 1995 and they remained operational till December of 1995. Calibration of the two WIM systems was effected by direct comparisons between the WIM and the static axle loads. Figure 8 shows the zero intercept least square regression calibration curve fitted for the lake Elmo WIM system.

IN-CONCLUSION

Two procedures were described here for the evaluation/calibration of WIM systems. The first involves a combination of test trucks and vehicle simulation models, while the other involves traffic stream vehicles equipped with AVI transponders. Although vehicle simulations were not suited to predict the discrete dynamic axle load values at WIM sensor locations, they were quite useful in establishing the extend of dynamic load variation expected for a given axle and speed. A calibration method was described based on these frequency distributions. Use of AVI-equipped vehicles for WIM calibration was shown to be quite feasible and inexpensive, were AVI facilities are available. Furthermore, it was shown that the portable AVI systems can be installed to effectively calibrate WIM systems.

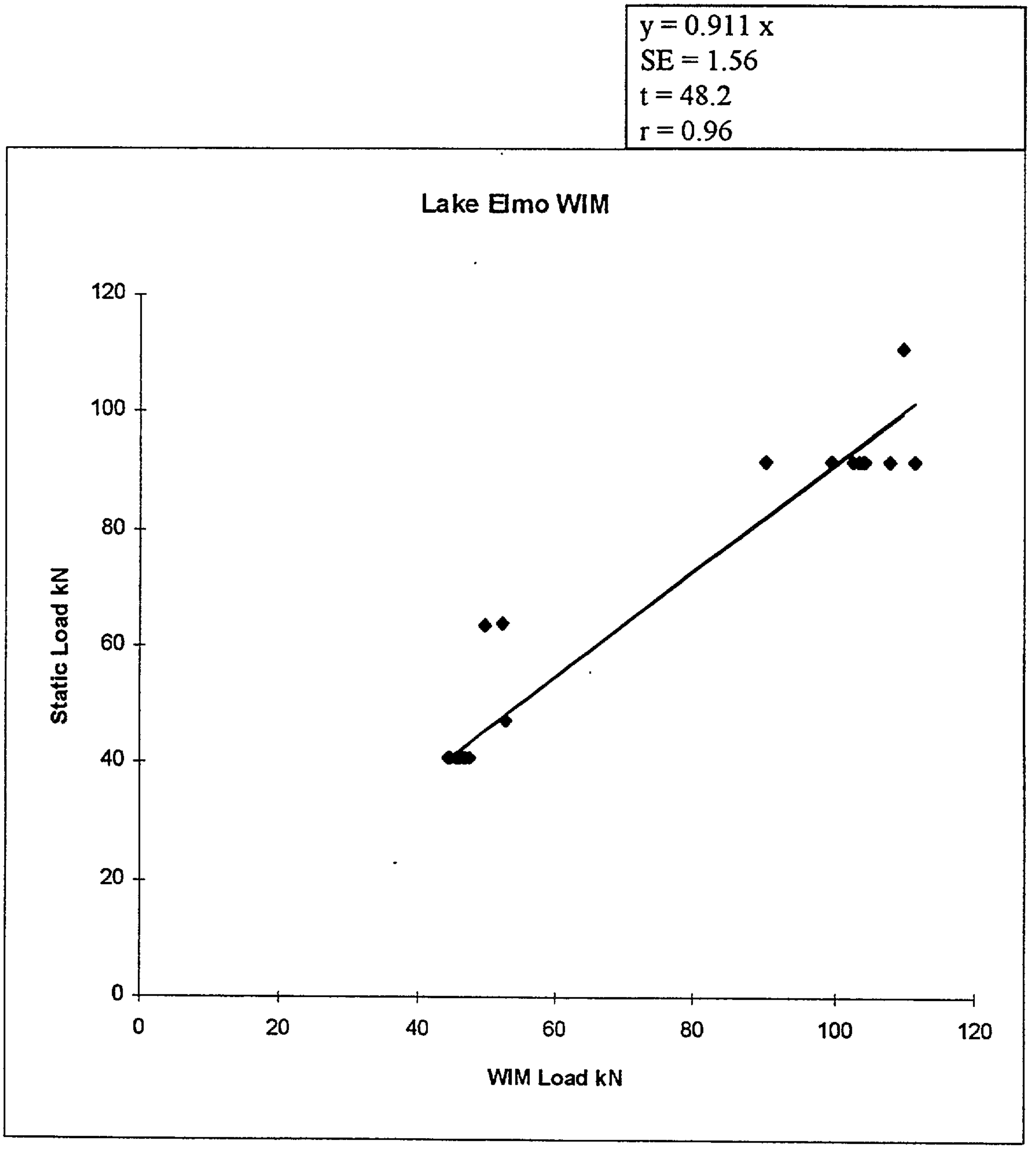


Figure 8: Calibration Relationship for the Lake Elmo WIM System.

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PRECISION OF ANNUAL ESAL LOADING ESTIMATES

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Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

Precision of Annual ESAL Loading Estimates

by

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How "good" are traffic loading estimates?

What sampling scheme is the most cost-effective?

If I know my sample size, how "accurate" is my load estimate?

"Good" or "Accurate" is a function of both

precision, and

bias

Theoretical approaches to developing formulas have been unable to accurately predict the precision and/or bias of weight estimates

---

LTPP is empirically estimating "accuracy"

based on:

effect of calibration shift
effect of sample size (weight and class)
relative importance of weights versus volume by classification

---

Approach uses "good," "annual" WIM data as "truth"

Calculates annual total based on complete data set

Explores the effects of different sample sizes and sample plans

---

Examines changes in load characteristics over time to determine relative importance of calibration versus sample size/plan

Relates site characteristics to results to provide expected accuracy given specific site characteristics and data availability

Conclusions To Date

There is more variability in truck volumes and loads than there is in automobile volumes

Conclusions To Date

Truck variability is usually different than automobile variability

Time of day, day of week, and seasonal patterns for trucks are all different than for cars

Conclusions To Date

Truck loading patterns are often very site specific

Conclusions To Date

Weighing only on weekdays may or may not have an adverse impact on estimating annual loads

Lack of classification counts on the weekends is likely to produce bias in the annual load estimate

Conclusions To Date - Weights

In many locations, WIM scale calibration appears to be much more important to the overall accuracy of the annual estimate than day-of-week or seasonal sampling

Conclusions To Date

In the LTPP database, seasonal weight differences are much larger than day-of-week weight differences

It is unclear how much of these differences are due to seasonal change, and how many are caused by calibration drift

Conclusions To Date

It appears that a significant reduction in the amount of required weighing can take place, IF calibration is assured, and IF known seasonal movements can be accounted for.

Conclusions To Date - Weights
Expected Errors

Assuming that you can measure truck volume correctly and your scale is correctly calibrated:

Weighing once during the year will result in an answer within ± 50% of the annual load 95% of the time

Conclusions To Date - Weights
Expected Errors

Weighing during two seasons will result in an answer within ± 30% of the annual load 95% of the time

Conclusions To Date - Weights
Expected Errors

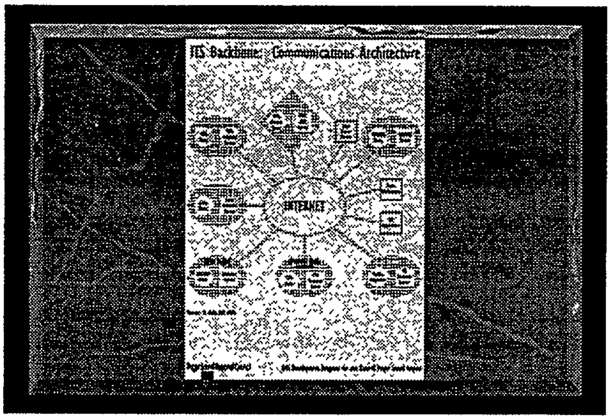
For most multi-day sampling plans, weighing during all four seasons will result in an answer within ± 10% of the annual load 95% of the time

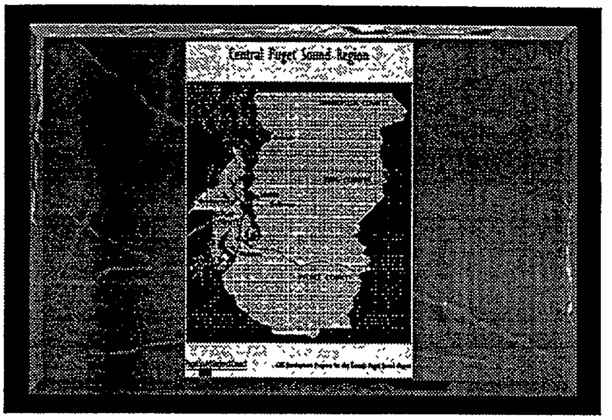
Conclusions To Date - Weights
Expected Errors

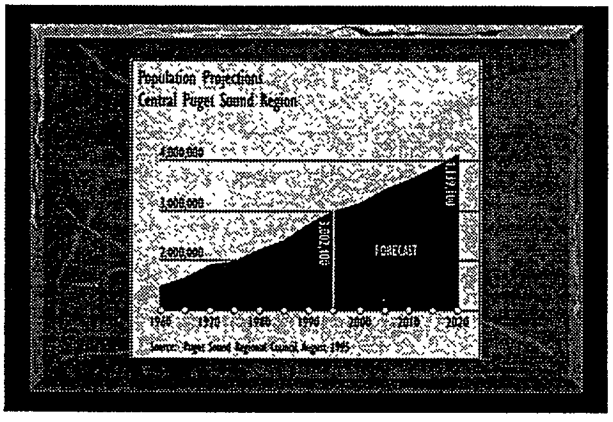
Weighing for seven consecutive days during all four seasons will result in an answer within ± 6% of the annual load 95% of the time

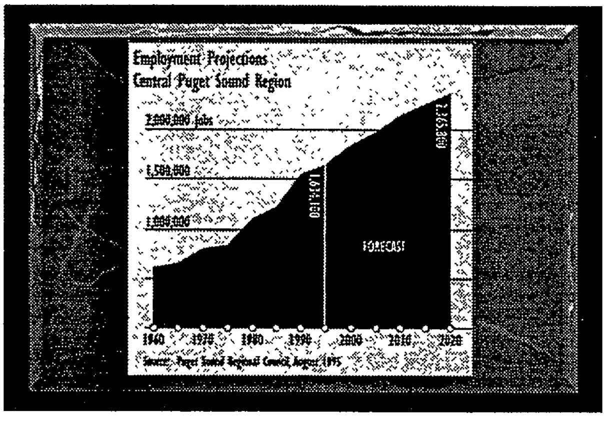
Conclusions To Date

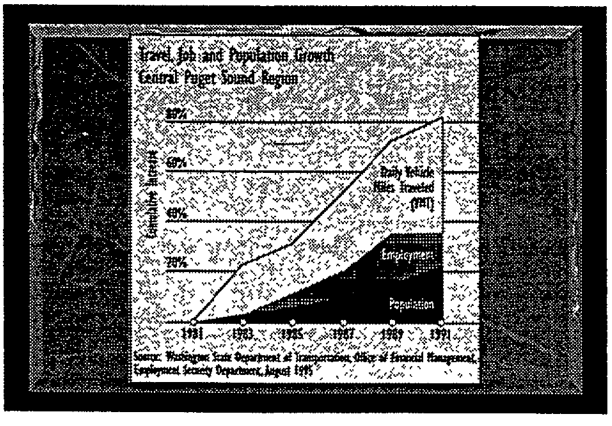
The marginal improvement in accuracy caused by additional days of data collection is very small

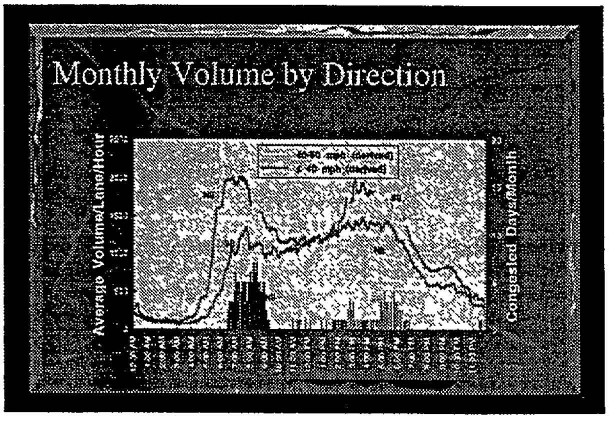

ITS Backbone: Communications Architecture
INTERNET

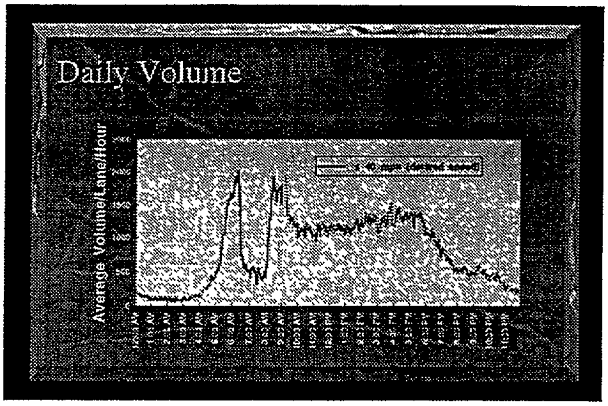

Central Puget Sound Region


Population Projections
Central Puget Sound Region
FORECAST


Employment Projections
Central Puget Sound Region
FORECAST


Travel, Job and Population Growth
Central Puget Sound Region
Daily Vehicle Miles Traveled (VMT)
Employment
Population


Monthly Volume by Direction
Average Volume/Lane/Hour
Congested Days/Month


Daily Volume
Average Volume/Lane/Hour

I-95 MULTI-STATE PROJECT

Bruce Littleton
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Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

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I-95 MULTI-STATE PROJECT

BRUCE LITTLETON

DELAWARE DEPARTMENT OF TRANSPORTATION

The current status of the I-95 Multi-State Traffic Monitoring Evaluation Project will be presented at the National Traffic Data Acquisition Conference.

The project began from casual conversations between DelDOT and PennDOT personnel attending the Mid-Atlantic Truck Weight Conference in September of 1990. Later joined by Maryland and New Jersey, the four states agreed to participate in an evaluation of traffic monitoring equipment, particularly low cost systems, as much of this was new technology. The four states were not aware of any definitive study that evaluated all of the Automatic Vehicle Classification (AVC) or WIM equipment available on the market. This project has evolved to provide such a study.

In May of 1991, FHWA participation was sought for financial support, and was granted in November of 1991. In the process, Delaware became the Lead State for the project.

Systems have been installed, a dry run evaluation conducted, four WIM evaluation sessions completed, and the four AVC evaluations are complete. The Second interim report containing the preliminary findings and recommendations for the WIM portion of the project was presented at NATDAC in Connecticut. The Final Report is anticipated for the Spring of 1996 and should be available at the conference.

THE RHODE ISLAND EXPERIENCE

Speaker: Michael J. Sprague
Rhode Island Department of Transportation
Authors: Henry L. Bishop, et al.
Rhode Island Department of Transportation

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

THE RHODE ISLAND EXPERIENCE

H. L. Bishop & M. J. Sprague

Rhode Island is a relative newcomer to the world of Weigh-In-Motion (WIM) and truck weighing. We stopped loadometer truck weighing in the mid 1970's. Only in 1987 did we decide to test WIM as an automatic data collection method to collect volume, vehicle classification, speed and weight data. We purchased two Golden River battery powered, capacitance pad, portable WIM systems. The following year we started weighing on a three year schedule developed in accordance with the provisions of the Traffic Monitoring Guide (TMG).

We questioned the TMG logic which said Rhode Island needed the same number of weighing sessions as California or Texas, particularly on the Rural Interstate where Rhode Island has only six sections in the entire state. We also questioned the logic that implied truck weights vary from functional system to functional system, by the amount of travel. We reasoned that class 9's, for example, range in weight from empty to over loaded on all systems. But the TMG gave us a starting point. It should be noted that Rhode Island still questions the sampling criteria of the TMG today.

Our objectives, when we started our WlM program, were to detect and define patterns and relationships between truck weights and other traffic planning data. We were hoping that we could collect data that would show us weight relationships, similar to volume and classification relationships, on which we could base estimates and forecasts of vehicle weights. We also wanted to provide five day, curb lane, weight data to the Strategic Highway Research Project (SHRP), seasonally.

We soon learned that one disadvantage of the Golden River system was that it only produced printed reports and print report files. It did not give us a file of 4 or 7 cards directly. We were limited in our analysis to reviewing the manufacture's printed summary reports until we had written our own software to produce the 4 and 7 cards from the "Individual Vehicle Report" file.

Initially, we analyzed the various site summary reports and quickly determined that there were not enough heavy trucks on the lower functional systems to justify exposing our equipment to damage and/or vandalism. We adjusted our program and moved the lower level sessions to higher level systems, where we had a larger sample of trucks. We also found little, if any, consistency in the average weights of any class of truck. A possible exception to this is class 9 trucks at our one SHRP site, where we collected larger five day samples. While the differences in the average weights by vehicle classification were not extreme for any one classification, they were obviously not the same between sites. No one seemed to know how much of a difference we could expect from site to site within a given functional system., between functional systems ,or seasonally. The lack of knowledge in this area concerns us.

About this time a permanent station was installed at the SHRP site. We included a requirement for production of 4 and 7 card files, as part of the reports in the specifications for this site. We also got the Federal Highway Administration's (FHWA) W-Table, microcomputer based software operational.

The issue of WIM equipment calibration became more critical with the installation of the permanent site. Rhode Island has always questioned the necessity and validity of calibrating the equipment to a truck of a known weight. Some transportation agencies expend great efforts in fine tuning the equipment to ensure that the weight of a test vehicle driven over the WIM system is identical or within a 20% range of the vehicle's static weight. It is our contention that calibrating to a moving truck of a known weight is only critical if the WIM equipment is going to be used for, or in conjunction with, vehicle weight enforcement activities. We think it is more important and useful if the equipment is calibrated to the actual dynamic forces being applied to the pavement. We believe that it is more reasonable to obtain the average actual force applied to the pavement rather than the weight of the truck applying the force.

We calibrated our portable WIM equipment to known dynamic forces. In the summer of 1993 we brought four, series eight, capacitance mats to the University of Rhode Island and subjected them to a series of tests using a falling weight deflectometer (see Table-l, Figure-la and Figure-lb). In each of the tests (with the exception of the first test) the capacitance mats correctly measured the forces being applied to them. These weight sensors were then installed at our SHRP site adjacent to the piezo WIM system. The data from the two systems were compared to each other, It was found that the gross vehicle weights obtained from both systems were similar with little variation. This indicated that the piezo system auto calibration was accurately recording the forces applied to the pavement.

We periodically check the autocalibration of the piezo system by plotting the number of class 9 vehicles by weight group to determine if there is any drifting in the average weights that would indicate sensor problems (see Table-2, Figure-2A and Figure-2B).

When we started looking at the data from our permanent piezo WIM equipment the first **thing** we found was that the ESAL values from the W-Tables were different than those from the manufacturer's summaries. The second thing we noted was the consistency in the monthly average class 9 weight was much stronger than indicated by weekly, or 48 hour, samples. This prompted us to look at the distribution of individual weights, around the average (see Table-2B, Table-2c, and figures-2c. .I).

It became apparent that the weight distributions were similar for each vehicle class, from all samples, permanent or portable, large or small. In the case of class 9 trucks there are 3 weight peaks, empty or lightly loaded, legally loaded and permit loaded (see Figure 2-a&b) We were surprised at the number of trucks that are operating well under the allowed legal limit.

It was discovered that the average weight of each vehicle class tended to stabilize at a very narrow range of values as sample size increased (see Table-3a..c). In addition it indicated that, for the most common vehicle types, class 5 and 9, almost all sample, both portable and permanent as well as any functional system, gave an average weight that is within one standard deviation of the average of any other sample (see Tables-4a. .g and Figure-4a. .g). We also noted that while the range of average weights decreased with sample size, the standard deviation does not.

What does all this mean? It may mean that the observed differences in average weights from portable, short term counts are the result of weak sampling rather than a different weight population. Rhode Island has only one permanent site where we can check the population, all other samples are statistically weak, monitoring the curb lane for 48 hours in one direction. We would like to know if any of the states with multiple permanent sites have tested long term data for statistically significant dif%rences in the average weights.

We had hoped that some of our questions concerning the statistical significance of the differences in the average gross weights, (within and between functional systems and seasonal variations), would be answered when Rhode Island joined the other New England states in a research project to determine the feasibility of a combined regional truck weight program to reduce the individual state's efforts. However, conclusions from this research, thus far, have been scarce and disappointing. It was recommended that the states improve their sampling by increasing the number of sites. We consider this unacceptable because our research seems to indicate that larger samples provide better average gross vehicle weights than increasing the number of WIM locations would. Also, the objective of a regional WIM program is to reduce the number of WIM sites that the individual states would need to sample, not to increase them.

We have asked other states in New England if they have seen any similar patterns. Vermont has also noted consistency in average weights on higher functional classes, where samples are larger but have not yet looked at the distributions of weights about the average. They have, though, noted significant differences in directional weights. Another state reported that " they were too busy collecting data to stop and look at it."! Several other states had no comment.

within our one and only permanent AVC/WIM site we have found that the average weight, every month, is greater at night and on weekends, but there is no increase in very heavy truck volume at these times. The heaver average weight is due to the fact that there are fewer light or empty trucks at night and on weekends. We have also found that there is a large and very distinct directional difference in average class 9 weights, and they mirror each other, (that is when north bound average weights go up the south bound go down (see Tables-5a,b and Figures-5a..g)) In general, the average gross weights in Rhode Island seem to be heaver than other states in New England. This may be attributed to the state's liberal truck weight permit policy. Also, a trucking industry official informed us that most of the class 9 fuel tankers traveling north through our SHRP site are loaded to the maximum permitted limit. This site is located on a major fuel route from the port of Providence to central Massachusetts.

We have found consistencies and inconsistencies, and we are not sure if either are significant. We have tried time series, frequency histograms, and statistical analysis such as averages, maximum value, minimum value, standard deviations, variances and any other tools our software packages have. With all this we only know one thing for sure; the more we examine the data the more we think we know, and the more unanswered questions we have.

Are the differences in average weights between sites significantly different?

Is one statewide average, based on large samples from diierent locations, as good or even better than several different averages, for estimating and forecasting?

Is our data significantly diierent from that in the states around us?

Could we improve our average weights or ESAL's estimates by combining data with other states?

Is any one else interested in these questions?

Has any one else looked for answers to them?

Has any one else found any answers?

Is any one else looking for answers?

Should we even be concerned?