MOSSMAIN TRUCK CLASSIFICATION STUDY

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APPROVAL

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This writing project has been read by the writing project director and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the Statistics Faculty.

3/11/03 — John J. Borkowski

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A Report For:

MOSSMAIN TRUCK CLASSIFICATION STUDY

Submitted by:

Melissa Harrington

I. INTRODUCTION

Summary

In the state of Montana, all commercial vehicles with gross vehicle weights (GVW) exceeding 14,000 pounds are required to stop for measurement at static scales (Montana Department of Transportation 61-10-141-b). With the advent of Weigh in Motion (WIM) and Automated Vehicle Identification (AVI) equipment, truck bypass programs have been developed. The bypass programs allow participating weight and credential compliant trucks with GVWs greater than 14,000 to proceed without stopping at the static scale. WIM systems provide a dynamic weight of trucks. Using a bypass program, trucks are weighed by a WIM system and identified by the AVI prior to reaching the scale. If the WIM system reads the truck as weight compliant, the truck is not required to stop at the scale; however, if the WIM system identifies the vehicle as over the legal operating weight, the vehicle must stop at the scale.

In order for any WIM system to be an effective option in bypass, the system must weigh and classify vehicles correctly under various weather and traffic conditions. Vehicle classification is a method of categorizing vehicles based on physical characteristics. The number of axles and the axle configurations determine the classification of a truck; and, the classification dictates the legal weight of the vehicle. The classifications of trucks vary from class 5 to class 13. A class 5 vehicle is a two-axle single unit truck while a class 13 is a seven or more axle multi-trailer truck (U.S. Department of Transportation).

Various WIM mechanisms are available for bypass systems; these include but are not limited to, piezoelectric sensor, single load cell, bending plate scale, and quartz piezoelectric sensor. Bending plate systems are used in Montana for bypass systems while piezoelectric systems are used throughout the state for collection of traffic and engineering data.

The bending plate WIM system consists of a steel plate with strain gauges attached, installed flush to the ground in a 300-foot length of concrete pavement. The weight is calculated from the strain on the plate using calibration factors. The piezoelectric system consists of two coaxial cables embedded in the pavement across the lane, one coaxial cable embedded in the right most wheel path, and an inductive loop. The inductive loop identifies the presence/absence of a vehicle from the change in electric field. The coaxial cables are compressed as a vehicle passes over; and, the recorded charge is converted from voltage to vehicle load with calibration factors. The two cables spanning the lane record weights; and, the average value is reported for each axle and GVW for each vehicle. The cable embedded in the right wheel path, on-scale sensor, identifies vehicles that are not lane compliant and associates an error with the vehicle record. The weighing accuracy of the two systems is reported as $\pm 15\%$ for the piezoelectric system and $\pm 10\%$ for the bending plate in 2001 (International Road Dynamics).

In a cooperative effort between the Montana Department of Transportation (MDT) and the Western Transportation Institute (WTI), the accuracy and precision of bending plate and piezoelectric WIM systems was analyzed under Montana-based traffic loading and weather conditions. The westbound Mossmain site located between Laurel and Billings on Interstate 90 (I-90) provides a unique study opportunity with a piezoelectric system, bending plate system, and static scale all within 1 ½ miles. For this evaluation, accuracy and precision of the piezoelectric and bending plate systems were analyzed at various temperature ranges.

Vehicles were matched by physical description and time on all three weighing systems: bending plate, piezoelectric, and static scale. The accuracy and precision of each system was determined by comparing the WIM weights to the static weight. Only trucks that could be matched between the three systems (static scale, bending plate, and piezoelectric) were used in determining the accuracy. The response of interest was the mean percent error and absolute mean percent error of the WIM systems.

Problem

The Mossmain Evaluation considered the weight accuracy and precision of bending plate and piezoelectric Weigh in Motions (WIM) systems under Montana-based traffic loading and weather conditions. The feasibility of the two WIM systems as a truck bypass tool was assessed in the Mossmain Evaluation using the weight accuracy, weight precision, and system cost. In order for any WIM system to be an effective option in bypass, the system must weigh and classify vehicles correctly under various weather and traffic conditions. The Mossmain Evaluation did not address the classification discrepancy between the two systems.

A sampling plan was designed to find the proportion of vehicles (p) classified differently on the two systems from the total of 6542 trucks collected for the Mossmain Evaluation. The 6542 trucks were collected in three different temperature ranges, 0F to 30F, 30F to 60F, and 60F to 95F. The weight accuracy for both WIM systems is negatively correlated with temperature to different degrees (Clark 81). Because bending plate and piezoelectric WIM systems classify using the number of axles, axle spacing, and gross vehicle weight, and the weight accuracy of the systems was shown to vary with temperature, the classification sample was also stratified by three temperature ranges.

<u>Scope</u>

For every truck included in this sample, classification data was available from both the bending plate and piezoelectric system. The objective of this sampling study is to determine the proportion of vehicles classified differently on the two WIM systems during the Mossmain Evaluation. The systems performed with different levels of accuracy in weighing vehicles at different temperature ranges; therefore, the temperature ranges will be considered when assessing classification accuracy (Clark 71-72).

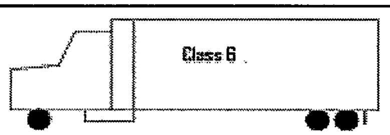
II. DISCUSSION

Mossmain Site

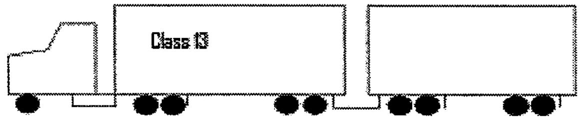
The Mossmain site is located on Interstate 90 (I-90) between Billings and Laurel, Montana. All of the data collected for the Mossmain Evaluation project was in the westbound direction. The physical characteristics of the westbound roadway are: a bending plate in a 300-foot length of concrete pavement, a piezoelectric sensor affixed in asphalt 0.2 miles downstream, and a static scale 1 mile further downstream. A Remote Weather Information System (RWIS) is on the north side of the road near the bending plate.

Classification

Vehicle classification is a method for categorizing vehicles. The Federal Highway Administration (FHWA) classification system has thirteen vehicle categories divided according to the number of axles, physical vehicle and characteristics. Classification is the criteria used for legal GVW truck operation. Truck classifications range from class 5 to 13; and, as the number of axles and truck units increases the classification and GVW limit increases. (See Figure 1.)



Class 6-Three-Axle Single-Unit Trucks



Class 13-Seven or More Axle Multi-Trailer Trucks

Figure 1. Truck Classification

There are two vehicular challenges in classifying the vehicle correctly are (1) numerous axle and tractor/trailer configurations within a class and (2) spacing with small amounts of metal.

Different class-specific axle spacing thresholds are implemented for the bending plate and piezoelectric systems. The class criteria are designed to capture all prevalent configurations in the traffic stream. As the number of axles on a truck increases, the number of possible configurations also increases with axle groupings; common axle groupings are single, tandem, split tandem, and tridem. (See Figure 2.)

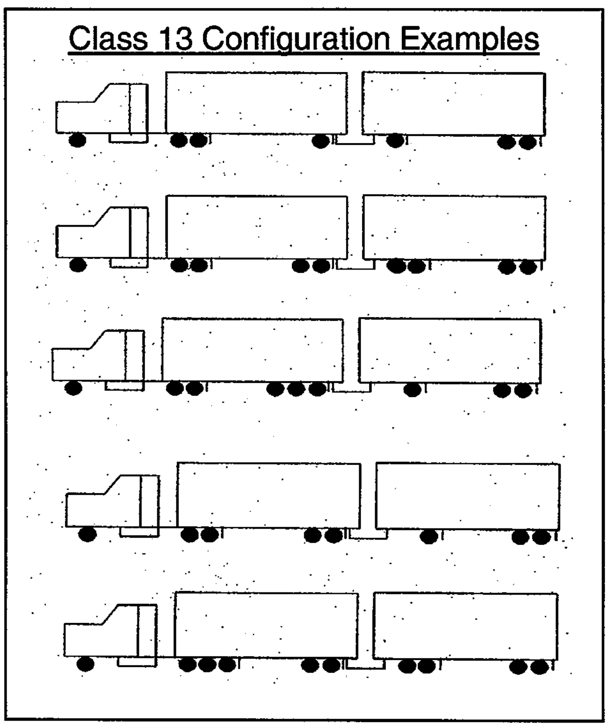


Figure 2. Five Possible Class 13 Configurations

An inductive loop identifies the presence or absence of a vehicle by the change in magnetic field; trucks with long tungs connecting tractor- trailers and logging trucks are difficult for the WIM. Log trucks and long tungs do not contain enough metal for the inductive loop to identify the tractor and trailer as one vehicle. Both piezoelectric and bending plate systems are programmed with a "loop delay" which prolongs the inductive loop "read" of the tractor unit. With the delay modification these vehicles should be classified correctly.

Data Collection

For the original Mossmain Evaluation, a sampling plan was developed to compare the accuracy and precision of the weights at 3 different temperature ranges; 0 F to 30 F, 30 F to 60 F, and 60 F to 90 F. Data was collected in 8-hour shifts for 18 days throughout the different temperature ranges.

The accuracy and precision of each system was determined by comparing the WIM weights to the static weight. Only trucks that could be matched between the three systems (static scale, bending plate, and piezoelectric) were used in determining the accuracy because the response of interest was the mean percent error of the WIM systems.

The data collection for the Mossmain Evaluation consisted of an observer on the roadside near the bending and piezoelectric systems, WIM files from the piezoelectric and bending plate systems, RWIS files, and static weights recorded by the MDT Motor Carrier Services (MCS) officer. The observer and MCS officer recorded a truck identification number, time the vehicle passed over the system, truck cab color, truck body style, load characteristics, and number of axles; intermittently noted was the vehicle company. The MCS officer also noted the individual axle group weights for all vehicles. The WIM file information included time, number of axles, classification, GVW, and individual axle weights.

To avoid noninclusion error, this classification study used the observer's records as the sampling frame because vehicles that are currently participating in the truck bypass program would not be recorded on the MCS officer's records. The number of vehicles collected during the Mossmain Evaluation study was determined from the observer's identification numbers.

Method

The strata sizes are summarized in the following table according to the temperature ranges. (See Table I.)

Table I. Number of Trucks per Temperature Range

Mossmain Data Summary	
Air Temperature (F)	Number of Trucks Observed
0 to 30	1490
30 to 60	2643
60 to 95	2409
Total	6542

The sample size was calculated using a conservative estimate of ½ for each stratum proportion, p_h. Equal sample sizes from the three strata were to be collected. Also, d=0.05 was used to obtain an estimator having probability of at least 0.95 of being no farther than 0.05 from the population proportion. (See Figures 3 and 4.)

$$d = 0.05$$
$$z^* = 1.96$$
$$1.96\sqrt{Var(\hat{p})} \leq 0.05$$
$$Var(\hat{p}) \leq \sum_{h=1}^{3} W_h^2 \left(\frac{N_h - n_h}{N_h}\right)\sigma_h^2$$
$$Let$$
$$n_1 = n_2 = n_3 = n$$
$$p_h = 0.5$$
$$s_h^2 = \frac{p_h(1-p_h)}{n} = \frac{1}{4n}$$

(Thompson 35)

Figure 3. Sample Size Criteria

Table II. Stratum Summary Values for Sample Size Determination

Stratum	N_h	$(N_h/N)^2$	N_h/N^2
0 to 30	1490	0.05187	3.48E-05
30 to 60	2643	0.16322	6.18E-05
60 to 95	2409	0.1356	5.63E-05
Total	6542	0.35069	0.000153

$$1.96\sqrt{Var(\hat{p})} \leq 0.05$$
$$Var(\hat{p}) \leq \sum_{h=1}^{3} \left(\frac{N_h}{N}\right)^2 \left(1 - \frac{n}{N_h}\right)\left(\frac{1}{4n}\right)$$
$$Var(\hat{p}) \leq \left(\frac{1}{4n}\right)\sum_{h=1}^{3}\left(\frac{N_h}{N}\right)^2 - \left(\frac{1}{4}\right)\sum_{h=1}^{3}\left(\frac{N_h}{N^2}\right)$$
$$Var(\hat{p}) \leq \frac{0.08767298}{n} - 0.000038146$$
$$1.96\sqrt{\left(\frac{0.08767298}{n} - 0.000038146\right)} \leq 0.05$$
$$n = 127.26 \approx 128$$

Figure 4. Stratum Sample Size Determination

An equal sample of 128 from each stratum was taken.

The trucks on the WIM systems will be sampled corresponding to the truck identification number for each stratum on the observer's sheet.The truck identification number was assigned to all vehicles recorded on the observer's sheet. 128 random numbers were generated without replacement between 1 and 1490 to sample in strata 1, 128 between 1 and 2643 to sample in strata 2, and 128 between 1 and 2409 to sample in strata 3. The truck identification numbers are assigned based on data collection day and stratum. (See Table III.)

Table III. Truck Identification Number

Mossmain Data Summary			
Air Temperature (F)	Data Collection Dates	Number of Trucks Observed	Truck Identification Number
0 to 30	November 27, 2001	308	1-308
	December 21, 2001	258	309-566
	January 22, 2002	349	567-915
	February 28, 2002	330	916-1245
	March 8, 2002	245	1246-1490
30 to 60	March 14, 2001	440	1-440
	April 3, 2001	466	441-906
	October 12, 2001	317	907-1223
	November 30, 2001	429	1224-1652
	April 16, 2002	441	1653-2093
	April 18, 2002	306	2094-2399
	May 1, 2002	244	2400-2643
60 to 95	April 26, 2001	455	1-455
	May 21, 2001	491	456-946
	May 25, 2001	295	947-1241
	July 10, 2001	431	1242-1672
	August 13, 2001	397	1673-2069
	May 2, 2002	340	2070-2409

Analysis

The response was determined by matching the observer's vehicles with the data files produced from the both WIM systems. If the truck classifications from each WIM system do not match, a 1 was recorded for the truck; and, if the classification does match a 0 was recorded. The truck classification for the 384 trucks was compared; and, 18 trucks in Strata 1, 14 trucks in Strata 2, and 17 trucks in Strata 3 had different classifications between the systems. (See Table IV.)

Table IV. Truck Sample Summary

Stratum	N_h	n_h	# of Trucks with Different Classification
0 to 30	1490	128	18
30 to 60	2643	128	14
60 to 95	2409	128	17
Total	6542	384	49

There are two possible errors on the systems; an unrecognized class or a system error with an individual record. The system must classify all vehicles correctly; therefore, if one system or both systems recorded errors on a vehicle, the vehicle was considered to be incorrect classification.

The estimated proportion of trucks classified differently on the two systems for each stratum ($\hat{p}_h$) was calculated by taking the number of trucks classified differently and dividing by 128. The estimated stratum proportions are calculated and summarized. (See Table V.)

Table V. Stratum Proportions

Stratum	N_h	n_h	$\sum_{i=1}^{128} y_{i,h}$	$\hat{p}_h$
0 to 30	1490	128	18	0.14063
30 to 60	2643	128	14	0.10938
60 to 95	2409	128	17	0.13281
Total	6542	384	49	

The variation between the stratum proportion of Strata 2 and the other strata appears large enough that stratification is appropriate rather than simple random sampling. The sample proportion is the sum of the weighted averages of the strata proportions. The estimated proportion ($\hat{p}_{st}$) of vehicles classified differently is 0.12512. (See Figure 5.)

$$\hat{p}_{st} = \left(\frac{1490}{6542}\right) * (0.14063) + \left(\frac{2643}{6542}\right) * (0.10938) + \left(\frac{2409}{6542}\right) * (0.13281) \approx 0.12512$$

Figure 5. Estimated Sample Proportion

The variance within strata is calculated using the estimated strata proportions. (See Table VI.)

Table VI. Estimated Sample Variance

Stratum	$(N_h/N)^2$	$(N_h\text{-}n_h/N_h)$	$(p_h(1\text{-}p_h)/n_h\text{-}1)$	$(N_h/N)^2(N_h\text{-}n_h/N_h)(p_h(1\text{-}p_h)/n_h\text{-}1)$
0 to 30	0.05187	0.914094	0.000951572	0.000045121
30 to 60	0.16322	0.95157	0.000767024	0.000119131
60 to 95	0.1356	0.946866	0.000906877	0.000116437
Total	0.35069			0.000280689

The variance of the estimated population proportion was calculated to be 0.000281; and, the standard error is 0.016754.

The degrees of freedom were calculated to be 336 using the Satterthwaite approximation. (See Figure 6.)

$$d = \frac{\left(\sum_{h=1}^{3} a_h s_h^2\right)^2}{\sum_{h=1}^{3} \frac{(a_h s_h^2)^2}{n_h - 1}} \text{ where } a_n = \frac{N_h(N_h - n_h)}{n_h} \text{ and } s_h^2 = \frac{n_h \hat{p}_h (1-\hat{p}_h)}{n_h - 1}$$

Figure 6. Satterthwaite Formula

The Satterthwaite formula is based on approximating the distribution of a linear combination of sample variances with a chi-squared distribution (Thompson 121). The z-value of 1.9600 was used to calculate the 95% confidence interval for the sample proportion.

$$\hat{p}_{st} \pm z^* SE(\hat{p}_{st})$$
$$0.12512 \pm 1.9600 * 0.016754$$
$$(0.09228, \quad 0.15796)$$

Therefore, the population proportion (p) is between 0.09228 and 0.15796 with 95% confidence. The sampling plan was developed with a margin of error of 0.05 (or, confidence interval width of 0.10). The actual confidence interval is of width .06568.

III. CONCLUSION

The variability within strata appears small while the variability between strata 1 and the others appears larger; therefore, stratification seems to be an appropriate sampling technique.

Prior to data analysis, the proportion of vehicles misclassified was believed to be largest for lower temperatures and decrease as the temperature increased while the variance within strata would be larger at lower temperatures, coinciding with weight accuracy and precision patterns. The sampled data does not indicate these assumptions are valid. After collecting the data, certain truck classifications along with commodities were identified to cause most of misclassification problems.

Type 13 vehicles seem to be misclassified more often than others. These large vehicles are 7 or more axle multiple unit trucks; therefore, various axle configurations and axle spacings are possible. The WIM systems may not contain algorithms appropriate to identify many of the class 13 vehicles. Class 13 vehicles near Mossmain can be associated with various commodities, particularly sugar beets. Since the Mossmain Evaluation data collection, MDT has developed several new algorithms for the piezoelectric WIM system to accurately classify additional class 13 vehicles.

Further, both piezoelectric and bending plate systems are programmed with a "loop delay" which prolongs the inductive loop "read" of the tractor unit. The observer during the Mossmain Evaluation noted truck commodity; and, several log trucks were misclassified in the sample.

Because the Mossmain Evaluation stratified based on temperature ranges, stratification based on temperature seems reasonable for further conclusions about the feasibility of piezoelectric or bending plate WIM systems used for bypass programs. If type 13 vehicles and logging trucks present the most common misclassification problems, temporal stratification may be more valid based on the harvest and non-harvest seasons for various commodities.

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