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Evaluation of Quartz-Piezoelectric WIM Sensors: Second Year Study

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Introduction/ Background

The Connecticut Department of Transportation (ConnDOT) Office of Research and Materials is responsible for the coordination of data collection for the FHWA Long Term Pavement Performance (LTPP) Study. In 1997 a SPS-9A study site for SuperPave was constructed on CT Route 2. Instrumentation of equipment was needed to collect research level quality data. Of particular interest were the quartz piezo sensors, which had been installed in a European COST 323 WIM study with promising results. The sensors were proposed and approved for acceptance in the FHWA Priority Technologies Program (PTP). A State Research study (SPR) was created to evaluate this sensor technology. Connecticut's Route 2 installation would be the first on an in-service highway in the United States.

Background/Project History

The objective of the research study is: to install a quartz piezo based WIM system, and to determine sensor survivability, accuracy and reliability under actual traffic conditions in Connecticut's environment. The scope of the study involves purchase, installation, and evaluation, for at least three years, of a quartz piezo sensor based WIM system having the capability to provide continuous vehicle classification and weight data, over all lanes of both directions of route 2 in the town of Lebanon, CT.

Information regarding the sensor and its installation has been presented in the conference proceedings at NATMEC 1998 and in the " Second Interim Report on the Installation and Evaluation of Weigh-In-Motion Utilizing Quartz-Piezo Sensor Technology." (Reference 1) Therefore this information is not repeated herein, but is available if needed.

The sensors were initially installed in October 1997. Problems were encountered however from moisture infiltration into the sensor wires via the equipment cabinet and metal conduit. Consequentially, the sensors were all reinstalled in July 1998 and several were reinstalled a second time in September 1998. The sensors that are currently in-place were installed in July and September 1998.

Four field validations using trucks of known weight: October 1998 (initial field set-up), March 1999, October 1999 and April 2000 have been conducted. The second interim report /Reference 1/ that was released in early 2000, includes complete field validation data through October 2000. The report is available in both electronic and paper formats.

Site Layout

The sensor layout is shown in shown in Figure 1. The layout configuration is an induction loop, two full lane-width strips of Quartz WIM sensors and a second induction loop. The sensor layout was selected in order to gather data in a manner similar to previously evaluated piezo-electric WIM systems. The full lane-width strip of quartz-piezo sensors is assembled by attaching four, one-meter sensors end-to-end. The two sensor strips are separated by a distance of sixteen feet, as recommended by the WIM manufacturer based on the average speed of the vehicles at the location. At the time of the installation the posted speed limit was 55mph. The posted speed limit was increased to 65 mph on October 1, 1998.

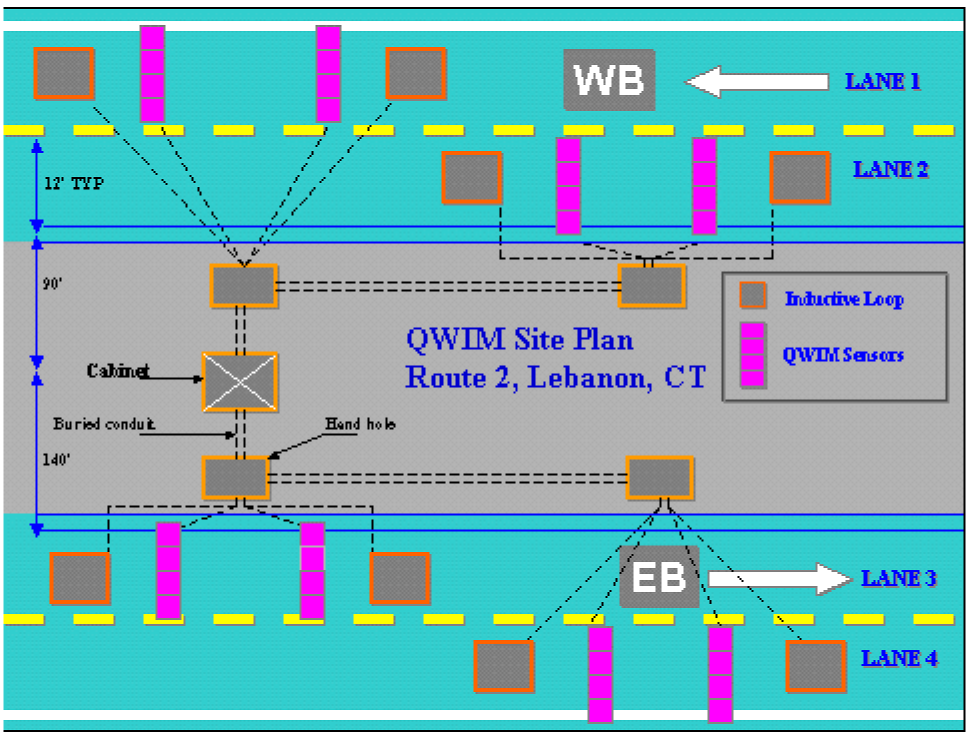

Figure 1: Site Layout

Field Work

Field validations/calibrations were scheduled in order to compare output results from the sensors with trucks of known weight. For the sake of clarity, the terminology used is defined accordingly: The term calibration is used for when the electronics or software program have been adjusted in some manner resulting in a change to the end value of the traffic data results. The term validation is used when trucks of known weight are used to collect traffic data without any adjustment to the electronics or software program.

Two five-axle semi-trailer (FHWA-Class 9) trucks were rented for two days. One of the five-axle semi-trailers had air-ride suspension on the trailer and the other had conventional spring suspension. It was intended that the air-ride truck be fully air-ride, but the air-ride on the trailer only was the best available. In each of the LTPP lanes, (lanes 1 & 4) the LTPP protocol was followed. Therefore the minimum of 20 passes of each truck was collected. In lanes 2 & 3, as many passes of the trucks as possible were conducted during the time allowed. Additional trucks were added to the test in order to collect supplementary data. These were a State 2-axle dump truck to run at varying speeds (March 1999 and April 2000), and a flatbed trailer configuration (5-axles) loaded with Jersey Barriers, intended to measure the same truck with varying loads (April 2000) over the validation period.

Field Calibrations

The WIM system set-up was conducted in October 1998. In March of 1999, no adjustments to system were deemed necessary. The validation results from April 2000 are listed in Table 1. In October 1999 the results from Lanes 2 & 4 did not warrant adjustment, but lane 1 was running low and therefore the factors were reduced by four percent. Lane 3 required a three percent increase in the calibration factors. It was noticed that lighter truck weights were a problem. Consequently, the sensor manufacturer checked the sensors in November 1999. It was determined that one sensor in Lane 3 did not provide the desirable signal resistance. Reviewing the number of errors that the system was producing further supported the existence of the problem. As a result, the configuration of Lane 3 was temporarily changed in February 2000, until the new sensors can be installed. The new configuration is measuring the half-lane left and then upstream a distance, half-lane right.

It was anticipated that from the field calibration/validation data gathered in 1999 and the ongoing office review of the data that the long-term data quality of the sensor-system could be evaluated. We did instead encounter software problems that hampered our data collection and investigation. The software is sold separately from the sensors and is therefore treated as a separate aspect from the sensors themselves in this study. The software vendor decided that as long as other changes were being conducted to make the software year 2000 compliant (Y2K) then it was an appropriate time for other adjustments and corrections. Unfortunately, changes had a direct impact as to how the system should be set-up. As a result, when the complete software was installed during February 2000, it was believed that the system was recording loads to be 50% higher than intended and the calibration factor was changed immediately the following day. When the field validation was conducted in April of 2000 it was discovered that the discrepancy was not a simple factor of 2 (50%) as was previously thought. In fact, that by using trucks of known weight in the field it was discovered that field calibrations were necessary. Specifically, the calibration factors needed reductions of 13% in lane 1, 5% in lane 2, 7% in lane 3 and 10% in lane 4. These necessary calibration changes were later determined to be the result of other parameters that were changed in the new (revised) software. The end result was that the data and tracking of the data were not reliable between December and April 2000 for the experiment and LTPP purposes. Tracking of the data has continued from April to the present in order to continue long-term examination of the sensor system status.

Results From Field Validations

There are two questions to address when assessing the data. How well did the system perform using the validation by trucks of known weight and how repeatable was the data over time? The data from the field validation through October 1999 is available in Reference 1. The data from the field validation after the calibrations were conducted are located in Table 1.

Figure 2 shows the data validation data over time for lane 1, which is representative of 20 to 25 passes of the air-ride truck during each field validation. The data for lane one, gross vehicle weights easily comply with the ASTM 1318 / Ref 3/ Margin of +/- 10% and 95% confidence interval using the t-test. We obtained similarly successful results for Lane 4 from October 1998 to April 2000. Lanes 2 & 3 do not provide the same level of results, as shown in Figure 3. Work needs to be conducted to determine why the difference in variability from Lanes 1& 4 and 2 & 3 exists. Lanes 1 & 4 are the slow speed lanes, the LTPP lanes, which carry a higher percentage of the trucks and are validated using a larger sample of truck passes.

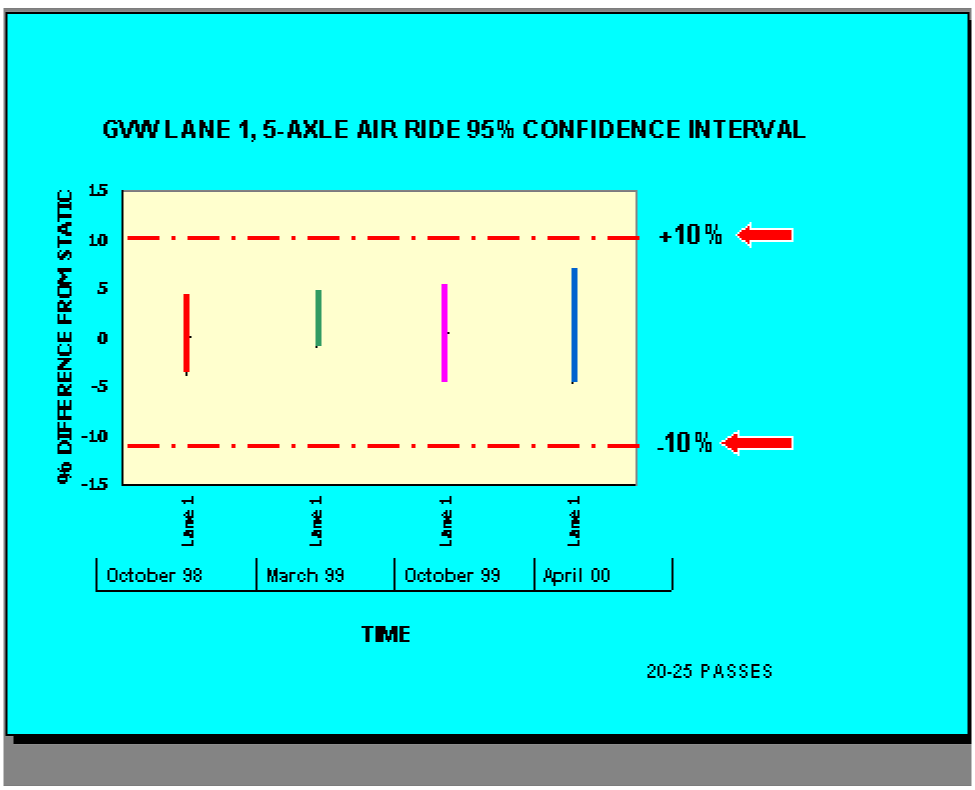

Figure 2 GVW 95% Confidence Interval for Lane 1, 5-Axle Air Ride

RESULTS FIELD VALIDATION AFTER CALIBRATION APRIL 2000

Type	Lane	Steering	Drive	Trailer	GVW	# of Passes	Speed
Non-Air Avg	1	-4.43%	6.49%	-3.37%	0.72%	20	60
Non-Air Std Dev		3.87%	3.20%	4.27%	1.88%		
Non-Air Avg	2	-13.37%	11.95%	-8.50%	-9.96%	10	60
Non-Air Std Dev		6.27%	3.67%	5.40%	2.46%		
Non-Air Avg	3	-7.33%	-4.94%	2.70%	-2.57%	10	60
Non-Air Std Dev		4.99%	3.76%	4.14%	3.76%		
Non-Air Avg	4	-3.70%	-1.55%	1.96%	-0.32%	29	60
Non-Air Std Dev		3.07%	2.96%	4.81%	3.32%		
Air Avg	1	0.45%	3.27%	-0.31%	1.16%	18	60
Air Std Dev		2.95%	3.22%	2.78%	2.86%		
Air Avg	2	-4.71%	-0.71%	-0.94%	-1.45%	10	60
Air Std Dev		3.54%	3.66%	10.01%	5.42%		
Air Avg	3	-10.69%	-6.08%	-7.40%	-7.49%	15	65
Air Std Dev		3.88%	5.10%	5.41%	4.85%		
Air Avg	4	-4.27%	1.26%	0.84%	0.19%	23	60
Air Std Dev		3.08%	3.59%	3.45%	3.35%		
		-3.25%	1.69%	--------	0.18%	3	40
		2.10%	5.04%	--------	3.45%		
Dump Avg	1	2.45%	0.97%	--------	1.77%	10	50
Dump Std Dev		1.87%	6.27%	--------	4.26%		
		0.43%	0.00%	--------	0.51%	9	60
		1.05%	4.74%	--------	3.00%		
Dump Avg	2	-6.27%	3.42%	--------	0.35%	3	55
Dump Std Dev		4.12%	8.20%	--------	5.78%		
Dump Avg	3	-11.04%	-0.27%	--------	-3.72%	2	59
Dump Std Dev		3.07%	1.89%	--------	0.18%		
Dump Avg	4	-12.36%	-3.55%	--------	-6.08%	7	40
Dump Std Dev		1.79%	2.86%	--------	2.21%		
		-9.20%	-8.76%	--------	-8.83%	10	50
		2.32%	4.28%	--------	3.31%		
		-7.81%	-2.25%	--------	-3.87%	12	60
		1.09%	3.73%	--------	2.40%		

Non-Air Ride = 5 Axle Semi-Trailer (FHWA Class 9), standard suspension.
Air = 5 Axle Semi-Trailer (FHWA Class 9), air ride supspension trailer.
Dump = 2 Axle (FHWA Class 5), dump truck.

TABLE 1: April 2000 Field Validation Results

The variability in the weight data results can be caused by from the sensors, the pavement condition, the software algorithm, the trucks or the sampling procedures.   It is possible that these lanes are physically different than the other lanes. To attempt to quantify this, profile data were collected prior to installation of the systems (1997) and again in the year 2000. The best manner to analyze these profile data needs to be determined. It is anticipated that work proposed in the LTPP program will be helpful in learning how to interpret these profile data in the future.

WIM Data were analyzed for each of the axle groups. The steering or front-axle met the ASTM range of +/- 1 20%, 95% of the time for all lanes using the air-ride truck from October 1998 to April 2000. Similarly to the GVW, lanes 1 & 4 provided the best data in comparison to Lanes 2 & 3. These data are depicted in Figure 4.

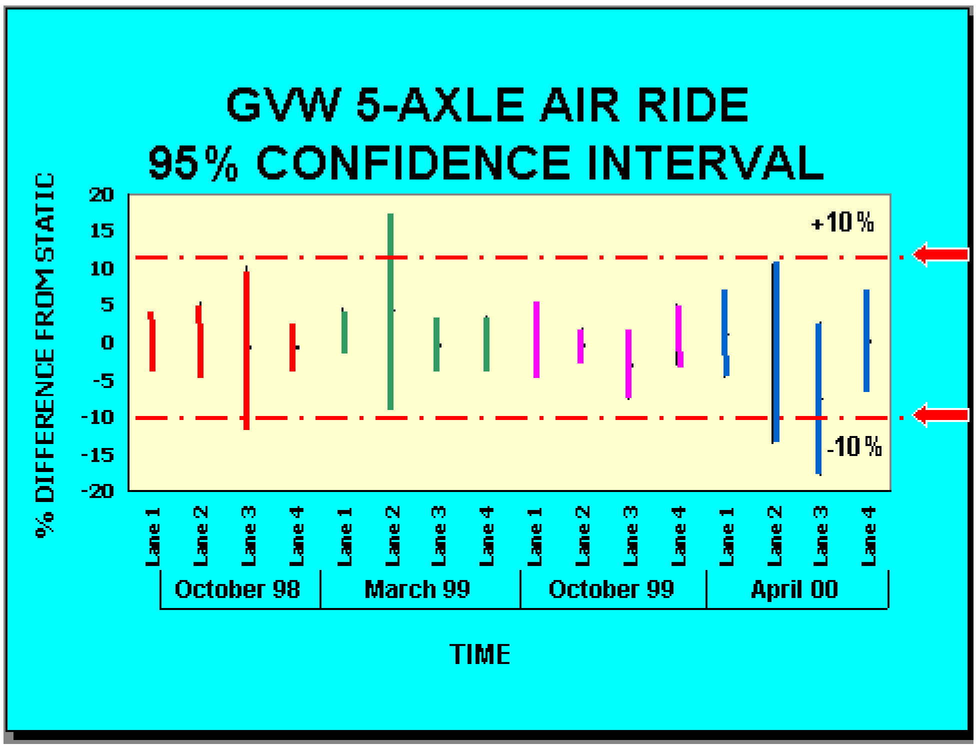

Figure 3 GVW 5-Axle Air Ride, 95% Confidence Interval for All Lanes

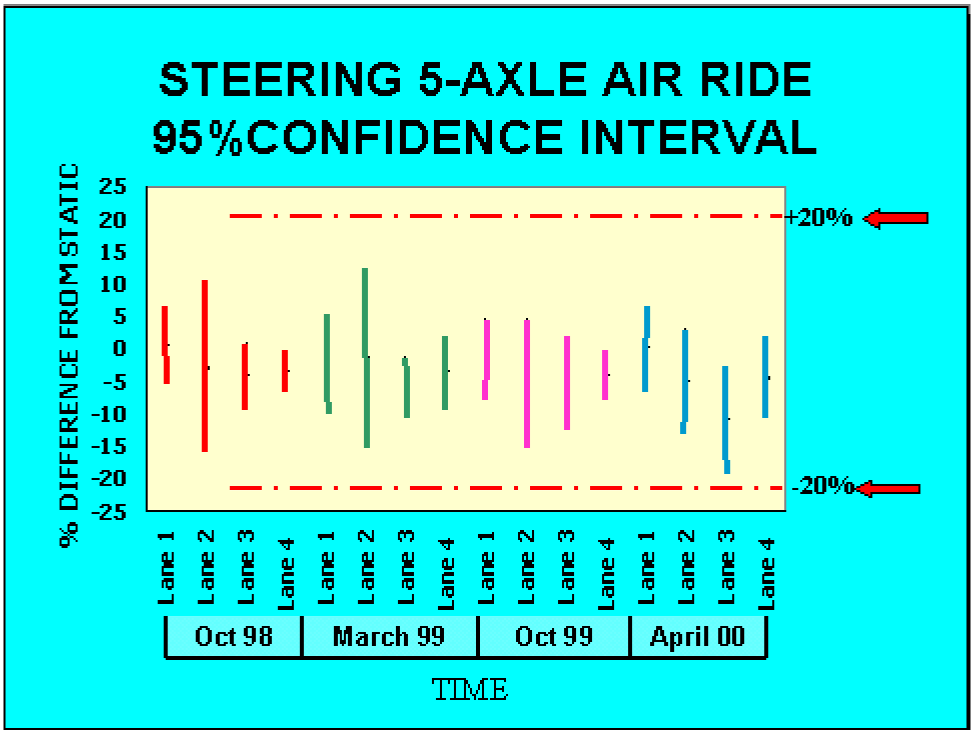

Figure 4 Front-Axle, 5-Axle Truck, 95% Confidence Interval, All Lanes

Office Monitoring of Data

The monitoring of traffic data from the office is a necessary element to check the data quality over time. From our experience, the traffic data at this test site is suitable for applying of the distribution of gross vehicle weight (GVW) and front-axle weight (FAW) distribution methods, as first introduced by Minnesota /Ref 2 /. Therefore for each week of WIM data that is collected the gross vehicle weight distribution, front-axle weight distribution and the percent errors are determined by lane. As shown in Figures 5 and 6, these FAW and GVW data have demonstrated excellent repeatability in the slow lanes.

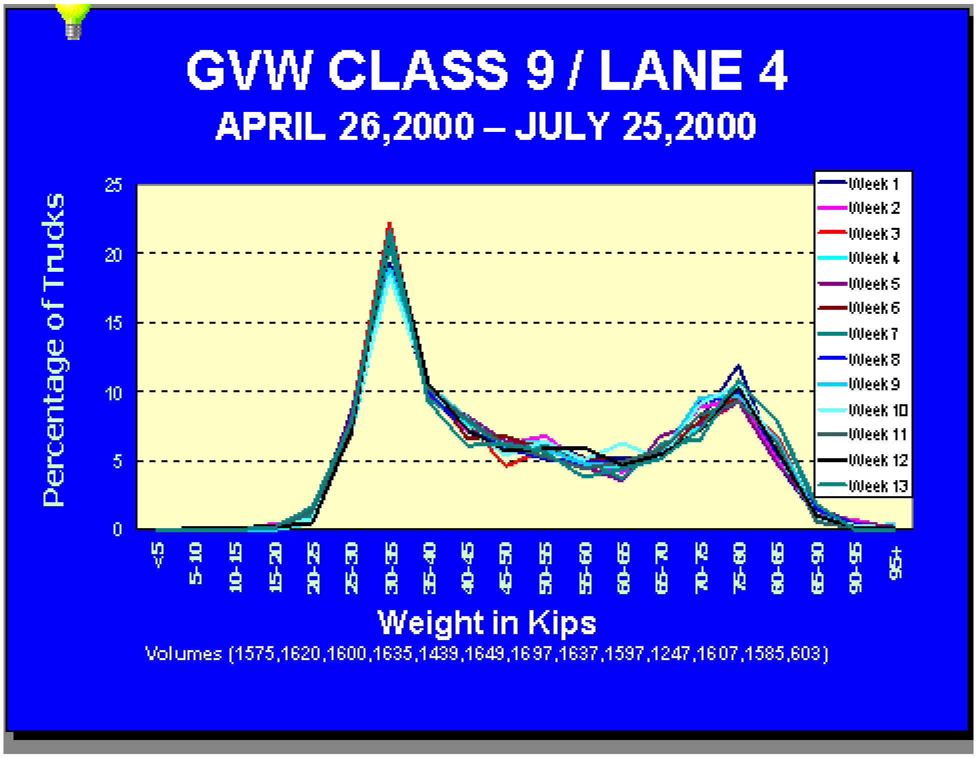

Figure 5 Gross Vehicle Weight (GVW) Distribution

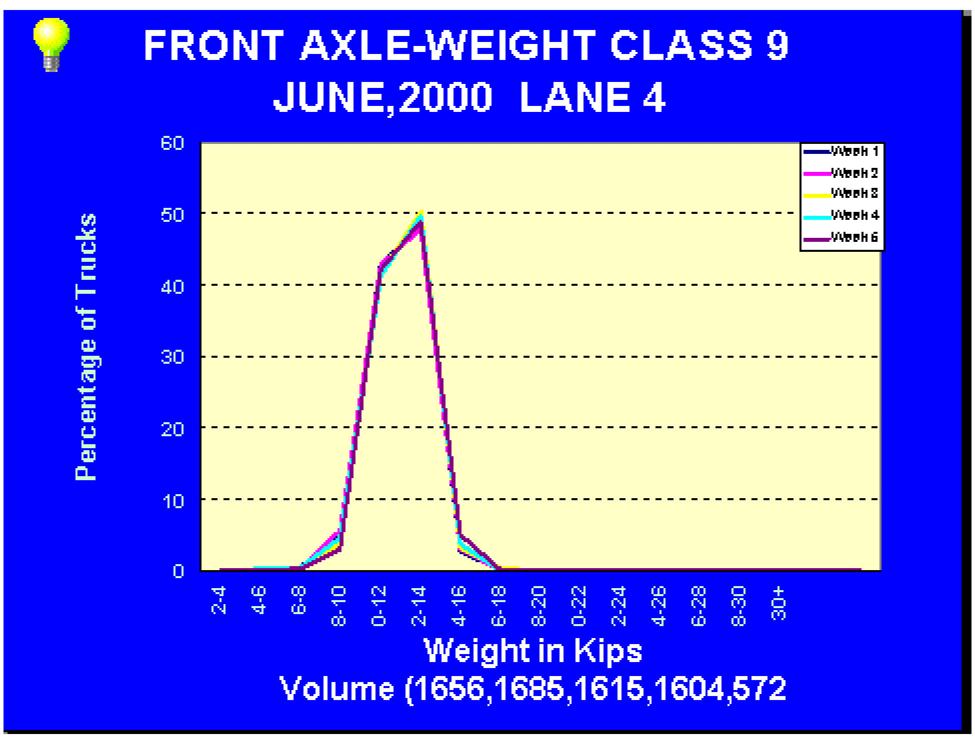

Figure 6 Front-Axle Weight (FAW) Distribution

Connecticut Traffic Data Analysis Tools

The office monitoring of the data, particularly the WIM data, is an extremely tedious process. Many state data collection operations cannot conduct an extensive office review of the data process simply due to the lack of resources. For our research we have found it necessary to hire cooperative education students from local universities, but this option requires conducting training every six-months. We have evaluated methods of improving the data evaluation process and determined the best method of improving this process is to automate as many elements as possible. To this end we have developed both a program to use as an analysis tool and an additional technique by which to assess changes in data trends. The program was written in Foxpro and is a tool to convert data from the FHWA W format into an Microsoft Excel™ spreadsheet that can be easily plotted. This tool does not eliminate the work required by the user, but it does provide assistance to simplify the process. The program was just recently completed and needs a small amount of additional testing. It is our intention to then make both the program and code available for free distribution through FHWA, in, for lack of a better term, "use as you can format."

Technique For Analysis of Traffic Data Shifts

For several years we have visually examined plots of Gross Vehicles Weight (GVW) and Front Axle Weight (FAW) data. We have recently developed a method to determine if and how much shift has taken place mathematically. It is anticipated that this method can then be used to further automate the analysis of data.

Essentially, we examined the curves generated by the GVW distribution. Values are selected to isolate the areas of the graph for unloaded and the loaded vehicles gross vehicle weights for the Class 9 vehicles. The average value for the isolated range area is determined for a specified amount of time (Example: one week.) These average points are then plotted. (Figure 9) A regression analysis is done (it is assumed the points are linear.) The slope of the regression equation line is determined. The value of the slope of the line is diagnostic of the existence and magnitude of any shift or change in the distribution over time. Obviously, the closer the slope of the line is to zero the more likely there is not any shift over time. Conversely, the larger the slope (plus or minus value) the greater the chance and magnitude of the change over time.

Using this technique it was determined (as shown in Reference 1 and Figures 7 and 8) that the weight data demonstrated a change over time for 1999. Such a change was not demonstrated in the 2000 data collected and analyzed thus far. At this point the cause or causes for these changes over time have not been determined. Changes over time could result from the sensors, pavement, environment or actual changes to the traffic stream. It was determined however that long continuous periods of time are best to assess changes. We have never collected full years of highly accurate data (because we did not own equipment capable of collecting it) by which to determine if such fluctuations occur systematically or randomly. This plotting method was then used to determine if the results from the 1999 data correlated well with the finding of the field calibration in

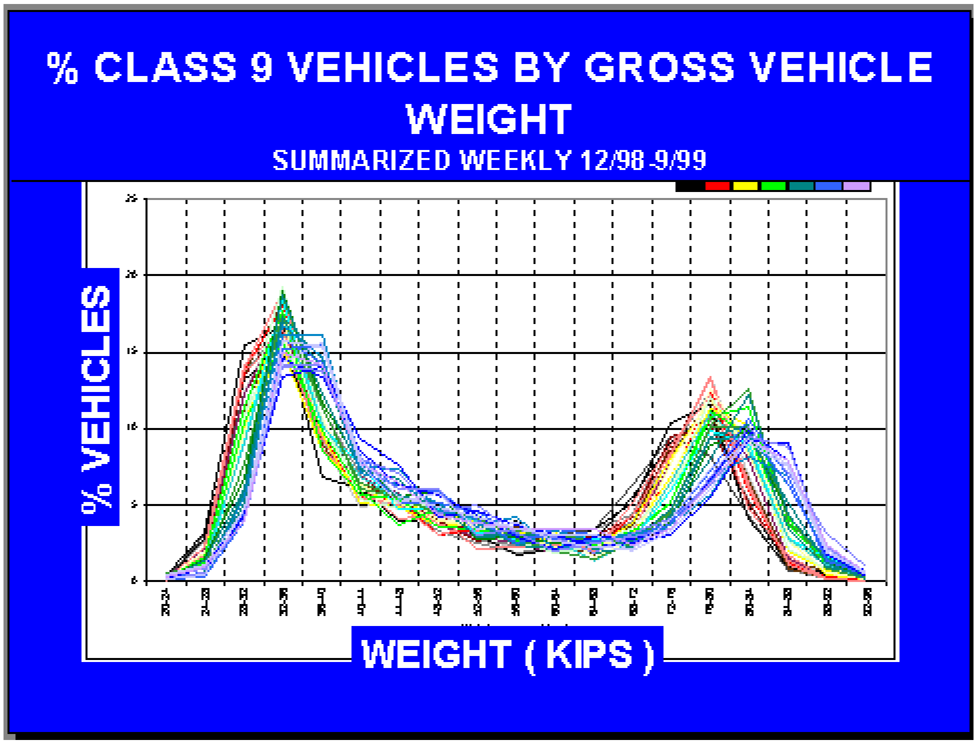

Figure 7 Gross Vehicle Weight Over Time 1999

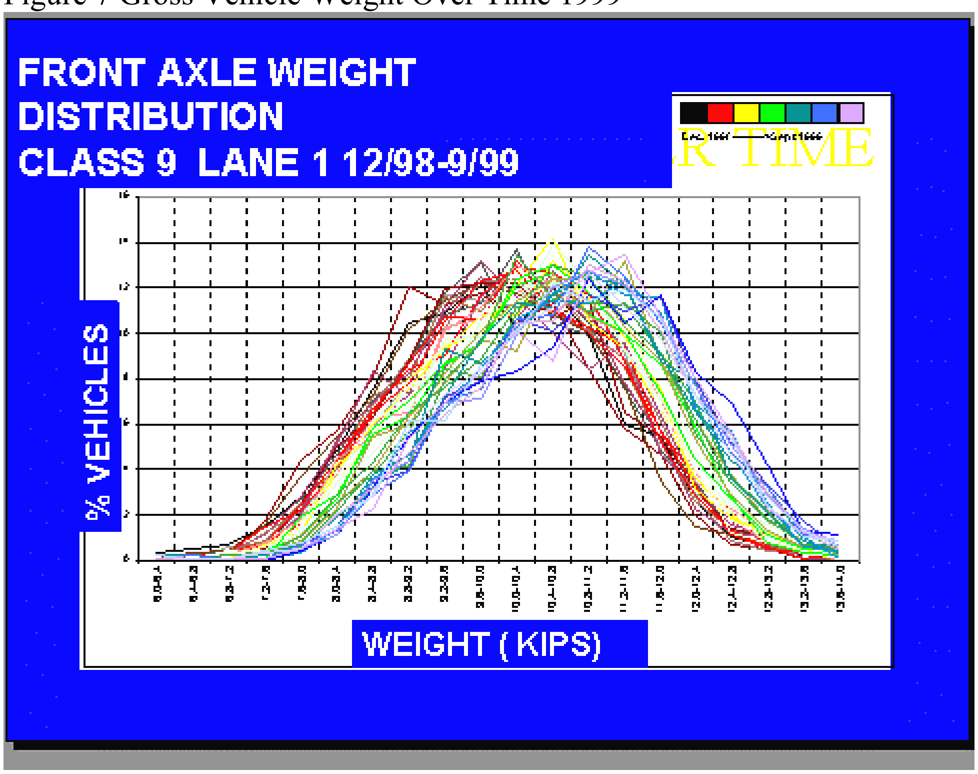

Figure 8 Front-Axle Distribution Over Time 1999

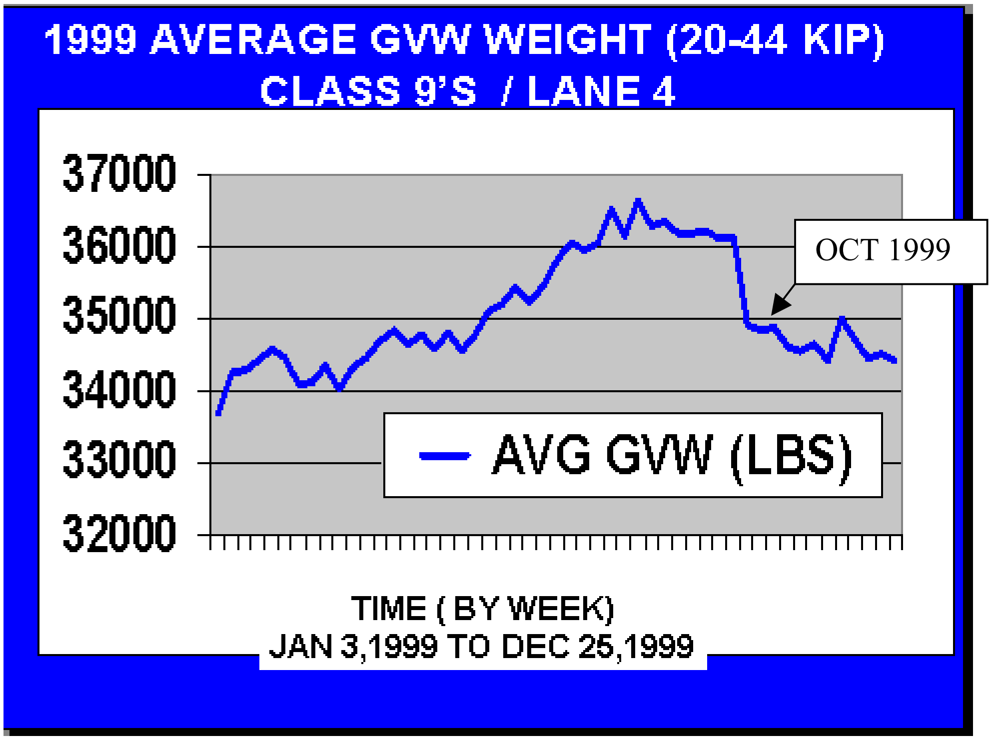

Figure 9 1999 Average Unloaded GVW Weight Over Time, Lane 4

October. In the field in October it was found that a calibration adjustment was needed in Lane 1 but not in Lane 4. Lane 4 returned to the same range just prior to the field calibration and therefore did not require adjustment and the graph in figure 9 support this finding. This technique will continue to be used to determine its application to different data sets.

Field Sensor Inspections

As part of the evaluation of the sensors, field inspections are conducted to determine the condition. From the first sensors that were installed in July 1998, cracking has been observed between the sensors and the connection points, as is shown in Figure 10. Additional cracking and deterioration of the sensors is noticeable in the high-speed shoulder area for the eastbound direction. (Shown in Figure 10). In the fall of 1999, this sensor was also observed to be higher than the pavement surface. It was then ground to match the pavement surface. It is unknown if the sensor was higher than the pavement or the pavement had sunk from the sensor. Additional cracking around the sensors have been sealed prior to the winters in efforts to reduce moisture infiltration and damage due to freezing and thawing. It is unknown if any cracking is the result of sawing and replacing sensors during 1998.

Representatives from the quartz-piezo sensor manufacturer tested all the sensors at the site in August 2000 and determined one sensor in lane 1 yielded less than desirable resistance and the one sensor in lane 3 was still in need of replacement. It is anticipated that this replacement will be scheduled for fall of 2000.

Figure 10 Field Inspection Images of Worse Case Conditions

Summary
The evaluation project is at the end of its second year of sensor evaluation. So far, the sensors have produced very good weight data. We have been able to share the weight data with traffic data collection experts who have wanted to examine the data output. They too have assessed the data and found it to meet many of the known guidelines for weight data quality acceptance.

Several states have installed Quartz-piezo WIM systems in the United States since our first installation and there are several configurations of sensors and electronics that are being used. Recognizing this, it is anticipated that in our evaluation in Connecticut the system will be tested operating with a modified/reduced configuration. Additional work needs to be conducted to determine reasons why lanes 2 & 3 do not produce the same high quality of data, as compared to lanes 1 & 4. We will continue to monitor the sensors over the next winter. The longevity of the sensors still remains under investigation. No conclusion on their useful expected life can be made at this time.

References

1. Larsen, D.A. and McDonnell, A.H.; " Second Interim Report on the Installation and Evaluation of Weigh-In-Motion Utilizing Quartz-Piezo Sensor Technology," ConnDOT Report No. 2306-2-99-7, November 1999.

2. Dahlin, Curtis and Novak, Mark. Compariosn of Weight Data collected at Weigh In Motion (WIM) Systems Located On the Same Route. Minnesota Department of Transportation for Transportation Research Board, January 1994.
3. Standard Specification for Highway Weigh-In-Motion (WIM) Systems with User Requirements and Test Methods, ASTM E 1318, 1994.

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