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16. Abstract

The objective of this research was to evaluate low cost weigh-in-motion systems. The three systems evaluated were (1) a capacitance weigh mat system, (2) a bridge weighing system, and (3) a piezoelectric cable sensor system. All three systems have a two-lane capability.

An evaluation was made of (1) the quality of the data, (2) the performance of the equipment, (3) the applications of the equipment and its ease of use, and (4) the format of the data and its usefulness. Although objective data were used when possible, the majority of the evaluation is subjective.

The quality of the data from each of the three systems is about the same. The piezoelectric cable system provides slightly lower quality data than the other two systems. The equipment of the capacitance weigh mat performed well; that of the bridge system was adequate; and there was concern about the durability of the piezoelectric cable system. Because of the tradeoffs between the capacitance weigh mat system and the bridge system, it is difficult to rank them. The piezoelectric cable system's sensors are permanently installed; therefore, it is not as portable as the other two systems. With regard to the format of the data and its usefulness (which are dependent mostly on the software and not the sensors), the capacitance weigh mat system is flexible and provides individual truck records in two formats, the bridge system provides the most comprehensive tables, and the piezoelectric cable system is limited and depends on other software to generate additional tables. Suggestions are made about how to use the systems and how to improve their performance.

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FINAL REPORT

EVALUATION OF WEIGH-IN-MOTION SYSTEMS

B. H. Cottrell, Jr.
Senior Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The objective of this research was to evaluate low cost weigh-in-motion systems. The three systems evaluated were (1) a capacitance weigh mat system, (2) a bridge weighing system, and (3) a piezoelectric cable sensor system. All three systems have a two-lane capability.

An evaluation was made of (1) the quality of the data, (2) the performance of the equipment, (3) the applications of the equipment and its ease of use, and (4) the format of the data and its usefulness. Although objective data were used when possible, the majority of the evaluation is subjective.

The quality of the data from each of the three systems is about the same. The piezoelectric cable system provides slightly lower quality data than the other two systems. The equipment of the capacitance weigh mat performed well; that of the bridge system was adequate; and there was concern about the durability of the piezoelectric cable system. Because of the tradeoffs between the capacitance weigh mat system and the bridge system, it is difficult to rank them. The piezoelectric cable system's sensors are permanently installed; therefore, it is not as portable as the other two systems. With regard to the format of the data and its usefulness (which are dependent mostly on the software and not the sensors), the capacitance weigh mat system is flexible and provides individual truck records in two formats, the bridge system provides the most comprehensive tables, and the piezoelectric cable system is limited and depends on other software to generate additional tables. Suggestions are made about how to use the systems and how to improve their performance.

FINAL REPORT

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PROBLEM STATEMENT

Weigh-in-motion (WIM) is the process of measuring the dynamic forces of a moving vehicle and estimating the weight of the vehicle. A WIM system is a set of sensors and supporting instruments that performs WIM. For over 30 years, a wide variety of research and development has been conducted to develop a diverse range of effective WIM systems. Recently, much emphasis has been directed to the research and development of low-cost (less than $50,000) WIM systems.

Truck weight data collected using WIM are more representative of highway load applications than data from static scales. Truck weight data from static scales are likely to be biased because some truck operators avoid or bypass the scales. Therefore, WIM is a means to improve the monitoring of truck weights and traffic loadings. Other advantages of WIM include (1) a high processing rate, (2) improved safety by minimizing traffic disruptions and truck queues along the highway, (3) reduced crew size and labor costs, (4) considerably improved data processing efficiency, (5) increased coverage (more sites) at the same cost, (6) minimized scale avoidance, (7) reduced cost per truck weighed, and (8) the provision of information on dynamic wheel loads.[1]

Truck weight data are used for (1) pavement design and monitoring, (2) bridge design and monitoring, (3) size and weight enforcement, (4) legislation and regulation, and (5) administration and planning.[1] Truck weight data are especially important for pavement design and monitoring. Because of the strong relationship between pavement deterioration and traffic loading, the Federal Highway Administration (FHWA) has made improved monitoring of traffic loadings a major element of the pavement management process. Moreover, FHWA has determined that WIM in coordination with a comprehensive automatic vehicle classification effort is a significantly beneficial approach to collecting traffic loading or truck weight data for the highway design and planning process. To obtain improved traffic loading, the FHWA[2] recommended that

> all states immediately move from the use of static weights for nonweight enforcement data gathering to the use of WIM data collection using techniques comparable to those outlined in the FHWA *Traffic Monitoring Guide* (*TMG*).

When load factors that were developed for each state from truck weight studies were compared, Virginia's load factors were in the lower quartile.[3] It is suspected that the low load factors are a result of data from static scales that are not representative of the actual highway loads.

OBJECTIVE AND SCOPE

The objective of this project was to evaluate various WIM systems on the quality of data collected (and its applications) and the performance of the equipment. The emphasis was on low-cost WIM systems. This research project is part of the Research Council's effort to determine the applicability of WIM equipment for the collection of data for planning and design in Virginia.

METHODS

Four activities were conducted to accomplish the study's objective.

Literature Review

Literature covering completed and ongoing development and evaluation of WIM systems was reviewed. The emphasis was on recent evaluations of WIM systems, information from state departments of transportation on the use of WIM, and information from WIM manufacturers.

Equipment Selection and Acquisition

Specifications for the three WIM systems were developed. Three types of low-cost WIM systems were selected for evaluation: (1) a portable capacitance weigh mat, (2) a bridge weighing system, and (3) piezoelectric cable sensors.

Field Evaluation Data Collection

The three systems were evaluated in the field under actual road conditions at selected locations. An evaluation methodology was developed that included (1) the conditions for evaluation (including pavement and traffic conditions), (2) a data collection plan, and (3) evaluation criteria and measures of performance. Site selection criteria were developed, and sites were selected. Some sites were placed near weigh stations in order to compare static versus WIM data. Evaluation criteria (and measures of performance) included: (1) the quality of data (accuracy and precision), (2) the performance of the equipment (reliability and durability), (3) the applications and ease of use (installation and removal requirements and roadway conditions for system use), and (4) the format of the data and its usefulness.

Data Analysis and Evaluation

The field evaluation data were summarized and analyzed. The WIM systems were evaluated using the above criteria.

CHARACTERISTICS COMMON TO ALL WIM SYSTEMS

In the system requirements, there were characteristics that were required of all three WIM systems. These characteristics are listed below.

1. Must provide WIM data for two lanes; must use a rechargeable battery, and must have the capability to operate in a fully automatic mode while unattended.

2. The housing must be rated weatherproof and compact by the National Electrical Manufacturers Association (NEMA).

3. The unit must be compatible with (1) an IBM PC convertible laptop computer with 512K RAM, two 3.5-inch diskette drives, and running with MS-DOS and (2) a Zenith Supersport 286 laptop computer 1 MB RAM, one 3.5-inch diskette drive, 20 MB hard disk, and running with MS-DOS. The computer is used to enter and retrieve data and monitor operations.

4. Must be able to display, print, and/or store cumulative data for each vehicle classification by lane. Must be able to provide a vehicle classification count (in FHWA *Traffic Monitoring Guide* format[4]), vehicle speed, and data for each individual truck including gross weight, all axle weights, all axle spacings, wheel base length, speed, time classification, violator identification, and lane number.

5. Must be able to classify vehicles using the 13 classifications of the FHWA's Scheme F.[4]

6. Must include the federal bridge formula and other weight limits to be used to check for compliance and to indicate the type of violation.[4]

7. It must be possible to calibrate the system with no more than 10 crossings of a test truck per lane.

8. The software must be user friendly and menu driven.

DESCRIPTION OF THE WIM SYSTEMS

Portable WIM Using Capacitance Weigh Mats

System Description

The portable WIM system using capacitance weigh mats is shown in Figures 1 and 2. The system requirements are shown in Appendix A. The system consists of four major components: one field unit, a capacitance weigh mat for each of two lanes, two portable induction loops for each lane, and computer software. Cabling to connect the major components and miscellaneous accessories is also required. Portable reusable induction loops were made by imbedding five turns of 18 gauge copper wire in a 3-ft by 6-ft rectangle in a 3 1/2-ft by 6 1/2-ft by 3/8-in 2-ply black rubber conveyer belt. Each loop mat weighs about 45 lb. The weigh mat is 20 in by 72 in by 3/8 in and weighs 52 lb. The field unit is 17.5 in by 7.75 in by 14 in and weighs 48 lb.

The capacitance weigh mat manufactured and marketed by Electromatic Company of South Africa (sole source) consists of three sheets of steel maintained in approximately parallel position by a rubber dielectric. The weigh mat acts as a variable three-plate capacitor within a tuned circuit.[5] Compression of the sensor by a wheel load causes a change in the oscillating frequency of the tuned circuit and the magnitude of the frequency change is interpreted as a weight. The weigh mat weighs the wheels on one side of the vehicle and doubles each wheel weight to obtain an axle weight. The weigh mat also determines the axle space and the vehicle's classification. The induction loops activate the system when a vehicle's presence is signaled and determine vehicle speed and length. The field unit receives and interprets the signals from these sensors and receives, stores, and downloads the data by microprocessor-based circuitry. A minimum data collection period of 48 hours was specified.

The PAT Equipment Corporation's Portable DAW200 System was obtained at a cost of $25,850. A cost of $30,000 to $35,000 is typical.

Training

Training for the capacitance weigh mat system consisted of two sessions for a total of 24 hours. The first session included an introduction and overview of the system for 3 hours in the classroom and an examination of the system's road layout in a parking lot for 2 hours. A second session was scheduled for 16 hours of hands-on field exercises including installation, calibration, monitoring traffic, trouble shooting, and removal of the system. The remaining 3 hours were used for data retrieval and report generation in the office. Having the training in two sessions was helpful because it allowed time to become familiar with the system between sessions. An additional 6 hours of training would have been helpful. An additional field exercise was conducted to improve confidence in using the system.

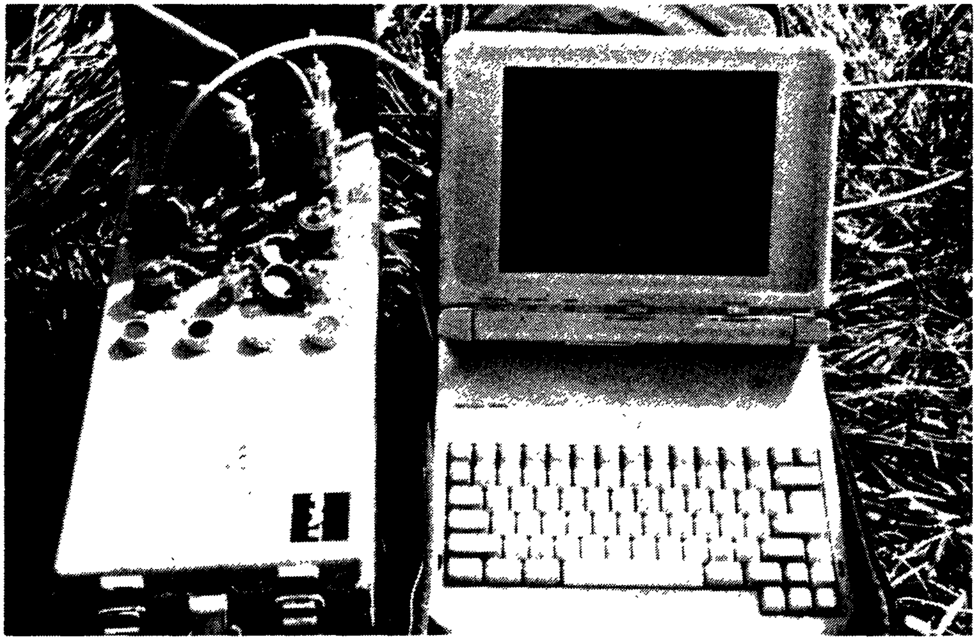


Figure 1. Capacitance weigh mat.

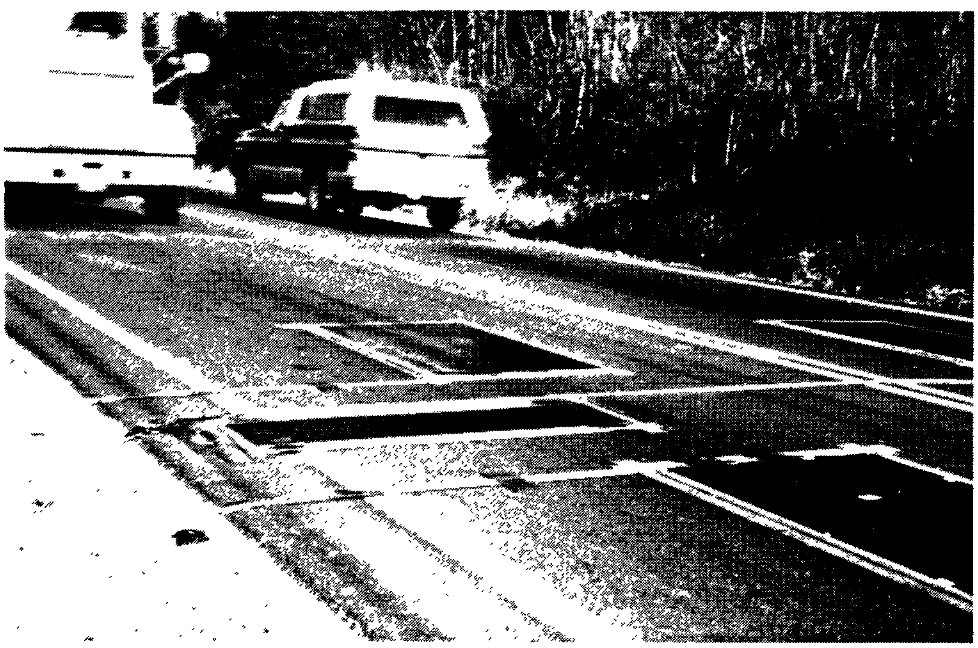


Figure 2. Capacitance weigh mat on the road.

Preparation and Transportation

The primary preparation required for installation is to tape the edges of the weigh mat and loop mat with duct tape (2 in wide) to facilitate the removal of the bitumen-based sealant tape used to secure the mats to the pavement. Preparation of the field unit includes inputting the site parameters, checking all of the data input parameters, and recharging the battery. A full-size van is recommended for transporting the system because of the size of the weigh and loop mats.

Installation

A lane closure is necessary to install this system. With a crew of two people, the installation time is about 30 minutes per lane. The installation consists of measuring to properly place each mat, taping the mats to the pavement, and taping the cables and wires with duct tape and then with bitumen-based sealant tape. Depending on the temperature and location, nails may be used to further secure the mats to the pavement. A loop and a weigh mat cable for each lane is then connected to the field unit. The field unit is usually chained to a sign post or tree. A dry pavement and an ambient temperature above approximately 50° F is needed for the bitumen tape to adhere to the roadway.

Calibration

The capacitance weigh mat system was calibrated using random truck traffic and the corresponding weights from a permanent static scale upstream. At least 30 vehicles were measured for each lane. Another calibration method consisted of a minimum of 5 crossings per lane by a truck of known weight (in this case, a loaded tandem dump truck). With either method, additional runs were recommended if there were large variations in the weights. Calibration is based on gross vehicle weight and may be valid for 6 months to 1 year (based on statements by the vendor and experience in other states).

When a calibration truck was in the area for use on another WIM system, the calibration on the capacitance weigh mat system was checked and verified. About 5 times over 6 months, the calibration was verified within 5 percent. Therefore, it was concluded that this system can operate up to 6 months without being recalibrated. If the truck weights are suspect, it is recommended that a calibration be performed.

Removal and Clean Up

Removal of this system involves cutting and/or pulling the bitumen based sealant tape off of the mats and cables, removing nails when necessary, and then removing the weigh mat, loop mats, and cables from the roadway. Removing the sensors from the roadway during gaps in the traffic takes about 10 minutes per lane with two people removing the sensors and one flagger. The cables are disconnected from the field unit. Off the road, the remaining bitumen-based sealant tape is removed from the sensors and cable, then the equipment is loaded into the van. The removal and loading is completed in about 30 minutes for two lanes. In the equipment storage room at the office, the equipment is inspected, cleaned, and prepared for the next usage.

Data Processing and Reporting

The data processing is divided into two parts: processing before and during data collection, and processing after data collection. Processing before and during data collection involves data entry to begin the system operations, traffic monitoring, and trouble-shooting.

Site parameters and the installation parameters for the sensors are typically entered in the preparation phase and checked after the installation of the sensors. Traffic monitoring is performed to verify that the system is functioning properly. An individual vehicle record is presented on the computer screen for each vehicle that crosses the sensors. The records scroll up as more vehicles are added. If a data measurement is incorrectly displayed or is not functioning properly, then trouble-shooting steps are taken to resolve the problem.

Data processing after data collection was facilitated by menu-driven software. The time required to download the collected data from the field unit to the computer was about 2 minutes for a typical day. The downloaded data are then processed into eight summary tables, truck record batch print, FHWA *Traffic Monitoring Guide* format, and ASCII format. Examples of the eight daily summary tables are shown in Appendix A.

Bridge WIM System

System Description

The portable bridge WIM system is shown in Figures 3 and 4, and the system requirements are in Appendix B. The system has four major parts: (1) the field unit, (2) the battery, (3) the strain transducers, and (4) the road sensors. Cabling to connect the major parts and other accessories is also required. The road sensors can be tape switches or road hoses. The road sensors installed in advance of the first bridge span activate the system and determine speed, axle spacing, and vehicle classification. The strain transducers are attached to bridge girders (longitudinal support beams) typically at 1/3 to 1/2 the span length from the beginning of the bridge, which allows the first bridge span to serve as a scale platform. The structural response to the axle weight, the bending moment, is measured by strain transducers on the load-carrying girders, and the live loads causing the bending moment are calculated. The field unit receives and interprets the signals from the road sensors and strain transducers and stores the data using microprocessor-based circuitry. A laptop computer is used to enter data parameters, monitor and troubleshoot weighing operations, and download data from the field unit.

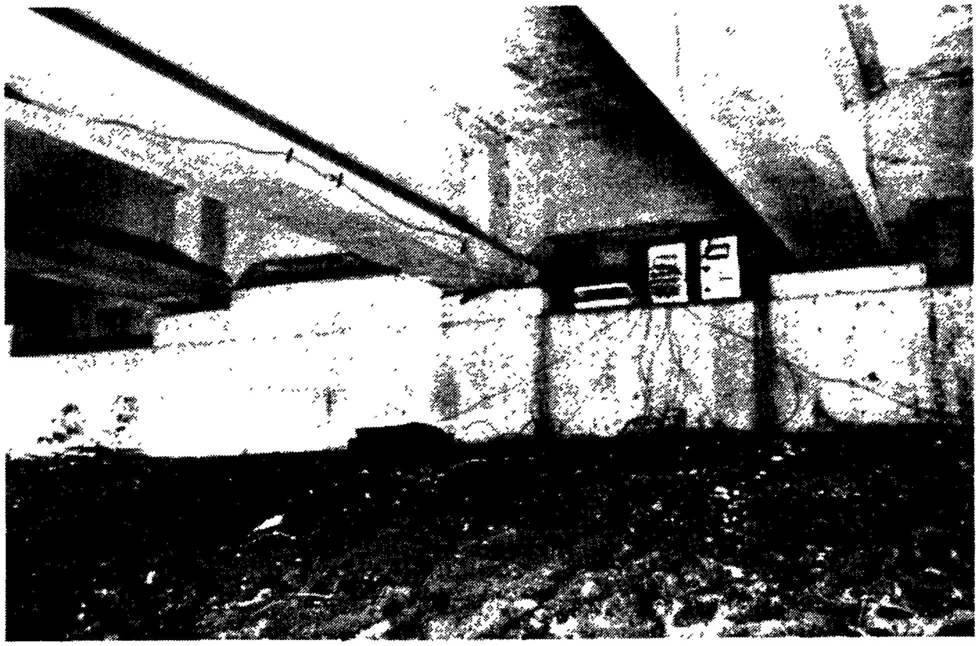


Figure 3. Bridge WIM.

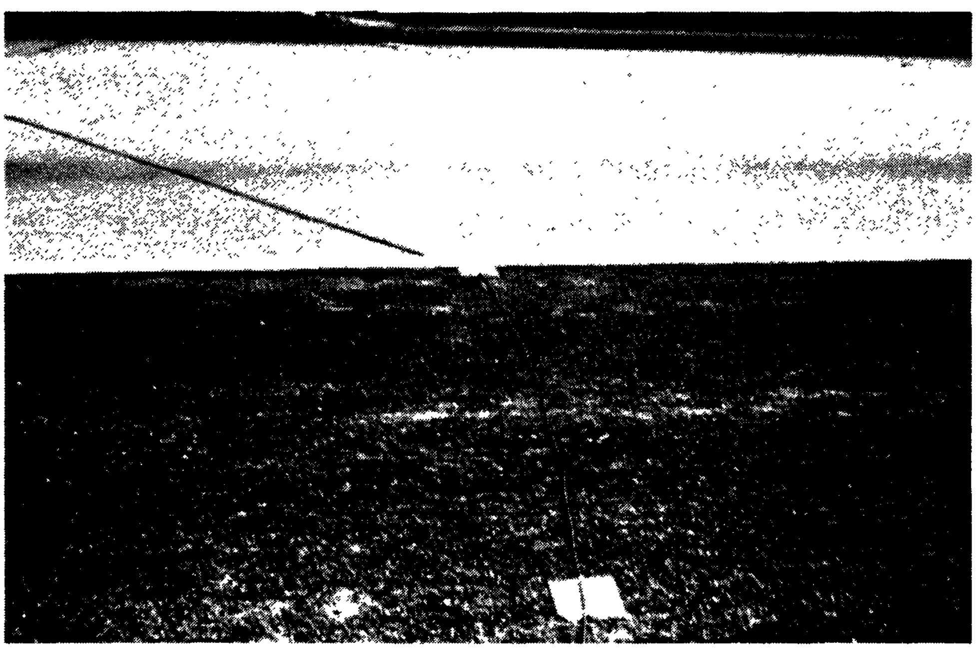


Figure 4. Bridge WIM on the road.

The bridge weigh-in-motion system was obtained from the Bridge Weighing Systems, Inc. at a total cost of $38,125. The system is now called the Bridge MATE and is marketed by Toledo Scale Corporation.

Training

Training was done during five consecutive work days. On Monday, classroom training took place. This included an introduction and overview of the system and fieldwork preparations. On Tuesday, the system was installed on a steel girder bridge in the morning, and the system was monitored and familiarity with the software was achieved in the afternoon and on Wednesday morning. On Wednesday afternoon, a concrete bridge was examined and prepared for a Thursday morning installation and calibration. On Thursday afternoon, a review of the system's overall operation was performed, and then the system was removed. On Friday, the process of downloading the data and generating summary tables was reviewed, and several bridges were assessed for use by the system. The five days of training appeared adequate. An additional field exercise was conducted to gain confidence in using the system.

Installation

Installation time was about 30 minutes per lane with a crew of two people and a flagger. The road sensors were prepared for installation on the road shoulder and were installed with assistance by the flagger in the lane during gaps in the traffic. Installation included: (1) measuring and marking the locations as needed, (2) taping the tape switches with duct tape, then taping the tape switches to the pavement with bitumen-based sealant tape (road hoses were clamped to the pavement using nails and road hose clamps), and (3) attaching the strain transducers to each bridge girder on the first approach span with C clamps or with screws to two metal plates glued to a concrete girder. The road sensors and strain transducers were connected to the field unit by cables. The field and battery units were placed under the bridge near the middle and were chained to a bridge support. Typically, tape switches are used on dry pavement when the ambient temperature is above about 50° F, and road hoses are used for lower temperatures and/or a wet pavement.

Calibration

Eight to ten crossings per lane by a calibration truck, a loaded tandem dump truck weighing more than 40,000 lb, was recommended for calibration with an error of 1.5 (eight crossings) to 1.0 percent (ten crossings). Because of the amount of time required for the recommended calibration, five crossings per lane with an error of 4.0 percent was deemed acceptable. The calibration truck had to be weighed with no other vehicles on the bridge. Therefore, either more than five crossings per lane were necessary to obtain five acceptable crossings, or calibration was made with fewer than five crossings per lane. Because of the time constraints on the first half of this effort, about 2 hr were allowed for calibration, during which time, three acceptable runs per lane were accomplished for an 11 percent error. On average, about 2.5 to 3 hr would be needed to calibrate the system with five crossings per lane. The vendor recommended eight crossings per lane, and we think eight crossings is preferable. The time required is a function of the distance the vehicle must travel for each round trip and the traffic volume on the study approach. The calibration values for a bridge are valid for 1 year. After 1 year, it is recommended that the bridge be recalibrated.

Removal and Cleanup

Removal of this system consisted of cutting or pulling the bitumen-based sealant tape off of the pavement and tape switches or removing the road hoses and clamps from the roadway, removing the strain transducers from the girders, and disconnecting the cables between the sensors or transducers to the field unit. Removing the sensors from the road during gaps in traffic takes fewer than 5 minutes per lane with one person removing the sensors and one flagger. It takes about 30 minutes to complete the removal and load the vehicle. At the office, the equipment is inspected, cleaned, and prepared for the next usage.

Data Processing and Reporting

The procedures for processing data were similar to the procedures used with the capacitance weigh mat system. Additionally, traffic monitoring was used for calibration, and for the calibration trucks, a captured strain record was produced. By changing the calibration factor, it was possible to review the calibration trucks' captured strain records and to view the revised weights based on the new calibration factor. In troubleshooting, some errors were coded and had to be interpreted by the staff of Bridge Weighing System, Inc.

Data processing was begun by summarizing the collected data. For each day, depending on the truck volume, the summarizing took about 30 to 45 minutes for a full 24-hr of data. With the most recent revision, the data from the previous day were summarized after midnight during data collection. The summarized data were then retrieved and stored on a computer file for printing 14 tables (see Appendix B). All truck records were then reformatted into the FHWA *Traffic Monitoring Guide* format and stored in a computer file. The summary tables include data from both lanes.

Piezoelectric Cable WIM System

System Description

The WIM system using permanently installed piezoelectric cable sensors is shown in Figures 5 and 6. The system requirements are shown in Appendix C. The

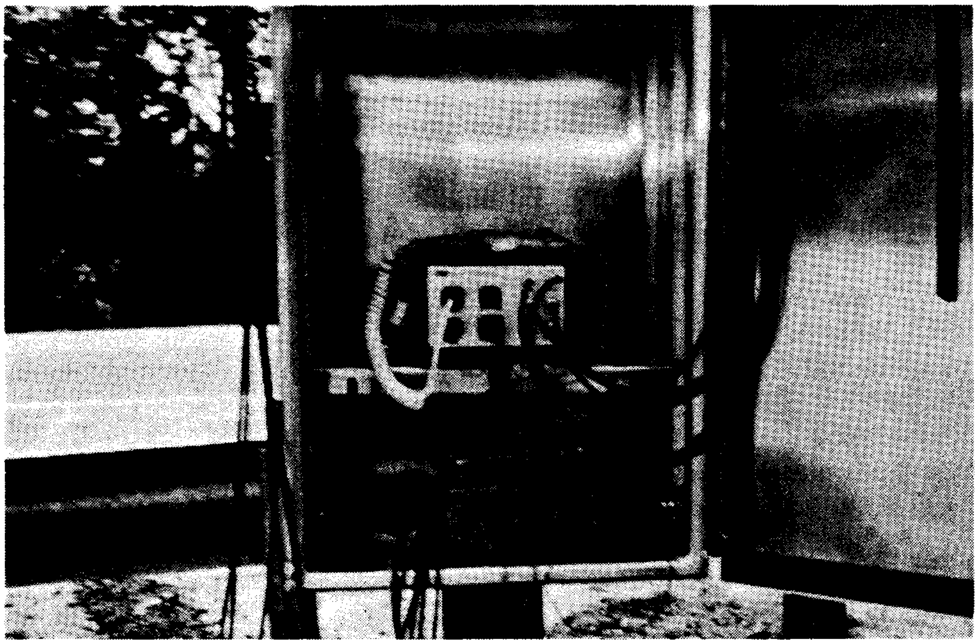


Figure 5. Piezoelectric field unit.

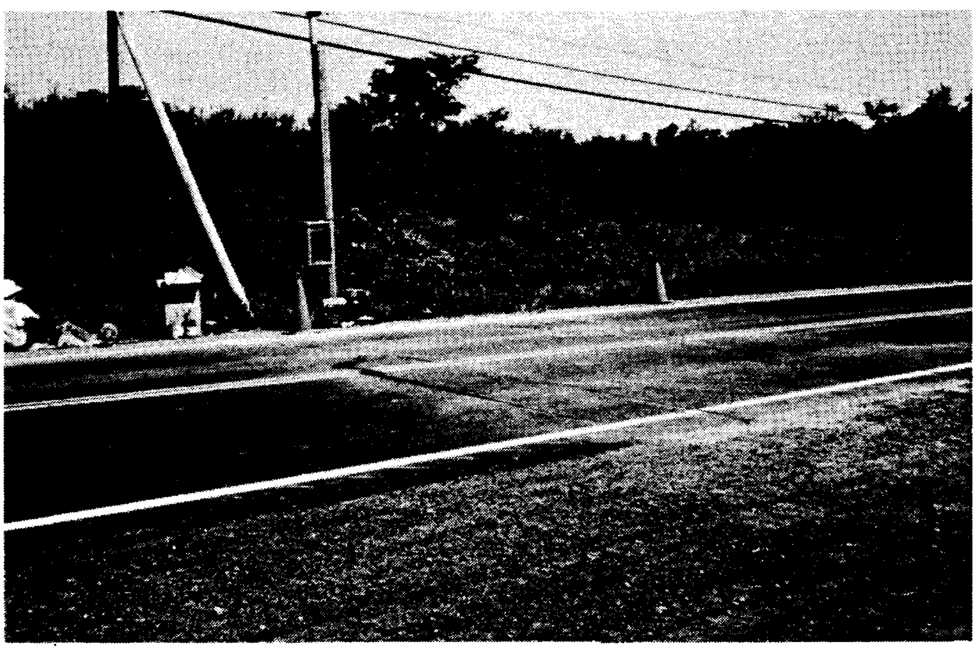


Figure 6. Piezoelectric road sensors.

system consists of three sensors per lane, two 12-ft sensors and one 18-in off-scale sensor, a field unit and battery, and cabinet. Cables are required to connect the sensors to the field unit. Also, a camera unit that connects to the field unit and can take photographs of vehicles exceeding a specified threshold weight or speed or vehicle class was examined for planning purposes only. Two field units were obtained. Two lanes of sensors were installed at two sites, and one lane was instrumented at a third site. The piezoelectric cable (trade name Vibracoax) was originally developed to sense vibrations in nuclear power plants and has a sole source supplier in Thermocoax, a French subsidiary of the Philips Corporation.

"Piezo-electricity is 'pressure electricity.' When a force or pressure is applied to certain parallel faces of a piezo-electric crystalline material, electrical charges of opposite polarity appear at the parallel faces. The size of the piezo effect depends on the direction of the force in relation to the axes of the crystal. Another characteristic is that the charge is generated only when the forces are changing. Should a constant force be applied, the initial charge will decay."[6] The piezoelectric cable consists of a solid copper wire core and a solid copper tubing sheath with a highly compressed powdered piezoelectric cable ceramic insulation between the core and sheath acting as a dielectric. When used as a WIM transducer, the cable is mounted in an aluminum channel and encapsulated in an epoxy resin mixture. The two 12-ft piezoelectric cables determine a vehicle's speed, vehicle class, and axle weight. Some piezoelectric cable systems include induction loops to activate the system and to determine speed and vehicle length. The field unit receives and interprets the signals and stores the data. VDOT personnel installed the sensors under the vendor's supervision.

The total cost of two field units, sensors for seven lanes, one camera system, sealant materials, and cables was $58,500. The systems were obtained from Castle Rock Consultants. The cost of two lanes of sensors, a field unit, and accessories is about $25,000. A typical installation would also include telemetry and a solar panel for continuous operation for a total cost of about $35,000 installed.

Training

Training for the piezoelectric cable WIM system was in four sessions: a classroom introduction and overview (1 day), a half day of field training, a half day of classroom training on the field unit, and two half days of field training. All sensor installations preceded the formal training.

Sensor Installation

Piezoelectric cable sensors were permanently mounted flush with the pavement. The sensor installation for one lane was completed in about 6 to 8 hr. Detailed installation procedures are described in Appendix C. Subsequent installations consisted of connecting the cables to the portable battery-operated field unit. This connection and removal takes fewer than 5 minutes. Mounting the camera system on a 16-ft post takes about 20 minutes. The camera system is an accessory and was used only occasionally. Sensors were installed at three locations: (1) Interstate 95 northbound in Sussex County less than 1 mile from the Prince George County Line (two lanes), (2) Route 15 in Loudon County about 3 miles north of Leesburg (both directions), and (3) Route 52 southbound at Fancy Gap in Carroll County (one lane).

Calibration

Each lane was calibrated using a loaded tandem dump truck for 5 to 8 crossings. The field unit also has an automatic or self-calibration feature based on the front axle weight of class 9 vehicles (5-axle semitrailer truck). An average value for the front axle weight of class 9 vehicles is entered in the field unit (9500 lb is a nationwide average). After 150 class 9 vehicle records were created, the average weight of their front axles was calculated. The calibration factor was automatically adjusted so that the average weight of the 150 measured vehicles equaled the average value specified.

Data Processing and Reporting

Data processing is similar to the other systems with one exception: only one individual vehicle record can be viewed on the screen at one time for each lane. Although the vehicle record will scroll up for the other systems, the vehicle record range is fixed for this system. The time required to download collected data from the field is less than 2 minutes for a typical day. The unit produces two summary files of binned data on speed and weights (Appendix C). The Traffic Monitoring Data Software (TMDS-1) that uses data formatted according to the *Traffic Monitoring Guide*[7] is used to generate tables.

EVALUATION RESULTS

The evaluation was made in five areas: (1) data quality, (2) equipment performance, (3) applications and ease of use, (4) data format and usefulness, and (5) lessons learned and recommended practices. Although objective data are used when possible, the majority of the evaluation is subjective.

Data Quality

Data quality was measured by accuracy and precision. *Accuracy* is the degree of conformity of a measure to a true value within applicable tolerances. It is measured as the mean error expressed as a percentage of a true value coupled with a confidence level, e.g., + or - 5 percent at the 90 percent confidence level. *Precision*, the degree of agreement of repeated measurements of a quantity, is measured by the standard deviation of the mean error. Precision is also called *reliability*. Regression analysis was used to determine a third measure, the coefficient of determination to correlate the WIM and static weights.

The specified accuracy and precision of the three WIM systems for at least a 90 percent confidence interval are displayed in Table 1.

Table 1
SPECIFIED ACCURACY AND PRECISION OF WIM SYSTEMS

	Systematic or Mean Error	Random Error or Standard Deviation
single axle weight	5%	15%
tandem axle weight	5%	13%
gross weight	5%	12%
axle spacing	+ 6 in	12 in
vehicle length (weigh mat only)	+12 in	18 in
speed	+1 mph	2.5 mph

Vehicle classification accurately classified at least 90% of the vehicles.
For the piezoelectric cable system, the standard deviation for all weights was 12 percent.

Limited tests were made on the accuracy of the speed. Vehicle classification was tested with a minimum of 100 vehicles. The accuracy and precision of all three systems for weight, vehicle classification, and speed met the specifications.

The quality of weight data depends on many factors including location specific factors such as the road alignment and surface, the calibration process, and accuracy testing. There are numerous other factors affecting the quality of weight data, including vehicle, WIM, and static weight factors.[8]

The bridge system was calibrated with less than the recommended number of vehicle samples, therefore the data quality measures are suspect. Six random vehicles were used based on the 5 crossings per lane for a calibration truck. Later, it was learned that 30 or more random vehicles were recommended. The mean error of the gross vehicle weight is typically 4 to 8 percent.

Accuracy

The results of accuracy tests for the three WIM systems using the one-tailed T test at a 0.05 level of significance are shown in Table 2.[9] The actual mean error was compared with the specified mean error of 5 percent.

With all three systems, there are no significant differences for gross weight, and for the steering and tandem axles for class 9 vehicles greater than 60 kips. Therefore, all three WIM systems achieved the mean error specification for the

Table 2
ACCURACY TESTS FOR THE WIM SYSTEMS

ALL VEHICLES:GVW	WEIGH MAT	BRIDGE WIM	PIEZO SENSORS
N	50	40	52
MEAN	9	8.6	2.8 **
STD DEV	13	11.9	14.4
T TEST	2.18 * NS 0.01	1.91 * NS 0.025	–1.10
ALL CLASS 9:GVW			
N	40	30	35
MEAN	8.9	9.4	0.8 **
STD DEV	14.6	13.4	13.6
T TEST	1.69 * NS 0.025	1.80 * NS 0.025	–1.83 * NS 0.025
ALL CLASS 9:STEERING AXLE			
N	40	30	35
MEAN	–6.3	–3.9 **	–4.3 **
STD DEV	0.8	14.2	17.5
T TEST	–10.28 *	0.42	0.24
ALL CLASS 9:FRONT TANDEM			
N	40	30	35
MEAN	16.3	16.8	3.1 **
STD DEV	15	29.8	20.1
T TEST	8.98 *	4.01 *	2.38 * NS 0.01
ALL CLASS 9:REAR TANDEM			
N	40	30	35
MEAN	11.7	13.7	4.2 **
STD DEV	34.2	25.1	17.1
T TEST	3.09 *	4.08 *	3.18 * NS 0.01
CLASS 9 > 60 KIPS:GVW			
N	19	7	11
MEAN	0.3 **	–1.3 **	–6.5
STD DEV	7.6	3.8	13.6
T TEST	–2.70	2.58	–0.37
CLASS 9 > 60 KIPS:STEERING AXLE			
N	19	7	11
MEAN	–5.6	–4.6 **	–9.7
STD DEV	4.9	10.6	15.9
T TEST	–0.53	0.10	–0.98
CLASS 9 > 60 KIPS:FRONT TANDEM			
N	19	7	11
MEAN	5.5	1.2 **	–4.9 **
STD DEV	9.1	18.1	16.8
T TEST	0.24	–0.56	0.02
CLASS 9 > 60 KIPS:REAR TANDEM			
N	19	7	11
MEAN	–2.7 **	–2 **	–4.3 **
STD DEV	10.9	12.7	23.3
T TEST	0.92	0.62	0.10

* significantly different at 0.05
** mean error is less than 5%
NS = not significantly different at the level of significance stated.

axles of the heavier vehicles. In general, the mean error was significantly greater for the tests involving all vehicles and all class 9 vehicles. Three exceptions were the piezoelectic cable system for all vehicles' GVW and all class 9 vehicles' steering axle, and the bridge WIM system for all class 9 vehicles' steering axle. It is suspected that the mean error is larger for lighter weight vehicles.

Precision

The results of precision tests for the WIM systems using the one-tailed F test at a 0.05 level of significance are shown in Table 3.[9] The actual standard deviation was compared with the appropriate standard deviation in the specifications. The weigh mat system achieved the specified standard deviation for all tests except those for all class 9 vehicles' rear tandem axles. The bridge WIM system performed similarly except that both the front and rear tandem axles of all class 9 vehicles were significantly different from the specified standard deviation. The piezoelectric cable WIM system showed significant differences for all vehicles' GVW, all class 9 vehicles' front and rear tandem axles, and the rear tandem axle of class 9 vehicles greater than 60 kips.

Regression Analysis

The regression equations for the weigh mat, bridge, and piezoelectric cable WIM systems are shown in Tables 4, 5, and 6, respectively. In the equations, y is the static weight and x is the WIM weight. The R-squared values indicate how well the WIM weight is predicting the static weight. In all three tables, the R-squared values are high (greater than 0.80) for the GVW of all vehicles, all class 9 vehicles, and the rear tandem axle of all class 9 vehicles. The front tandem axles of all class 9 vehicles also have a high R-squared for the weigh mat and piezoelectric cable WIM systems.

All categories for class 9 vehicles greater than 60 kips have lower R Squared values possibly as a result of the smaller sample sizes.

In Figures 7 through 12, scatter diagrams displaying a 90 percent confidence interval (the area between the two lines) are shown for all vehicles' GVW, all class 9 vehicles' GVW, all class 9 vehicles' front tandem axle weight, and all class 9 vehicles' rear tandem axle weight. The confidence interval is influenced by the standard deviation, i.e., a larger standard deviation results in a larger confidence interval.

Summary

The overall data quality based on accuracy and precision tests that meet the specifications is equal for the weigh mat and bridge WIM systems and slightly less for the piezoelectric cable WIM system.

Because the truck weights of major interest are the heavier trucks, the data quality for vehicles greater than 60 kips are ranked for the three systems. The

Table 3
PRECISION TESTS FOR THE WIM SYSTEMS

ALL VEHICLES:GVW	WEIGH MAT	BRIDGE WIM	PIEZO SENSORS
N	50	40	52
STD DEV	13	11.9 **	14.4
F TEST	1.17	0.98	1.44 * NS 0.01
ALL CLASS 9:GVW			
N	40	30	35
STD DEV	14.6	13.4	13.6
F TEST	1.48	1.25	1.28
ALL CLASS 9:STEERING AXLE			
N	40	30	35
STD DEV	0.8 **	14.2 **	17.5
F TEST	0.00	0.90	1.36
ALL CLASS 9:FRONT TANDEM			
N	40	30	35
STD DEV	15	29.8	20.1
F TEST	1.33	5.25 *	2.39 *
ALL CLASS 9:REAR TANDEM			
N	40	30	35
STD DEV	34.2	25.1	17.1
F TEST	6.92 *	3.73 *	1.73 *
CLASS 9 > 60 KIPS:GVW			
N	19	7	11
STD DEV	7.6 **	3.8 **	13.6
F TEST	0.40	0.10	1.28
CLASS 9 > 60 KIPS:STEERING AXLE			
N	19	7	11
STD DEV	4.9 **	10.6 **	15.9
F TEST	0.11	0.50	1.12
CLASS 9 > 60 KIPS:FRONT TANDEM			
N	19	7	11
STD DEV	9.1 **	18.1	16.8
F TEST	0.49	1.94	1.67
CLASS 9 > 60 KIPS:REAR TANDEM			
N	19	7	11
STD DEV	10.9 **	12.7 **	23.3
F TEST	0.70	0.95	3.21 *

* significantly different at 0.05
** standard deviation is less than specifications
NS 0.01 not significantly different at 0.01

Table 4
REGRESSION EQUATIONS FOR THE WEIGH MAT SYSTEM

ALL VEHICLES GVW
Regression Output:

Constant	10.901
Std. Error of Y Est	4.597
R Squared	0.929
No. of Observations	50
Degrees of Freedom	48
X Coefficient(s)	0.860
Std. Error of Coef.	0.034

ALL CLASS 9 GVW
Regression Output:

Constant	17.141
Std. Error of Y Est	4.251
R Squared	0.904
No. of Observations	40
Degrees of Freedom	38
X Coefficient(s)	0.763
Std. Error of Coef.	0.040

CLASS 9 > 60 KIPS GVW
Regression Output:

Constant	12.840
Std. Error of Y Est	5.474
R Squared	0.471
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	0.819
Std. Error of Coef.	0.205

ALL CLASS 9 STEERING
Regression Output:

Constant	0.477
Std. Error of Y Est	0.539
R Squared	0.682
No. of Observations	40
Degrees of Freedom	38
X Coefficient(s)	0.891
Std. Error of Coef.	0.099

CLASS 9 > 60 KIPS STEERING
Regression Output:

Constant	–0.701
Std. Error of Y Est	0.528
R Squared	0.637
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	1.001
Std. Error of Coef.	0.178

ALL CLASS 9 FRONT TANDEM
Regression Output:

Constant	7.939
Std. Error of Y Est	2.296
R Squared	0.878
No. of Observations	40
Degrees of Freedom	38
X Coefficient(s)	0.800
Std. Error of Coef.	0.048

CLASS 9 > 60 KIPS FRONT TANDEM
Regression Output:

Constant	2.756
Std. Error of Y Est	2.961
R Squared	0.463
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	0.962
Std. Error of Coef.	0.244

ALL CLASS 9 REAR TANDEM
Regression Output:

Constant	7.314
Std. Error of Y Est	2.372
R Squared	0.882
No. of Observations	40
Degrees of Freedom	38
X Coefficient(s)	0.725
Std. Error of Coef.	0.043

CLASS 9 > 60 KIPS REAR TANDEM
Regression Output:

Constant	6.188
Std. Error of Y Est	3.043
R Squared	0.475
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	0.759
Std. Error of Coef.	0.188

Table 5
REGRESSION EQUATIONS FOR THE BRIDGE WIM SYSTEM

ALL VEHICLES GVW — Regression Output:

Constant	55.990
Std. Error of Y Est	41.176
R Squared	0.936
No. of Observations	40
Degrees of Freedom	38
X Coefficient(s)	0.924
Std. Error of Coef.	0.039

ALL CLASS 9 GVW — Regression Output:

Constant	82.377
Std. Error of Y Est	44.445
R Squared	0.921
No. of Observations	30
Degrees of Freedom	28
X Coefficient(s)	0.878
Std. Error of Coef.	0.048

ALL CLASS 9 STEERING — Regression Output:

Constant	74.453
Std. Error of Y Est	7.243
R Squared	0.078
No. of Observations	30
Degrees of Freedom	28
X Coefficient(s)	0.160
Std. Error of Coef.	0.104

ALL CLASS 9 FRONT TANDEM — Regression Output:

Constant	55.261
Std. Error of Y Est	44.279
R Squared	0.667
No. of Observations	30
Degrees of Freedom	28
X Coefficient(s)	0.815
Std. Error of Coef.	0.109

ALL CLASS 9 REAR TANDEM — Regression Output:

Constant	29.118
Std. Error of Y Est	26.797
R Squared	0.907
No. of Observations	30
Degrees of Freedom	28
X Coefficient(s)	0.887
Std. Error of Coef.	0.054

CLASS 9 > 60 KIPS GVW — Regression Output:

Constant	486.646
Std. Error of Y Est	14.244
R Squared	0.441
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	0.300
Std. Error of Coef.	0.151

CLASS 9 > 60 KIPS STEERING — Regression Output:

Constant	116.685
Std. Error of Y Est	4.736
R Squared	0.143
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	−0.202
Std. Error of Coef.	0.221

CLASS 9 > 60 KIPS FRONT TANDEM — Regression Output:

Constant	477.938
Std. Error of Y Est	33.944
R Squared	0.200
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	−0.589
Std. Error of Coef.	0.527

CLASS 9 > 60 KIPS REAR TANDEM — Regression Output:

Constant	150.100
Std. Error of Y Est	43.909
R Squared	0.100
No. of Observations	7
Degrees of Freedom	5
X Coefficient(s)	0.489
Std. Error of Coef.	0.654

Table 6
REGRESSION EQUATIONS FOR THE PIEZOCABLE WIM SYSTEM

ALL VEHICLES GVW
Regression Output:

Constant	4459.629
Std. Error of Y Est	6614.097
R Squared	0.894
No. of Observations	52
Degrees of Freedom	50
X Coefficient(s)	0.892
Std. Error of Coef.	0.044

ALL CLASS 9 GVW
Regression Output:

Constant	5655.800
Std. Error of Y Est	7523.028
R Squared	0.853
No. of Observations	37
Degrees of Freedom	35
X Coefficient(s)	0.872
Std. Error of Coef.	0.061

CLASS 9 > 60 KIPS GVW
Regression Output:

Constant	–32757.2
Std. Error of Y Est	13084.13
R Squared	0.151
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.367
Std. Error of Coef.	1.08

ALL CLASS 9 STEERING
Regression Output:

Constant	–1010.69
Std. Error of Y Est	1810.616
R Squared	0.337
No. of Observations	37
Degrees of Freedom	35
X Coefficient(s)	1.068
Std. Error of Coef.	0.253

CLASS 9 > 60 KIPS STEERING
Regression Output:

Constant	–323.481
Std. Error of Y Est	2863.797
R Squared	0.150
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.989
Std. Error of Coef.	0.785

ALL CLASS 9 FRONT TANDEM
Regression Output:

Constant	4132.140
Std. Error of Y Est	3283.641
R Squared	0.830
No. of Observations	37
Degrees of Freedom	35
X Coefficient(s)	0.781
Std. Error of Coef.	0.060

CLASS 9 > 60 KIPS FRONT TANDEM
Regression Output:

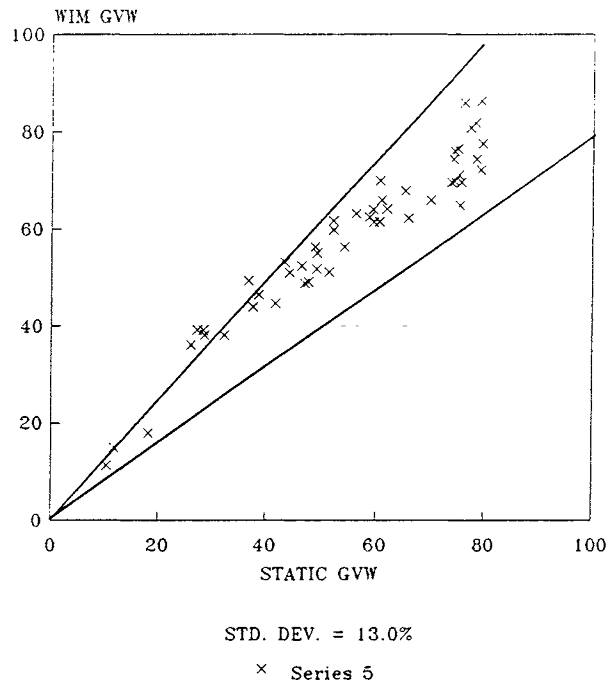
Constant	1724.360
Std. Error of Y Est	5563.928
R Squared	0.139
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.849
Std. Error of Coef.	0.704

ALL CLASS 9 REAR TANDEM
Regression Output:

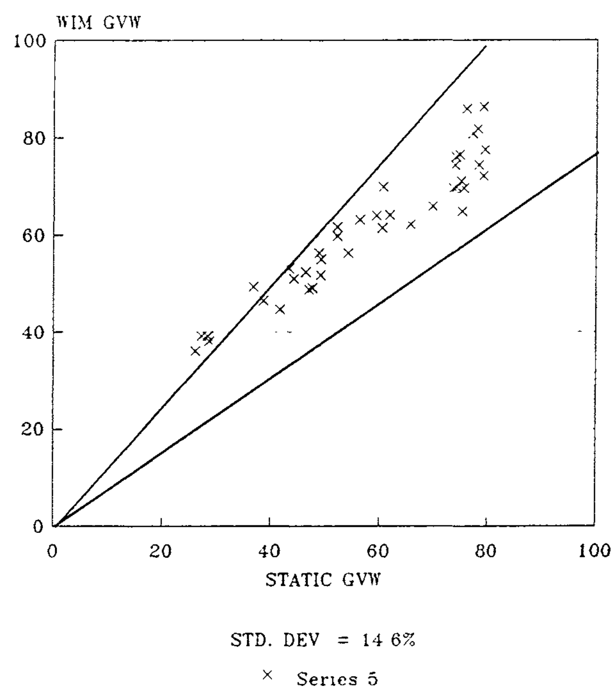
Constant	1895.687
Std. Error of Y Est	3422.101
R Squared	0.893
No. of Observations	37
Degrees of Freedom	35
X Coefficient(s)	0.892
Std. Error of Coef.	0.052

CLASS 9 > 60 KIPS REAR TANDEM
Regression Output:

Constant	24298.62
Std. Error of Y Est	5991.194
R Squared	0.005
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.221
Std. Error of Coef.	1.089

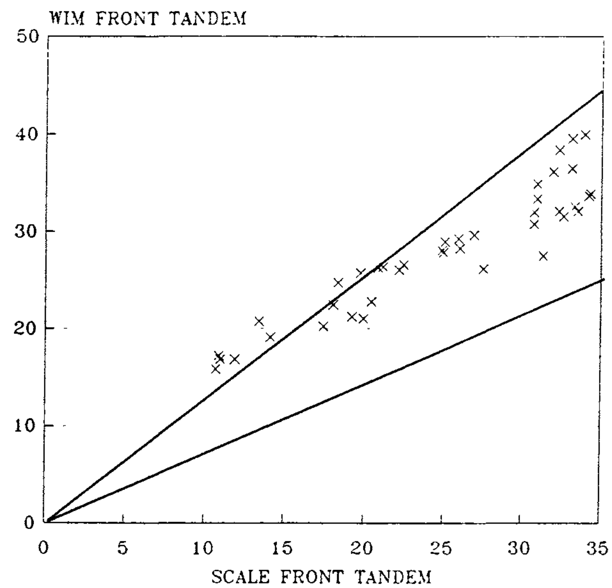


a. **Gross vehicle weight of all vehicles.**



b. Gross vehicle weight of all class 9 trucks.

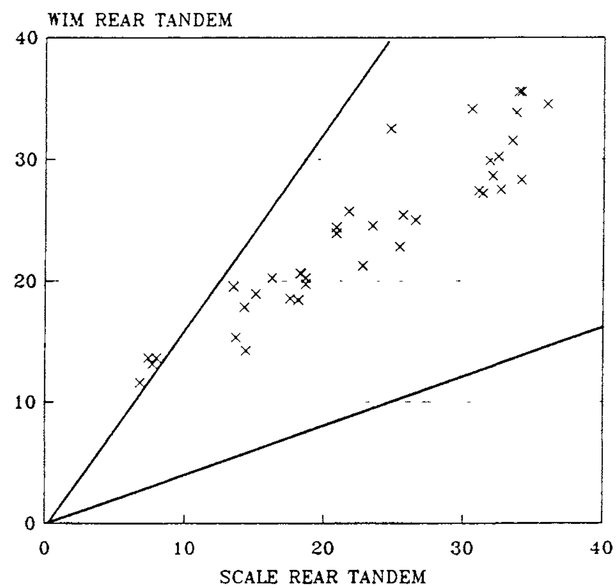
Figure 7. Weigh Mat graph.



STD. DEV. = 15.0%

× Series 5

a. Front tandem weight of class 9 trucks.

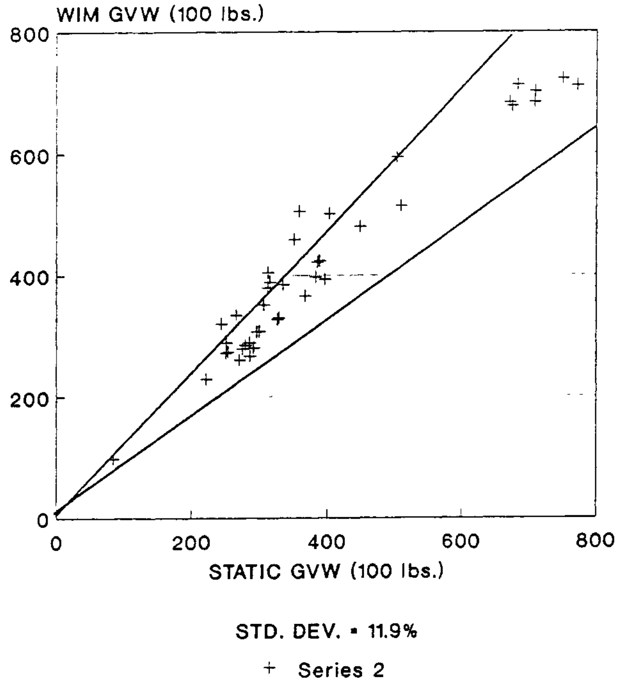


STD. DEV. = 34.2%

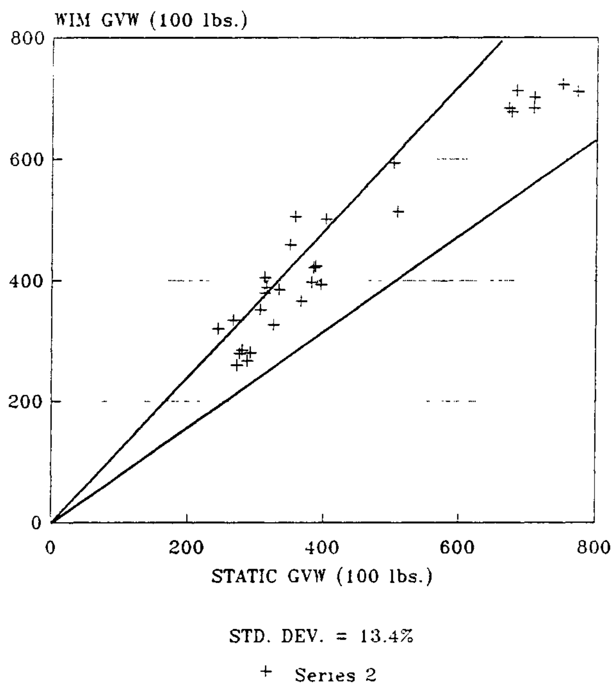
× Series 5

b. Rear tandem weight of class 9 trucks.

Figure 8. Weigh Mat graph.

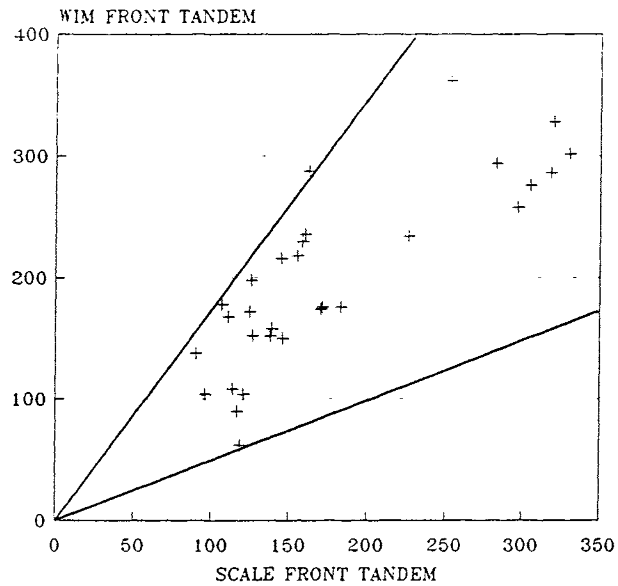


a. Gross vehicle weight of all vehicles.



b. Gross vehicle weight of all class 9 trucks.

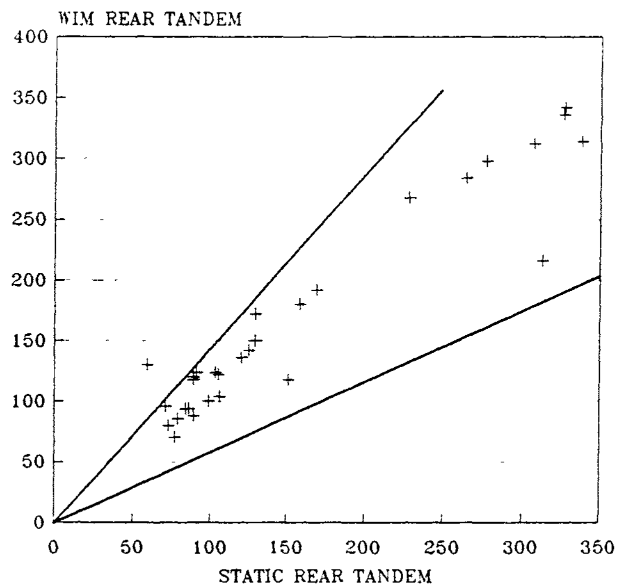
Figure 9. Bridge WIM graph.



STD. DEV. = 29 8%

+ Series 2

a. **Front tandem weight of class 9 trucks.**

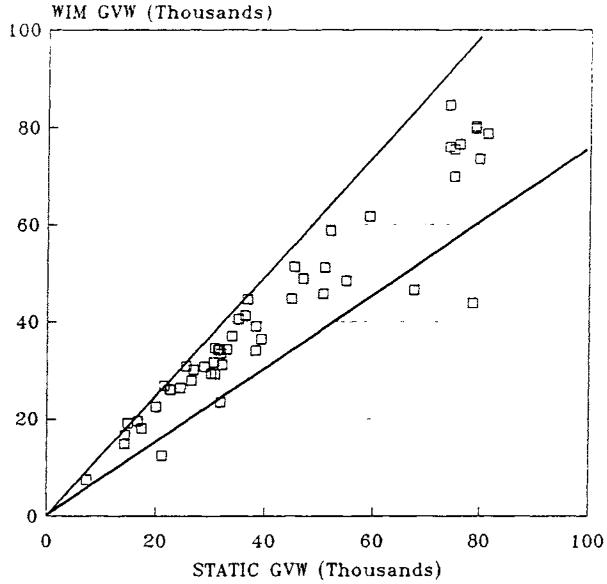


STD. DEV. = 25.1%

+ Series 2

b. **Rear tandem weight of class 9 trucks.**

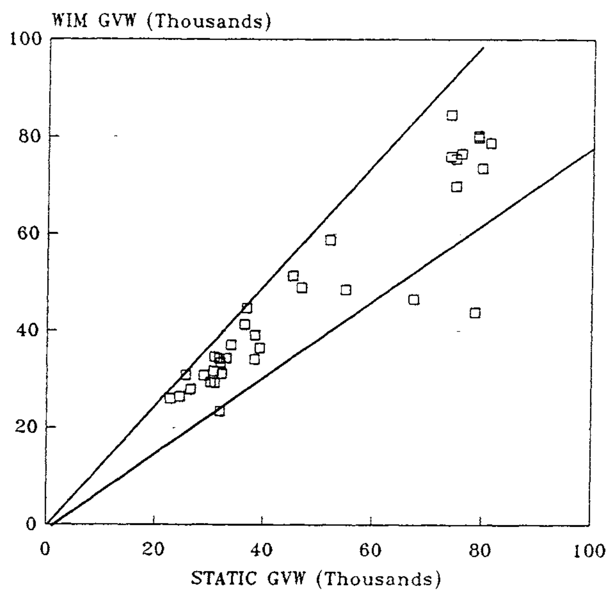
Figure 10. Bridge WIM graph.



STD. DEV. = 14.4%

Series 4

a. Gross vehicle weight of all vehicles.

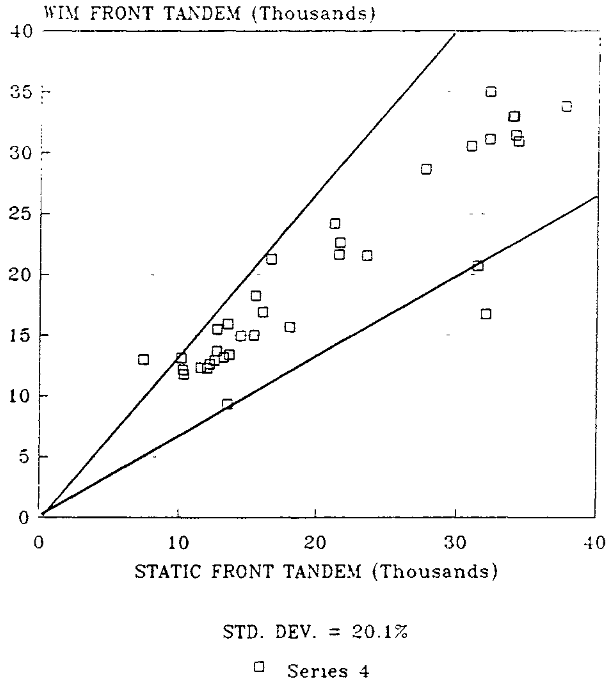


STD. DEV. = 13 6%

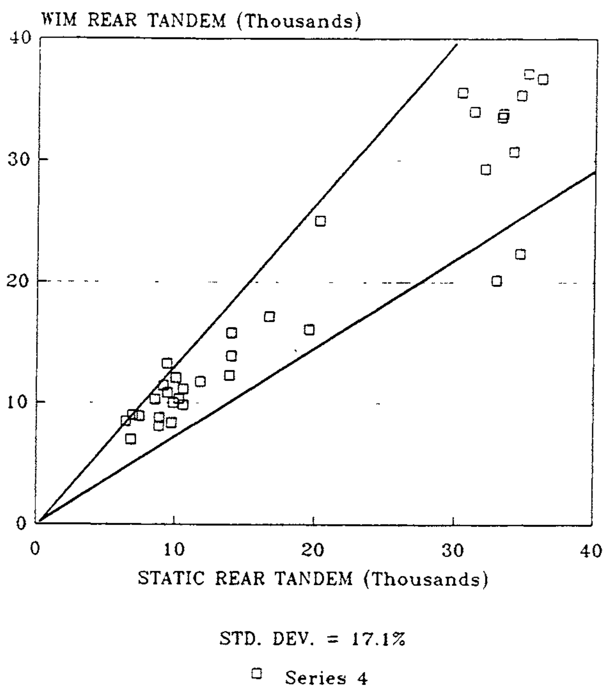
Series 4

b. Gross vehicle weight of class 9 trucks.

Figure 11. Piezoelectric Cable WIM.



a. Front tandem weight of class 9 trucks.



b. Rear tandem weight of class 9 trucks.

Figure 12. Piezoelectric Cable WIM.

Table 7
APPLICATIONS AND EASE OF USE

	Weigh Mat	Bridge WIM	Piezoelectric Cable WIM
Installation time for 2 lanes and cost[1]	1 hr (excluding lane closure) 2-3 hr including lane closures	1 hr (concrete bridges need time to install metal plates)	sensor installation 2 days (16 hr) field unit installation 5 min. more + 1 hr)
Processing Time for typical 24-hr data collection	5 min	30-45 min[2]	5 min
Trouble Shooting	easy	moderate (some error messages require vendor consultation)	easy
Calibration	periodically	each site or every 12 months at the same site	one time; then self-calibration
Calibration time/site	every 6 months 2-3 hr	2-3 hr	2-3 hr
Removal Time[1]	30 min	30 min	field unit–5 min
Limitations	dry pavement temperature > 50° F	need a bridge that is suitable for study	good quality pavement; straight, level road section
Flexibility	anywhere, flat, level road section	limited	anywhere given above factors
Usefulness and completeness of Documentation	fair	good	fair
Organization of software	fair	good	good
Organization of program/user interface	good	good	good
Housing of instrumentation	good	good	good
System Maintenance	low	low	low
Initial Cost per two-lane system	$25,850	$38,125	$28,000 (including installation)
Operating Cost per two-lane data	$800	$260	no additional cost

[1]The time estimates for installation and removal are based on having a two-person crew with assistance for traffic control during installation. With the Bridge System, the calibration truck driver may serve as a flagger.
[2]The bridge system automatically processes the previous day after midnight during data collection.

ranking is based on ranking the sum of the absolute value of the mean error for the four tests for vehicles greater than 60 kips in Tables 2 and 3. For accuracy, the ranking is bridge WIM system, weigh mat, and piezoelectric cable WIM system. For precision, the ranking is weight mat, bridge WIM system, and piezoelectric cable WIM system based on the sum of the standard deviation for the four tests. Therefore, the weigh mat and bridge WIM system are rated higher than the piezoelectric cable WIM in the data quality for heavier vehicles.

Applications and Ease of Use

The evaluation of measures of performance for applications and ease of use are shown in Table 7. Selected measures of performance are discussed below.

Although the actual installation times for the weigh mat and bridge systems were the same, the weigh mat was more physically demanding because of its heavy sensors, whereas the bridge system requires more measuring and parameter inputs. Additional time is needed for lane closures for the weigh mat system and for installing metal plates on concrete bridges. The permanent piezoelectric cable sensors require 12 to 16 hr to install two lanes. Because of the need for calibration of the bridge system at virtually every site, this system requires the most time for calibration. The piezoelectric cable WIM requires one calibration with subsequent selfcalibration.

Although the weigh mat system requires a dry pavement and temperatures above 50° F for use, it can be flexibly used anywhere, but it is best to use it on a straight, level section of pavement in good condition. The bridge system is limited by the need for a suitable bridge. There are very few suitable bridges on non-interstate highways. On the other hand, weather is less of a factor if road tubes are used instead of tape switches.

The initial cost of the bridge system is higher than the other two systems. The operating cost of the weigh mat system is higher because of the estimated cost of $750 for lane closure traffic control and $50 for materials, primarily tape. The bridge system's operating cost includes $230 for a calibration truck and $30 for tape. The lane closure and calibration costs are based on the assumption that 8 hours will be charged to this activity, and this was confirmed by the experience gained during this research.

Data Format and Usefulness

Data format and usefulness are presented in Table 8. The data monitoring quality was good for the weigh mat and bridge systems, both of which have scrollable screens. On the other hand, the piezoelectric cable system's monitoring screen showed only one vehicle per lane at a time. The collected truck data format was good for the bridge WIM and piezoelectric cable WIM systems and very good for the

Table 8
DATA FORMAT AND USEFULNESS

	Weigh Mat	Bridge WIM	Piezoelectric Cable WIM
Data Monitoring Quality	good (scrolling screen)	good (scrolling screen)	fair (one vehicle/lane monitored)
Data Format			
Collected Truck Data	very good	good	good
Summarized Data	good	very good	fair
Summarized Data Tables	8 Tables	15 Tables	Limited
Usefulness of Data Tables	good comprehensive	very good comprehensive	fair very limited, depends on TMG for ESALS
Flexibility of Data Tables	very flexible –single table v. all tables –one lane or both lanes	limited –all tables only –both lanes only	
Traffic Monitoring Guide (TMG) Compatibility	2-, 4-, 7-card	4-, 7-card	4-, 7-card
Data Storage	raw truck data stored in computer file for future use if needed	raw truck data not stored; only tables and TMG records stored	raw truck data stored in computer file

capacitance weigh mat system, which provided both an ASCII format with vehicle numbers and the exact time. The summarized data from the piezoelectric cable WIM system was fair. It consisted of hourly summaries of speed and weight binned data. The weigh mat system has 8 daily summary tables including 5 tables on truck data, and the bridge system has 15 daily tables including 10 tables on truck data. The piezoelectric cable system depends on the *Traffic Monitoring Guide* software to generate tables. Consequently, the bridge system tables were most useful, and the weigh mat system's tables were useful especially for pavement design.[10] The weigh mat system is very flexible in that tables can be generated for either lane individually or both lanes. The 8 tables can be generated individually or all together.

The *Traffic Monitoring Guide* has two-card site identification, four-card vehicle classification, and a seven-card truck weight records file. The weigh mat system has all three cards, the bridge system and the piezoelectric cable system have the four- and seven-card files.

Equipment Performance

Equipment performance is measured by reliability, which is a measure of the failures during the normal life of a device, and durability, which is a measure of the wear or endurance of a device. The study period was too short to thoroughly assess the reliability and endurance of these systems. Nevertheless, the performance of the equipment during the study period is discussed below.

Weigh Mat System

The weigh mat system was installed 7 times using one lane for a total of 10 days and 10 times using two lanes for a total of 32 days. Nine installations were concerned with training, demonstrations, and accuracy testing.

One weigh mat oscillator was replaced after 3 months. According to the vendor, if there is a defect in an oscillator, failure usually occurs early during its use. On two occasions that were 1 year apart, loop mats were lost or stolen during or following a heavy rain. In March 1990, one weigh mat and wiring was found about 1/3 mile downstream of the site. It was suspected that the loop mat was flapping and a mat or mat wire caught on a truck axle. In March 1991, the removal of two loop mats appeared to be clean; therefore, theft was suspected.

Three incidents of suspected vandalism occurred on Alternate Route 220, which is used by trucks to avoid permanent scales on Interstate 81 at Troutville. In the first incident, it was suspected that by braking or skidding on a gravel shoulder, a trucker damaged the loop mat cable connections. In the second incident, 6 days later, a weigh mat cable that crossed the road from shoulder to shoulder was damaged by a trucker braking or skidding on the WIM system. A similar incident occurred at the same site 18 days earlier during rain. Skid marks were evident at the point of damage in each case. Therefore, these three incidents were determined to be the result of vandalism.

Other performance problems were the result of software bugs and human error that resulted from a lack of information after the system was upgraded. Overall, the system performed well.

Bridge WIM System

The bridge WIM system was installed 17 times for a total of 34 days. Seven installations were for training, demonstration, and accuracy testing. The installations were made on 5 prestressed concrete bridges, 2 steel girder bridges, and 2 reinforced concrete bridges. There were 5 tape switch failures in 15 installations, and 1 road hose failure in 4 installations (road hoses replaced failed tape switches on 2 installations). Three technical problems were experienced with the field unit. Minor problems with battery recharging, an air switch box, and software were resolved. Much difficulty was experienced in obtaining reasonably accurate data on reinforced concrete bridges. The vendor stated that some testing may be required on reinforced concrete bridges because cracks in the concrete girders affect the strain measurements. Others speculated that the variability in the material composition of reinforced concrete girder may be a factor. It was observed on one bridge that 1 girder vibrated more than the others. In general, care should be used in installing and calibrating the system. Although many problems were experienced, overall, the system performed adequately.

Piezoelectric Cable WIM

In three of the five lanes of installations, the piezoelectric cable sensors have failed. One month after installation in the two northbound lanes on Interstate 95, both full-length sensors in the right lane failed in the left wheel path. The sensors were broken in the left wheel path. The right wheel path of both sensors was beginning to fail. It was concluded that pavement rutting in the wheel path added stress to the bond between the pavement and the sensor. The pavement rutting increased from 1/4 in in October 1989 to almost 1/2 in. in May 1990.

Some patching was done in the right wheel path of one sensor in the left lane on Interstate 95 one month after installation. Seven months after installation, pavement failure at the point of pavement bonding with the sensor resulted in damage to that sensor. The second full-length sensor and the off scale sensor showed no signs of wear after 12 months.

At the Route 15 site, some patching was done in the right wheel path of the first sensor southbound 7 months after installation. After 11 months, the sensor failed because either there was a short in the cable or some vehicle or object low to the ground (possibly a snow plow) may have damaged it where its end was slightly above the pavement at the roadway's centerline marking. Eleven months later, patching was done for the second sensor in the southbound lane.

At the Route 52 site, the sensors have shown no signs of wear after 12 months. The truck traffic at this site is much lower than at the other sites.

The performance of the sensors was the major concern with this system. Two causes were identified that might have contributed to their failure. The pavement was stressed during installation when sensors were forced in place with weights to conform with the road surface and the crown at the center. It may be helpful to reduce the stress by reducing the length of the sensor and keeping the sensor as straight as possible even if it means having the sensor endpoints below the surface. The actual bonding between pavement and sensor takes place only at the bottom of the sensor channel because foam strips are placed on both sides. Additional bonding may be achieved by placing the sensor 3/16 in below the surface and covering it with epoxy to achieve a pavement-sensor bond on the top. At least one vendor recommends installing the sensor below the pavement surface.

There were delays in the software development process and also in the resolution of subsequent software problems. The camera unit that took photographs of vehicles exceeding a designated weight, speed, or vehicle class threshold performed adequately. A sample photo is shown in Figure 13. Overall, the system performed adequately.

Lessons Learned and Recommended Practices

General

1. Each WIM installation should be thoroughly checked and the data should be monitored for reasonableness. Any suspected problems should be investigated.
2. Calibration is important and should be properly performed.
3. Spare parts should be available for replacement if problems occur.
4. The data should be carefully inspected after each collection period for completeness and reasonableness.
5. Upgrades or other changes made in the field unit or software, were often accompanied by adverse impacts. Such adverse changes should be identified by thoroughly checking the operations after a change.
6. System changes and software updates were often made without documentation of the changes. An explanation of the changes is important and should be requested.

Weigh Mat

1. Periodic monitoring of the system at high-risk areas (where there is heavy truck traffic and/or where the potential for vandalism is high) should be considered.

Figure 13. Photograph taken with the camera unit of the piezoelectric cable WIM System

2. It may be helpful to avoid installing the system during cooler temperatures (below 50° F) or when rain is expected.

3. Installing two lanes with the cables of one lane completely crossing the roadway should be avoided. One lane of WIM and one lane of classification should be used. Also, the use of cable protectors may be considered for two lane installations.

4. The reusable loop mats are durable and cost-effective and should continue to be used.

Bridge WIM

1. Calibration takes time, but it is critical and should be done with care.

2. If possible, weigh the calibration truck several times with brakes released.

3. Avoid using reinforced concrete bridges because additional testing may be needed.

Piezoelectric Cable WIM

1. The pavement should be thoroughly inspected, especially for rutting, before installation. Pavement strength tests should be considered.

2. To increase the bonding between the pavement and the sensors, installing the sensors up to 3/16 in below the road surface should be considered.

3. To reduce stress on the sensor installation, consider keeping the sensor straight by mounting its ends below the surface.

4. The field unit should be fully operational and thoroughly tested before the sensors are installed.

5. The off-scale sensors were not useful; therefore, they should be omitted.

CONCLUSIONS

The following conclusions were drawn from this research.

1. Each WIM system met the specifications.

2. The capacitance weigh mat system performed well and consistently. This system is relatively easy to use and requires little effort in inputting site-specific factors. Periodic calibration is needed.

3. The bridge weighing system works well. However, data collection on reinforced concrete bridges was unsuccessful because additional tests were required to

collect reliable data. This system requires a moderate amount of effort in inputting parameters and calibrating for each site.

4. The piezoelectric cable system performed well. There is some concern about the durability of the sensors. Durability is especially dependent on the quality of the pavement and the installation.

RECOMMENDATION

The Traffic Engineering Division should use the three WIM systems for 18 Kip studies, special studies, and most importantly, in conjunction with a statistically based truck weight study program that will be presented in the Research Council report *Assessment of the Truck Weight Sample of the Traffic Monitoring Guide for Use in Virginia* (Fall, 1991). Subsequently, the Traffic Engineering Division should provide the necessary resources to conduct studies and maintain the equipment.

ACKNOWLEDGMENTS

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APPENDIX A

CAPACITANCE WEIGH MAT SPECIFICATIONS AND TABLES

PORTABLE WEIGH-IN-MOTION SYSTEM USING WEIGH MATS

SYSTEM REQUIREMENTS

Description

The portable weigh-in-motion system using weigh mats shall provide for the in-motion weighing of all vehicles in two adjacent lanes of a highway. The system will include the following major components:

3 - high speed weigh mats
4 - sets of two portable loops
1 - field unit
1 - power supply (rechargeable battery)

--- all necessary cabling, software, and miscellaneous materials and accessories
--- training
--- equipment service support

Quantities

An itemized bid proposal shall be submitted. If applicable, a schedule of quantity discounts for specific items should be attached to the bid. Bidder shall specify optional recommended spare parts and their costs.

Construction

All electronic components shall be of solid state design with high noise immunity and low power consumption. Logic and data storage components shall be mounted on firmly replaceable plug in circuit boards. All components shall be mounted and housed so that they will not be damaged by jolts and vibrations encountered in transportation and use. Electronic components shall be protected against overloads, power surges, and transients.

Material

Material shall be specified herein. Material not definitely specified shall be of good commercial quality entirely suitable for the purpose. Material shall be free from all defects and imperfections that might affect the serviceability of the finished product.

Standard Products

The equipment shall be essentially standard manufactured products, so that prompt and continuing service and delivery of spare parts may be assured. The component parts of the system need not be products of the same manufacturer.

High Speed Weigh Mats

Two high speed, low profile weigh mats with attachment plates to permit mounting to either concrete or asphalt surfaces with fasteners into inserts in the road bed or tape and nails shall be provided.

The mats shall sense the weight of each axle of each vehicle moving over each lane by producing a capacitance change proportional to weight. The oscillator assembly shall be suitably protected from tires moving over it.

Portable Loops

Portable loops capable of providing data for computing vehicle speed and vehicle presence that can be mounted on the road surface shall be provided.

The loops shall be of size specified by the vendor for optimal system operation. The loops shall be constructed using an adhesive type material that will operate under most traffic conditions for at least one week. They shall not be removable by the normal braking action of trucks during this period of time.

Field Unit

The field unit shall be enclosed in a NEMA rated weatherproof, compact, portable, metal housing with carrying handles and lock hasp. The field unit shall couple with the weigh mats and loops through the cabling and transmit the data to the control unit through a RS 232C cable or similar device. The field unit shall include an A/D converter microcomputer module for weight and axle spacing determination, two dual, automatically tuned loop detectors that couple to the loops, two mat amplifiers that couple to mat oscillators, a power supply and necessary lightning protection for each connecting cable.

The field unit shall have the capability of sampling the outputs from the combined weigh mats and each lane over the full range of operating speeds.

Key Pad

A 15 programmable category key pad or similar device for operator manual activation.

Power Supply

A rechargeable battery capable of operating the system for a minimum of 48 hours shall be included, along with the recharger, at least 2 spare batteries, and necessary accessories.

Monitoring System

The system shall include a high-speed monitoring system capable of displaying individual vehicle records within 1 second of the desired vehicle exiting the system. VDOT shall provide a personal computer.

Software

The systems shall include all necessary software for configuring, calibrating, setting up, diagnosing, and operating the system. It shall also include means for directly transferring the data to the following IBM compatible laptop personal computers: (a) IBM PC convertible laptop computer, 512K, two 3.5 inch diskette drives, MS-DOS; and (b) Zenith Supersport 286 laptop computer, 1MB, one 3.5 inch diskette drive, 20MB hard disk, MS-DOS. Specifically, the system:

A. shall be capable of acquiring vehicle data by lane in a fully automatic mode in one or two lanes of traffic.

B. shall display, print and/or store at a minimum, the following cumulative data for each vehicle classification by lane:

--vehicle classification count (in FHWA Traffic Monitoring Guide format)
--vehicle speed

plus the following (in FHWA Traffic Monitoring Guide format) for each individual truck:

--gross weight
--all axle weights
--wheel base length
--all axle spacings
--speed
--time
--classification
--violator identification
--lane number

Bidder shall identify data items that are available but not required.

C. shall be capable of in-field processing and simultaneous storage of data.

D. shall complete in-field processing with a maximum headway between vehicles equal to the time needed by a vehicle to exit the system plus 0.05 seconds

E. shall classify vehicles using the 13 classifications of Scheme F of the Federal Highway Administration. The classification code shall be displayed on the vehicle display screen when the truck data are displayed. (Bidders shall identify those items that are optional extras and their individual cost.)

F. shall provide a total vehicle count that includes those vehicles not properly classified in accordance with the classification logic, i.e., total vehicle count shall equal the sum of vehicles classified and vehicles not classified properly.

G. shall provide data for printout or display, including summary reports, and shall provide samples of each. Bidder shall describe extent to which output formats are user modifiable.

H. shall also include the federal bridge formula table and means for changing any weight limits. The system shall check for compliance with the bridge formula and other axle and gross weight limits and indicate possible violations by type of violation in the display, printout, and storage.

I. shall display digital data using the U.S. Customary Weights and Measures System. Weight shall be 1000s of pounds to 1 decimal place. Spacing shall be in feet and tenths.

J. shall use operator programmable timers as necessary for determining start and ending times for operations and arrival time for individual vehicles.

K. shall provide for a diagnostic check of system hardware and software. Bidders shall briefly describe the procedures and extent of this function.

L. shall provide for changing, adding, or deleting site data such as pavement type, weather, site identification numbers, etc.

M. shall provide full edit capabilities including detection and where possible, correction of questionable data. Bidders shall briefly describe the procedures and extent of this function.

N. shall allow operator calibration of the system with no more than 10 crossings of a test truck per lane. One test truck weighing at least 40,000 pounds of no more than 3 axles shall be adequate to accurately calibrate the system for any weight truck. Bidder to specify calibration procedures and recalibration conditions.

O. shall provide sufficient data storage capacity to allow for the continuous collection and storage of two lanes of traffic data over a continuous 48-hour period (i.e., 12,000, 3-axle truck records). Bidder shall provide the number of 3-axle truck records that can be stored.

P. shall provide clearly documented software. A software manual, including documentation, shall be provided. Any proposed software licensing agreements shall be provided.

Q. updates of the software for one year at no cost shall be provided.

WIM SYSTEM FUNCTIONAL SPECIFICATIONS

The WIM system shall automatically determine within the accuracies specified below the following data for each vehicle by lane of travel for at least a 90% confidence level:

	Systematic or Mean Error	Random Error or Standard Deviation
single axle weight	5%	15%
tandem axle weight	5%	13%
gross weight	5%	12%
axle spacing	± 6 in	12 in
vehicle length	± 12 in	18 in
speed	± 1 mph	2.5 mph

Vehicle classification--The system must accurately classify at least 90% of all vehicles.

USER REQUIREMENT

The vendor shall specify the following user requirements for effective use of the WIM system where applicable:

Site Condition Factors - pavement smoothness, horizontal curvature, longitudinal gradient, cross-slope, width of paved lane
Foundation for Installation
Proper Climatic Environment
Adequate Power

TRAINING OF PERSONNEL

The successful bidder will provide a reasonable and adequate amount of training in Charlottesville to state personnel in operation, maintenance, trouble shooting, and repairs to the system. Each bidder shall define the recommended level of training to be provided and the cost of that training. At a minimum, 24 hours of training, including at least 8 hours of hands-on field exercises, shall be provided. The training period shall commence at the discretion of the State. Training is anticipated immediately following delivery of the equipment.

WARRANTIES AND ACCEPTANCE

Warranties

For a period of one year to begin upon notification of acceptance of the system by the State as described below under acceptance procedure, item no. 2, the vendor shall repair or replace at no charge, any component that fails or does not function properly and, if necessary, will provide technical assistance on site to aid in repair or replacement of faulty components. The failed component shall be repaired or replaced within 21 calendar days of delivery of the failed component to the vendor. The vendor shall be responsible for all shipping costs incurred in fulfilling this warranty. For components not manufactured by the bidder, the bidder shall provide the manufacturer's warranty.

Acceptance Procedure

(1) The vendor shall certify in writing to the State when the system is ready for use by the State. The following conditions must be met before issuing this certification:

--the vendor must have provided sufficient training to enable State personnel to operate the system

--the vendor must provide the State with evidence of a successful system audit performed on the system which demonstrates that the equipment meets minimum design specifications.

(2) Upon the State receiving the above certification, an acceptance testing period of 60 calendar days will begin. The State will notify the vendor in writing at the end of this period of system acceptance or rejection. Acceptance or rejection will be determined through testing and operation of the system for compliance with the specifications contained herein. The vendor shall have the opportunity to remedy the cause(s) for rejection. Payment in full will be made upon acceptance of the equipment.

MAINTENANCE AND TECHNICAL SUPPORT

The vendor must be responsive to equipment problems Monday through Friday between 8:00 a.m. and 4:30 p.m. with 5 work days or less response time.

Bidders shall provide the following information (preferably in a manual):

--escalation policy in regard to equipment repair costs
--maintenance plans available and their costs
--duration and frequency of preventive maintenance
--location of account representative in case of problems and where service would originate
--the dimensions and schematics of each component part and the whole system
--environmental operating requirements for all equipment, including heating, cooling, circuit and grounding requirements
--ongoing technical support policy, practices, and procedures

DELIVERY TIME

Upon award of this contract to a vendor, the complete WIM system must be delivered within 30 days of receipt of the order.

USER MANUALS

The selected vendor shall provide four complete sets of documentation (User Manuals) that describe the capabilities, procedures for set-up, calibration, diagnostic testing, operation and maintenance of the WIM system. One user manual <u>must</u> be included with the Bid and the other User Manuals delivered to the state at least 10 calendar days prior to delivery of the WIM systems and subsequent training period.

SYSTEM COST

Bids shall be provided on an itemized basis and include:

--purchase price for all components and recommended spare parts,
--delivery costs
--software (licensed) costs
--training costs
--total cost
--other appropriate costs

AWARD

The contract will be awarded to the vendor on the basis of an evaluation of the total bid with respect to system design, compatibility with bid specifications, and costs.

NON-PERFORMANCE OF VENDOR

Failure of the vendor to fulfill any commitment made by the vendor within the scope of the contract agreement may, at the option of the State, result in the termination of the contract agreement and the assessment of damages to be paid to the State by the vendor.

In the event that the State determines that such failure to fulfill a commitment has occurred, the State shall provide written notification to the vendor. Upon receipt of such notification, the vendor shall have five (5) working days to remedy the failure or to propose a remedy which will be satisfactory to the State, in which case the right to terminate shall not be invoked.

Addendum to the Weigh Mat Specifications

- o 1 spare weigh mat oscillator
- o 6 reusable loop mats
- o 1 spare battery not 2
- o upgrade of field unit at no additional cost for 1 year
- o 1 15 ft loop cable

DISTRIBUTION OF VEHICLE CLASSIFICATIONS BY HOUR OF DAY

SITE NO : 001 Location : BOTETOURT COUNTY Lane(s) : 1 4
DATE : 11/28/90 County : 000 State-ID : 51 Direction : 1 1

HOURLY SUMMARY — VEHICLE COUNTS

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
0- 1	0	16	0	0	3	1	0	2	20	0	0	0	0	0	3	45
1- 2	0	15	1	0	2	0	0	0	13	0	1	0	0	0	1	33
2- 3	0	7	1	0	0	0	0	1	19	0	0	0	0	0	1	29
3- 4	0	5	1	0	0	0	0	0	14	0	0	0	0	0	0	20
4- 5	0	23	3	0	1	0	0	0	17	0	1	0	0	0	5	50
5- 6	0	71	16	0	2	0	0	0	18	0	0	0	0	0	5	112
QTR TOTALS	0	137	22	0	8	1	0	3	101	0	2	0	0	0	15	289
6- 7	0	97	28	0	3	1	0	2	17	0	0	0	0	0	8	156
7- 8	1	213	34	0	7	10	1	4	33	0	0	0	0	0	4	307
8- 9	1	200	34	1	16	6	0	1	38	0	0	0	0	0	10	307
9-10	0	134	24	0	8	5	0	5	37	0	0	0	0	0	18	231
10-11	0	112	22	0	8	7	0	4	31	0	0	0	0	0	10	194
11-12	0	104	22	0	4	3	0	3	29	0	0	0	0	0	15	180
QTR TOTALS	2	860	164	1	46	32	1	19	185	0	0	0	0	0	65	1375
12-13	1	142	29	0	8	4	0	3	39	0	0	0	0	0	13	239
13-14	0	112	39	0	2	4	0	7	27	0	1	0	0	0	10	202
14-15	0	143	25	0	10	5	0	3	25	1	0	0	0	0	13	225
15-16	0	196	36	0	5	5	0	3	34	0	0	0	0	0	17	296
16-17	0	211	33	0	2	3	0	4	34	0	0	0	0	0	5	292
17-18	0	220	40	0	8	0	0	3	29	0	0	0	0	0	13	313
QTR TOTALS	1	1024	202	0	35	21	0	23	188	1	1	0	0	0	71	1567
18-19	0	164	31	2	3	1	0	3	28	0	1	0	0	0	6	239
19-20	0	90	15	0	2	1	0	2	26	0	0	0	0	0	3	139
20-21	0	88	10	0	1	0	0	1	20	0	1	0	0	0	4	125
21-22	0	70	7	1	0	2	0	2	17	0	3	0	0	0	6	108
22-23	0	36	6	0	0	1	0	0	17	0	2	0	0	0	4	66
23-24	0	32	0	0	1	1	0	2	13	0	2	0	0	0	1	52
QTR TOTALS	0	480	69	3	7	6	0	10	121	0	9	0	0	0	24	729

DAILY SUMMARY — VEHICLE COUNTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
TOTAL	3	2501	457	4	96	60	1	55	595	1	12	0	0	0	175	3960

DISTRIBUTION OF SPEEDS BY VEHICLE CLASSIFICATION

SITE NO : 001   Location : BOTETOURT COUNTY   Lane(s) : 1 4
DATE : 11/28/90   County : 000   State-ID : 51   Direction : 1 1

VEHICLE COUNTS

SPEED MPH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
1- 5	1	21	0	0	0	1	0	0	0	0	0	0	0	0	0	23
6- 10	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	14
11- 15	0	3	0	0	0	1	0	0	1	0	0	0	0	0	0	5
16- 20	0	34	6	0	1	6	0	0	19	0	0	0	0	0	2	68
21- 25	0	100	20	0	4	9	0	5	144	1	3	0	0	0	9	295
26- 30	0	244	51	0	13	20	1	8	186	0	5	0	0	0	18	546
31- 35	1	188	28	1	18	9	0	12	117	0	3	0	0	0	19	396
36- 40	0	266	62	1	19	4	0	13	64	0	1	0	0	0	25	455
41- 45	0	502	83	0	25	7	0	10	32	0	0	0	0	0	37	696
46- 50	1	651	122	0	10	3	0	7	23	0	0	0	0	0	26	843
51- 55	0	373	58	0	4	0	0	0	8	0	0	0	0	0	11	454
56- 60	0	86	23	0	1	0	0	0	1	0	0	0	0	0	2	113
61- 65	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	6
66- 70	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
71- 75	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	3
76- 80	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2	4
81- 85	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
86- 90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91- 95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96-100	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
> 100	0	8	0	2	0	0	0	0	0	0	0	0	0	0	24	34
TOTALS	3	2501	457	4	96	60	1	55	595	1	12	0	0	0	175	3960
AVG. SPEED	28	42	42	69	39	30	28	36	30	23	29	0	0	0	49	40

DAILY SPEED SUMMARY

TOTAL VEHICLES : 3960	TOTAL VEHICLES > 55 MPH -- 165	PERCENTAGE OF VEHICLES > 55 MPH -- 4.2
AVERAGE SPEED : 40.3	TOTAL VEHICLES > 60 MPH -- 52	PERCENTAGE OF VEHICLES > 60 MPH -- 1.3
MEDIAN SPEED : 43.0	TOTAL VEHICLES > 65 MPH -- 46	PERCENTAGE OF VEHICLES > 65 MPH -- 1.2
85th PERCENTILE : 53.0	TOTAL VEHICLES > 70 MPH -- 44	PERCENTAGE OF VEHICLES > 70 MPH -- 1.1

DISTRIBUTION OF VEHICLE SPEEDS BY HOUR OF DAY

SITE NO : 001 Location : BOTETOURT COUNTY Lane(s) : 1 4
DATE : 11/28/90 County : 000 State-ID : 51 Direction : 1 1

SPEED RANGE, MPH

HOUR	00-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	> 80
0- 1	12	9	4	3	10	3	2	0	0	0	0	2
1- 2	7	8	0	4	5	4	3	0	1	0	1	0
2- 3	14	5	3	1	2	2	1	0	0	0	0	1
3- 4	10	3	2	2	0	0	3	0	0	0	0	0
4- 5	16	2	6	7	6	10	2	0	0	1	0	0
5- 6	25	8	9	19	19	19	13	0	0	0	0	0
QTR TOTALS	84	35	24	36	42	38	24	0	1	1	1	3
6- 7	29	13	17	21	36	29	9	1	0	0	0	1
7- 8	89	32	29	52	66	33	5	0	0	0	0	1
8- 9	91	50	29	40	50	38	4	1	0	0	0	4
9-10	54	24	29	32	47	30	8	0	0	0	1	6
10-11	37	23	18	32	48	27	5	0	0	0	0	4
11-12	57	10	14	33	37	26	0	0	0	0	0	3
QTR TOTALS	357	152	136	210	284	183	31	2	0	0	1	19
12-13	73	13	19	34	65	31	3	0	0	0	0	1
13-14	62	13	30	30	39	19	6	1	0	0	0	2
14-15	39	26	34	43	48	27	6	0	0	1	0	1
15-16	43	33	45	66	69	29	9	1	0	0	0	1
16-17	51	26	26	75	57	45	11	0	0	0	0	1
17-18	59	27	61	64	73	24	3	0	0	0	1	1
QTR TOTALS	327	138	215	312	351	175	38	2	0	1	1	7
18-19	46	30	33	48	50	20	7	0	1	1	0	3
19-20	39	11	14	32	31	10	1	1	0	0	0	0
20-21	31	6	10	23	40	11	3	0	0	0	0	1
21-22	27	16	13	16	20	7	5	1	0	0	1	2
22-23	25	5	5	10	10	8	1	0	0	0	0	2
23-24	15	3	5	9	15	2	3	0	0	0	0	0
QTR TOTALS	183	71	80	138	166	58	20	2	1	1	1	8

DAILY SPEED SUMMARY

TOTAL VEHICLES :	3960	TOTAL VEHICLES > 55 MPH --	165	PERCENTAGE OF VEHICLES > 55 MPH --	4.2
AVERAGE SPEED :	40.3	TOTAL VEHICLES > 60 MPH --	52	PERCENTAGE OF VEHICLES > 60 MPH --	1.3
MEDIAN SPEED :	43.0	TOTAL VEHICLES > 65 MPH --	46	PERCENTAGE OF VEHICLES > 65 MPH --	1.2
85th PERCENTILE :	53.0	TOTAL VEHICLES > 70 MPH --	44	PERCENTAGE OF VEHICLES > 70 MPH --	1.1

DISTRIBUTION OF WEIGHT VIOLATIONS AND INVALID MEASUREMENTS FOR VEHICLE CLASSIFICATIONS 4 THROUGH 15

SITE NO : 001 Location : BOTETOURT COUNTY Lane(s) : 1 4
DATE : 11/28/90 County : 000 State-ID : 51 Direction : 1 1

CLASSIFICATION	TOTAL VEHICLE COUNTED	VEHICLES WITH INVALID MEASURE	TOTAL VEHICLES WEIGHED	TOTAL VEHICLES OVERWT.	PERCENT VEHICLES OVERWT.	******** ******** AXLE	NUMBER OF WEIGHT VIOLATIONS TANDEM	GROSS	********** ********** BRIDGE
4	4	0	4	1	25	0	0	0	1
5	89	0	89	3	3	3	0	0	3
6	59	0	59	14	24	0	14	0	14
7	1	0	1	1	100	0	1	0	0
8	53	0	53	2	4	1	1	0	2
9	594	0	594	246	41	0	227	45	246
10	1	0	1	0	0	0	0	0	0
11	12	0	12	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	111	0	111	3	3	2	0	0	3
TOTALS	924	0	924	270	29	6	243	45	269

NUMBER OF VEHICLES WITH DATA ERRORS : 13

PERCENT VEHICLES NOT CLASSFIED (CLASS 15) : 12.0

PERCENT VEHICLES WITH INVALID MEASUREMENTS : 0.0

DISTRIBUTION OF WEIGHT VIOLATIONS BY HOUR OF DAY FOR VEHICLE CLASSIFICATIONS 4 THROUGH 15

SITE NO : 001 Location : BOTETOURT COUNTY Lane(s) : 1 4
DATE : 11/28/90 County : 000 State-ID : 51 Direction : 1 1

HOURLY SUMMARY

HOUR	TOTAL VEHICLES WEIGHED	TOTAL VEHICLES OVERWEIGHT	PERCENT VEHICLES OVERWEIGHT	NUMBER OF WEIGHT VIOLATIONS AXLE	TANDEM	GROSS	BRIDGE
0- 1	28	13	46	1	12	5	13
1- 2	17	5	29	0	4	0	5
2- 3	20	11	55	0	11	5	11
3- 4	14	6	43	0	5	2	6
4- 5	23	9	39	1	8	2	9
5- 6	23	8	35	0	6	1	8
QTR TOTALS	125	52	42	2	46	15	52
6- 7	29	8	28	0	8	4	8
7- 8	54	20	37	0	19	0	19
8- 9	66	18	27	0	18	1	18
9-10	66	14	21	2	11	1	14
10-11	55	14	25	0	12	4	14
11-12	47	15	32	0	12	2	15
QTR TOTALS	317	89	28	2	80	12	88
12-13	62	19	31	1	17	1	19
13-14	48	22	46	1	19	4	22
14-15	52	11	21	0	11	2	11
15-16	56	11	20	0	11	2	11
16-17	45	11	24	0	10	2	11
17-18	44	5	11	0	5	1	5
QTR TOTALS	307	79	26	2	73	12	79
18-19	41	15	37	0	13	1	15
19-20	34	8	24	0	8	2	8
20-21	26	5	19	0	3	0	5
21-22	30	8	27	0	7	1	8
22-23	23	11	48	0	10	2	11
23-24	21	3	14	0	3	0	3
QTR TOTALS	175	50	29	0	44	6	50

DAILY SUMMARY

TOTAL	TOTAL VEHICLES WEIGHED	TOTAL VEHICLES OVERWEIGHT	PERCENT VEHICLES OVERWEIGHT	NUMBER OF WEIGHT VIOLATIONS AXLE	TANDEM	GROSS	BRIDGE
	924	270	29	6	243	45	269

DISTRIBUTION OF OVERWEIGHT VEHICLES BY HOUR OF DAY FOR VEHICLE CLASSIFICATIONS 4 THROUGH 15

SITE NO : 001 Location : BOTETOURT COUNTY Lane(s) : 1 4
DATE : 11/28/90 County : 000 State-ID : 51 Direction : 1 1

HOURLY SUMMARY

NUMBER OVERWEIGHT VEHICLES

HOUR	TOTAL VEH'S WEIGHED	TOTAL VEH'S OVERWT	PERCENT VEH'S OVERWT	4	5	6	7	8	9	10	11	12	13	14	15
0- 1	28	13	46	0	1	0	0	0	12	0	0	0	0	0	0
1- 2	17	5	29	0	0	0	0	0	5	0	0	0	0	0	0
2- 3	20	11	55	0	0	0	0	0	11	0	0	0	0	0	0
3- 4	14	6	43	0	0	0	0	0	6	0	0	0	0	0	0
4- 5	23	9	39	0	1	0	0	0	8	0	0	0	0	0	0
5- 6	23	8	35	0	0	0	0	0	8	0	0	0	0	0	0
QTR TOTALS	125	52	42	0	2	0	0	0	50	0	0	0	0	0	0
6- 7	29	8	28	0	0	0	0	0	8	0	0	0	0	0	0
7- 8	54	20	37	0	0	5	1	0	14	0	0	0	0	0	0
8- 9	66	18	27	0	0	0	0	1	17	0	0	0	0	0	0
9-10	66	14	21	0	0	2	0	1	10	0	0	0	0	0	1
10-11	55	14	25	0	0	1	0	0	13	0	0	0	0	0	0
11-12	47	15	32	0	0	1	0	0	14	0	0	0	0	0	0
QTR TOTALS	317	89	28	0	0	9	1	2	76	0	0	0	0	0	1
12-13	62	19	31	0	1	1	0	0	17	0	0	0	0	0	0
13-14	48	22	46	0	0	1	0	0	20	0	0	0	0	0	1
14-15	52	11	21	0	0	2	0	0	9	0	0	0	0	0	0
15-16	56	11	20	0	0	0	0	0	11	0	0	0	0	0	0
16-17	45	11	24	0	0	0	0	0	11	0	0	0	0	0	0
17-18	44	5	11	0	0	0	0	0	5	0	0	0	0	0	0
QTR TOTALS	307	79	26	0	1	4	0	0	73	0	0	0	0	0	1
18-19	41	15	37	1	0	0	0	0	14	0	0	0	0	0	0
19-20	34	8	24	0	0	0	0	0	8	0	0	0	0	0	0
20-21	26	5	19	0	0	0	0	0	5	0	0	0	0	0	0
21-22	30	8	27	0	0	0	0	0	7	0	0	0	0	0	1
22-23	23	11	48	0	0	1	0	0	10	0	0	0	0	0	0
23-24	21	3	14	0	0	0	0	0	3	0	0	0	0	0	0
QTR TOTALS	175	50	29	1	0	1	0	0	47	0	0	0	0	0	1

DAILY SUMMARY

NUMBER OVERWEIGHT VEHICLES

	TOTAL VEH'S WEIGHED	TOTAL VEH'S OVERWT	PERCENT VEH'S OVERWT	4	5	6	7	8	9	10	11	12	13	14	15
TOTAL	924	270	29	1	3	14	1	2	246	0	0	0	0	0	3

DISTRIBUTION OF GROSS WEIGHTS FOR VEHICLE CLASSIFICATIONS 4 THROUGH 15

SITE NO :	001	Location : BOTETOURT COUNTY		Lane(s) :	1 4
DATE :	11/28/90	County : 000	State-ID : 51	Direction :	1 1

VEHICLE COUNTS

GROSS WT KIPS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTALS
0- 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5- 10	0	0	0	0	5	0	0	0	0	0	0	0	0	0	21	26
10- 15	0	0	0	3	16	0	0	5	0	0	0	0	0	0	29	53
15- 20	0	0	0	0	36	0	0	6	0	0	0	0	0	0	14	56
20- 25	0	0	0	0	26	8	0	9	0	0	0	0	0	0	4	47
25- 30	0	0	0	0	3	9	0	7	1	0	0	0	0	0	18	38
30- 35	0	0	0	0	3	9	0	7	13	0	0	0	0	0	10	42
35- 40	0	0	0	1	0	11	0	8	28	0	0	0	0	0	5	53
40- 45	0	0	0	0	0	7	0	5	36	0	0	0	0	0	4	52
45- 50	0	0	0	0	0	14	0	5	34	1	1	0	0	0	2	57
50- 55	0	0	0	0	0	1	1	0	26	0	6	0	0	0	3	37
55- 60	0	0	0	0	0	0	0	0	25	0	4	0	0	0	0	29
60- 65	0	0	0	0	0	0	0	1	24	0	1	0	0	0	0	26
65- 70	0	0	0	0	0	0	0	0	85	0	0	0	0	0	1	86
70- 75	0	0	0	0	0	0	0	0	154	0	0	0	0	0	0	154
75- 80	0	0	0	0	0	0	0	0	123	0	0	0	0	0	0	123
80- 85	0	0	0	0	0	0	0	0	41	0	0	0	0	0	0	41
85- 90	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	4
90- 95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95-100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100-105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105-110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
110-115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
115-120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
> 120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTALS	0	0	0	4	89	59	1	53	594	1	12	0	0	0	111	924

DISTRIBUTION OF 18 KIP ESALS BY HOUR OF DAY FOR VEHICLE CLASSIFICATIONS 4 THROUGH 15

SITE NO : 001 Location : ALT 220 BOTETOURT COUNTY Lane(s) : 1 4
DATE : 11/28/90 County : 001 State-ID : 51 Direction : 1 5

FOR : FLEXIBLE PAVEMENT / SN VALUE = 5 VEH STATUS : ALL

HOURLY SUMMARY — ESALS BY HOUR BY CLASS

HOUR	TOTAL VEH'S WEIGHED	TOTAL ESALS	4	5	6	7	8	9	10	11	12	13	14	15
0- 1	28	43.5	0.0	1.9	0.5	0.0	0.9	39.1	0.0	0.0	0.0	0.0	0.0	1.0
1- 2	17	23.5	0.0	0.5	0.0	0.0	0.0	21.9	0.0	1.0	0.0	0.0	0.0	0.1
2- 3	20	38.8	0.0	0.0	0.0	0.0	0.1	38.8	0.0	0.0	0.0	0.0	0.0	0.0
3- 4	14	23.4	0.0	0.0	0.0	0.0	0.0	23.4	0.0	0.0	0.0	0.0	0.0	0.0
4- 5	23	29.0	0.0	3.1	0.0	0.0	0.0	24.1	0.0	1.3	0.0	0.0	0.0	0.5
5- 6	23	30.7	0.0	1.5	0.0	0.0	0.0	28.1	0.0	0.0	0.0	0.0	0.0	1.1
QTR TOTALS	125	189.0	0.0	7.1	0.5	0.0	1.0	175.5	0.0	2.3	0.0	0.0	0.0	2.7
6- 7	29	36.8	0.0	0.7	0.0	0.0	0.9	33.0	0.0	0.0	0.0	0.0	0.0	2.3
7- 8	54	63.9	0.0	1.3	11.3	1.0	1.1	49.2	0.0	0.0	0.0	0.0	0.0	0.0
8- 9	66	68.7	0.1	3.5	3.6	0.0	2.4	55.2	0.0	0.0	0.0	0.0	0.0	3.9
9-10	66	61.0	0.0	2.3	3.4	0.0	3.4	46.0	0.0	0.0	0.0	0.0	0.0	6.0
10-11	55	54.8	0.0	1.4	4.1	0.0	1.0	47.4	0.0	0.0	0.0	0.0	0.0	0.8
11-12	47	52.0	0.0	0.3	2.4	0.0	0.2	44.4	0.0	0.0	0.0	0.0	0.0	4.7
QTR TOTALS	317	337.3	0.1	9.5	24.9	1.0	8.9	275.3	0.0	0.0	0.0	0.0	0.0	17.6
12-13	62	67.9	0.0	3.7	2.1	0.0	1.6	59.5	0.0	0.0	0.0	0.0	0.0	0.9
13-14	48	66.8	0.0	0.2	3.1	0.0	1.7	52.7	0.0	1.0	0.0	0.0	0.0	8.1
14-15	52	46.2	0.0	2.5	4.5	0.0	1.9	35.9	0.3	0.0	0.0	0.0	0.0	1.2
15-16	56	49.7	0.0	1.5	1.4	0.0	0.6	45.8	0.0	0.0	0.0	0.0	0.0	0.4
16-17	45	45.7	0.0	0.1	1.4	0.0	1.8	42.3	0.0	0.0	0.0	0.0	0.0	0.1
17-18	44	35.5	0.0	1.4	0.0	0.0	0.8	32.5	0.0	0.0	0.0	0.0	0.0	0.7
QTR TOTALS	307	311.9	0.0	9.4	12.6	0.0	8.5	268.7	0.3	1.0	0.0	0.0	0.0	11.5
18-19	41	42.5	0.6	0.3	0.7	0.0	0.2	38.9	0.0	0.8	0.0	0.0	0.0	0.9
19-20	34	43.7	0.0	0.2	0.0	0.0	1.8	41.1	0.0	0.0	0.0	0.0	0.0	0.6
20-21	26	27.6	0.0	0.1	0.0	0.0	0.0	24.9	0.0	0.9	0.0	0.0	0.0	1.7
21-22	30	34.9	0.0	0.0	0.8	0.0	1.8	27.2	0.0	2.2	0.0	0.0	0.0	2.9
22-23	23	34.3	0.0	0.0	1.9	0.0	0.0	30.2	0.0	1.3	0.0	0.0	0.0	0.9
23-24	21	22.4	0.0	1.0	1.3	0.0	1.0	16.4	0.0	2.2	0.0	0.0	0.0	0.5
QTR TOTALS	175	205.4	0.6	1.6	4.7	0.0	4.9	178.8	0.0	7.3	0.0	0.0	0.0	7.6

DAILY SUMMARY

	TOTALS	4	5	6	7	8	9	10	11	12	13	14	15
VEH'S WEIGHED	924	4	89	59	1	53	594	1	12	0	0	0	111
18 KIP ESALS	1043.6	0.7	27.5	42.7	1.0	23.2	898.2	0.3	10.5	0.0	0.0	0.0	39.3
AVERAGE ESALS	1.1	0.18	0.31	0.72	1.02	0.44	1.51	0.31	0.88	0.00	0.00	0.00	0.35

APPENDIX B

BRIDGE WIM SPECIFICATIONS AND TABLES

PORTABLE BRIDGE WEIGH-IN-MOTION SYSTEM

SYSTEM REQUIREMENTS

Description

The bridge weigh-in-motion system shall provide for the in-motion weighing of all vehicles in two adjacent lanes of a highway bridge. The system will include the following major components:

8 - strain transducers with C-clamps
2 - sets of two tapeswitches
16 - heavy duty 2-inch clamps with a centering pin
1 - field unit
1 - power supply (rechargeable battery)

--- all necessary cabling, software, and miscellaneous materials and accessories
--- training
--- equipment service support

Quantities

An itemized bid proposal shall be submitted. If applicable, a schedule of quantity discounts for specific items should be attached to the bid. Bidder shall specify recommended optional spare parts and their costs.

Construction

All electronic components shall be of solid state design with high noise immunity and low power consumption. Logic and data storage components shall be mounted on firmly replaceable plug in circuit boards. All components shall be mounted and housed so that they will not be damaged by jolts and vibrations encountered in transportation and use. Electronic components shall be protected against overloads, power surges, and transients.

Material

Material shall be specified herein. Material not definitely specified shall be of good commercial quality entirely suitable for the purpose. Material shall be free from all defects and imperfections that might affect the serviceability of the finished product.

Standard Products

The equipment shall be essentially standard manufactured products, so that prompt and continuing service and delivery of spare parts may be assured. The component parts of the system need not be products of the same manufacturer.

Strain Transducers

Full bridge arrangement of 350 ohm foil type gauges on reusable aluminum frame capable of being clamped on girders to permit the mounting of one strain transducer on each longitudinal load carrying girder (for up to 6 girders) shall be provided.

The transducer shall sense the weight of each axle of each vehicle moving over each lane by measuring the deflection of the longitudinal girders.

Tape Switches

Reusable tape switches capable of providing data for computing vehicle speed, axle spacings, and vehicle classification that can be mounted on the road surface shall be provided. The system shall be capable of using road tubes, permanent loops, or piezoelectric sensors.

The tape switches shall be of the size and type specified by the vendor for optimal system operation. The tape switches shall be installed using an adhesive type material that will operate under most traffic conditions for at least one week. They shall not be removable by the normal braking action of trucks during this period of time.

Field Unit

The field unit shall be enclosed in a NEMA rated weatherproof, compact, portable, metal housing with carrying handles and lock hasp. The field unit shall couple with the transducers and tape switches or road tubes through the cabling and transmit the data to the control unit through a RS 232C cable or similar device. The field unit shall include a power supply and necessary lightning protection for each connecting cable.

The field unit shall have the capability of sampling the outputs from the combined transducers and each lane over the full range of operating speeds.

Power Supply

A rechargeable battery capable of operating the system for a minimum of 7 days shall be included, along with the recharger, at least 2 spare batteries, and necessary accessories.

Monitoring System

The system shall include a high-speed monitoring system capable of displaying individual vehicle records within 1 second of the desired vehicle exiting the system. VDOT shall provide a personal computer.

Software

The systems shall include all necessary software for configuring, calibrating, setting up, diagnosing, and operating the system. It shall also include means for directly transferring the data to the following IBM compatible laptop personal computers: (a) IBM PC convertible laptop computer, 512K, two 3.5 inch diskette drives, MS-DOS; and (b) Zenith Supersport 286 laptop computer, 1MB, one 3.5 inch diskette drive, 20MB hard disk, MS-DOS. Specifically, the system:

A. shall be capable of acquiring vehicle data by lane in a fully automatic mode in one or two lanes of traffic.

B. shall display, print and/or store at a minimum, the following cumulative data for each vehicle classification by lane:

--vehicle classification count (in FHWA Traffic Monitoring Guide format)
--vehicle speed

plus the following (in FHWA Traffic Monitoring Guide format) for each individual truck:

--gross weight
--all axle weights
--wheel base length
--all axle spacings
--speed
--time
--classification
--violator identification
--lane number

Bidder shall identify data items that are available but not required.

C. shall be capable of in-field processing and simultaneous storage of data.

D. shall complete in-field processing with a maximum headway between vehicles equal to the time needed by a vehicle to exit the system plus 0.05 seconds

E. shall classify vehicles using the 13 classifications of Scheme F of the Federal Highway Administration. The classification code shall be displayed on the vehicle display screen when the truck data are displayed. (Bidders shall identify those items that are optional extras and their individual cost.)

F. shall provide a total vehicle count that includes those vehicles not properly classified in accordance with the classification logic, i.e., total vehicle count shall equal the sum of vehicles classified and vehicles not classified properly.

G. shall provide data for printout or display, including summary reports, and shall provide samples of each. Bidder shall describe extent to which output formats are user modifiable.

H. shall also include the federal bridge formula table and means for changing any weight limits. The system shall check for compliance with the bridge formula and other axle and gross weight limits and indicate possible violations by type of violation in the display, printout, and storage.

I. shall display digital data using the U.S. Customary Weights and Measures System. Weight shall be 1000s of pounds to 1 decimal place. Spacing shall be in feet and tenths.

J. shall use operator programmable timers as necessary for determining start and ending times for operations and arrival time for individual vehicles.

K. shall provide for a diagnostic check of system hardware and software. Bidders shall briefly describe the procedures and extent of this function.

L. shall provide for changing, adding, or deleting site data such as pavement type, weather, site identification numbers, etc.

M. shall provide full edit capabilities including detection and where possible, correction of questionable data. Bidders shall briefly describe the procedures and extent of this function.

N. shall allow operator calibration of the system with no more than 10 crossings of a test truck per lane. One test truck weighing at least 40,000 pounds of no more than 3 axles shall be adequate to accurately calibrate the system for any weight truck. Bidder shall specify calibration procedures and recalibration conditions.

O. shall provide sufficient data storage capacity to allow for the continuous collection and storage of two lanes of traffic data over a continuous 7-day period (i.e., 20,000, 3-axle truck records). Bidder shall provide the number of 3-axle trucks that can be stored.

P. shall provide clearly documented software. A software manual, including documentation, shall be provided. Any proposed licensing agreements shall be provided.

Q. updates of the software for one year at no cost shall be provided.

WIM SYSTEM FUNCTIONAL SPECIFICATIONS

The WIM system shall automatically determine within the accuracies specified below the following data for each vehicle by lane of travel for at least a 90% confidence level:

	Systematic or Mean Error	Random Error or Standard Deviation
single axle weight	5%	15%
tandem axle weight	5%	13%
gross weight	5%	12%
axle spacing	$\pm$ 6 in	12 in
vehicle length	$\pm$ 12 in	18 in
speed	$\pm$ 1 mph	2.5 mph

Vehicle classification--The system must accurately classify at least 90% of all vehicles.

USER REQUIREMENT

The vendor shall specify the following user requirements for effective use of the WIM system where applicable:

Site Condition Factors - pavement smoothness, horizontal curvature, longitudinal gradient, cross-slope, width of paved lane
Foundation for Installation (Bridge Types and Features)
Proper Climatic Environment
Adequate Power

TRAINING OF PERSONNEL

The successful bidder will provide a reasonable and adequate amount of training in Charlottesville to state personnel in operation, maintenance, trouble shooting, and repairs to the system. Each bidder shall define the recommended level of training to be provided and the cost of that training. At a minimum, 32 hours of training, including at least 8 hours of hands-on field exercises, shall be provided. The training period shall commence at the discretion of the State. Training is anticipated immediately following delivery of the equipment.

WARRANTIES AND ACCEPTANCE

Warranties

For a period of one year to begin upon notification of acceptance of the system by the State as described below under acceptance procedure, item no. 2, the vendor shall repair or replace at no charge, any component that fails or does not function properly and, if necessary, will provide technical assistance on site to aid in repair or replacement of faulty components. The failed component shall be repaired or replaced within 21 calendar days of delivery of the failed component to the vendor. The vendor shall be responsible for all shipping costs incurred in fulfilling this warranty. For those components not manufactured by the bidder, the bidder shall provide the manufacturer's warranty.

Acceptance Procedure

(1) The vendor shall certify in writing to the State when the system is ready for use by the State. The following conditions must be met before issuing this certification:

--the vendor must have provided sufficient training to enable State personnel to operate the system
--the vendor must provide the State with evidence of a successful system audit performed on the system which demonstrates that the equipment meets minimum design specifications.

(2) Upon the State receiving the above certification, an acceptance testing period of 60 calendar days will begin. The State will notify the vendor in writing at the end of this period of system acceptance or rejection. Acceptance or rejection will be determined through testing and operation of the system for compliance with the specifications contained herein. The vendor shall have the opportunity to remedy the cause(s) for rejection. Upon delivery, payment of 25 percent of the total cost will be made. The remainder shall be paid upon acceptance of the equipment. If, during the acceptance testing, the equipment is found to be unacceptable, the equipment shall be returned to the vendor and all funds paid by VDOT shall be repaid within 14 days of delivery of the equipment to the vendor.

MAINTENANCE AND TECHNICAL SUPPORT

The vendor must be responsive to equipment problems Monday through Friday between 8:00 a.m. and 4:30 p.m. with 5 work days or less response time.

Bidders shall provide the following information (preferably in a manual):

--escalation policy in regard to equipment repair costs
--maintenance plans available and their costs
--duration and frequency of preventive maintenance
--location of account representative in case of problems and where service would originate
--the dimensions and schematics of each component part and the whole system
--environmental operating requirements for all equipment, including heating, cooling, circuit and grounding requirements
--ongoing technical support policy, practices, and procedures

DELIVERY TIME

Upon award of this contract to a vendor, the complete WIM system must be delivered within 90 days of receipt of the order.

USER MANUALS

The selected vendor shall provide four complete sets of documentation (User Manuals) that describe the capabilities, procedures for set-up, calibration, diagnostic testing, operation and maintenance of the WIM system. One user manual must be included with the Bid and the other User Manuals delivered to the state at least 10 calendar days prior to delivery of the WIM systems and subsequent training period.

SYSTEM COST

Bids shall be provided on an itemized basis and include:

--purchase price for all components and recommended spare parts,
--delivery costs
--software (licensed) costs
--training costs
--total cost
--other appropriate costs

AWARD

The contract will be awarded to the vendor on the basis of an evaluation of the total bid with respect to system design, compatibility with bid specifications, and costs.

NON-PERFORMANCE OF VENDOR

Failure of the vendor to fulfill any commitment made by the vendor within the scope of the contract agreement may, at the option of the State, result in the termination of the contract agreement and the assessment of damages to be paid to the State by the vendor.

In the event that the State determines that such failure to fulfill a commitment has occurred, the State shall provide written notification to the vendor. Upon receipt of such notification, the vendor shall have five (5) working days to remedy the failure or to propose a remedy which will be satisfactory to the State, in which case the right to terminate shall not be invoked.

Addendum to the Bridge WIM Specifications

o 1 spare battery not 2
o If a supply of tape switches is available, thru tape switch cables with saurio connectors
o 3 air switch boxes for road tubes

date : 12/11/1990

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 1: Vehicle Classification by Gross Vehicle Weight

GVW IN KIPS		0	5	10	20	30	40	50	60	70	80	85	90
TO	total	5	10	20	30	40	50	60	70	80	85	90	+
CLASS 4	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	328	8	136	151	28	5	0	0	0	0	0	0	0
CLASS 6	121	0	2	34	38	23	8	16	0	0	0	0	0
CLASS 7	1	0	0	0	0	0	1	0	0	0	0	0	0
CLASS 8	118	1	14	17	39	28	7	6	5	1	0	0	0
CLASS 9	671	0	0	3	106	106	84	85	98	127	40	14	8
CLASS 10	4	0	0	0	0	1	1	1	1	0	0	0	0
CLASS 11	18	0	0	0	0	2	2	9	5	0	0	0	0
CLASS 12	2	0	0	0	0	0	0	1	1	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	13	2	2	0	1	3	1	1	2	0	0	0	1
ALL SINGLE	450	8	138	185	66	28	9	16	0	0	0	0	0
ALL COMBIN	813	1	14	20	145	137	94	102	110	128	40	14	8
ALL TRUCKS	1276	11	154	205	212	168	104	119	112	128	40	14	9

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 2: Vehicle Classification by Hour of Day

TIME FROM		0	1	2	3	4	5	6	7	8	9	10	11
TO	total	1	2	3	4	5	6	7	8	9	10	11	12
CLASS 1	9547	63	39	29	31	28	101	304	834	794	473	504	472
CLASS 2	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 3	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 4	43	0	0	0	0	1	1	1	2	7	8	3	1
CLASS 5	328	2	1	0	4	4	4	12	16	24	27	21	17
CLASS 6	121	1	1	0	1	3	2	2	5	6	7	9	12
CLASS 7	1	0	0	0	0	0	0	0	0	0	0	0	1
CLASS 8	118	2	1	1	1	0	3	8	12	7	6	8	9
CLASS 9	672	21	22	11	28	37	28	29	33	45	42	48	30
CLASS 10	4	1	0	0	0	0	0	0	0	0	1	1	0
CLASS 11	18	2	1	0	0	1	0	0	0	1	1	0	0
CLASS 12	2	0	0	0	0	0	0	1	0	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	25	1	0	0	0	0	1	0	2	0	1	1	2
ALL NON-COM	9547	63	39	29	31	28	101	304	834	794	473	504	472
ALL SINGLE	493	3	2	0	5	8	7	15	23	37	42	33	31
ALL COMBIN	814	26	24	12	29	38	31	38	45	53	50	57	39
ALL TRUCKS	1332	30	26	12	34	46	39	53	70	90	93	91	72

TIME FROM		12	13	14	15	16	17	18	19	20	21	22	23
TO	total	13	14	15	16	17	18	19	20	21	22	23	24
CLASS 1	9547	418	473	582	736	954	1059	573	334	261	207	174	104
CLASS 2	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 3	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 4	43	2	1	1	6	2	1	2	2	2	0	0	0
CLASS 5	328	23	24	32	31	24	25	14	10	6	2	2	3
CLASS 6	121	8	12	11	12	19	3	0	3	1	0	2	1
CLASS 7	1	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 8	118	7	5	9	12	5	6	1	3	5	6	1	0
CLASS 9	672	34	36	27	28	20	26	14	23	25	18	22	25
CLASS 10	4	0	0	0	1	0	0	0	0	0	0	0	0
CLASS 11	18	1	2	0	1	1	1	2	3	0	1	0	0
CLASS 12	2	0	0	0	0	0	0	0	0	0	1	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	25	0	3	3	3	2	2	0	1	0	2	0	1
ALL NON-COM	9547	418	473	582	736	954	1059	573	334	261	207	174	104
ALL SINGLE	493	33	37	44	49	45	29	16	15	9	2	4	4
ALL COMBIN	814	42	43	36	42	26	33	17	29	30	26	23	25
ALL TRUCKS	1332	75	83	83	94	73	64	33	45	39	30	27	30

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 3: Gross Vehicle Weight by Hour of Day

TIME FROM			0	1	2	3	4	5	6	7	8	9	10	11
TO		total	1	2	3	4	5	6	7	8	9	10	11	12
GVW 0	5	11	0	0	0	0	0	1	1	0	0	0	0	1
GVW 5	10	154	2	1	0	1	0	1	7	7	8	13	9	4
GVW 10	20	205	1	0	0	3	4	2	3	7	11	18	15	19
GVW 20	30	212	1	3	2	1	5	9	8	13	15	17	23	14
GVW 30	40	168	5	2	0	8	4	3	4	11	16	6	16	9
GVW 40	50	104	4	2	4	2	2	3	11	7	5	8	5	2
GVW 50	60	119	4	7	3	4	6	5	4	3	10	5	6	5
GVW 60	70	112	6	6	0	3	10	5	4	9	8	3	4	8
GVW 70	80	128	4	5	2	8	10	6	8	6	7	5	5	3
GVW 80	85	40	2	0	1	2	1	2	2	4	1	5	3	4
GVW 85	90	14	0	0	0	2	2	0	0	0	0	2	2	0
GVW 90	+	9	1	0	0	0	1	0	0	0	2	2	0	1

TIME FROM			12	13	14	15	16	17	18	19	20	21	22	23
TO		total	13	14	15	16	17	18	19	20	21	22	23	24
GVW 0	5	11	1	0	1	2	1	1	1	1	0	0	0	0
GVW 5	10	154	8	6	15	17	11	14	10	10	6	1	1	2
GVW 10	20	205	15	24	22	19	16	13	3	0	3	1	4	2
GVW 20	30	212	17	16	13	19	16	4	1	3	2	6	1	3
GVW 30	40	168	12	9	12	10	12	7	3	7	4	2	3	3
GVW 40	50	104	6	5	2	4	5	7	2	4	6	3	2	3
GVW 50	60	119	5	9	5	6	1	3	4	6	6	5	3	4
GVW 60	70	112	5	5	4	4	1	3	2	5	4	6	6	1
GVW 70	80	128	4	5	3	2	4	7	3	6	6	5	5	9
GVW 80	85	40	0	2	0	3	0	1	2	1	0	1	1	2
GVW 85	90	14	0	0	2	0	4	0	0	0	0	0	0	0
GVW 90	+	9	0	0	1	0	0	0	0	0	0	0	1	0

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 4: Speed Distribution by Hour of Day

TIME FROM		0	1	2	3	4	5	6	7	8	9	10	11
TO		1	2	3	4	5	6	7	8	9	10	11	12
	total												
SPEEDS 0 40	5	0	0	0	0	0	0	0	0	1	0	0	2
SPEEDS 40 50	72	0	0	0	2	1	3	4	3	3	9	5	3
SPEEDS 50 53	75	2	2	2	2	5	2	6	6	6	4	2	6
SPEEDS 53 54	66	2	4	1	4	3	3	2	0	2	8	3	2
SPEEDS 54 55	65	2	1	1	4	4	1	2	5	1	1	4	4
SPEEDS 55 56	86	1	5	3	3	1	1	2	7	6	5	10	6
SPEEDS 56 57	96	3	2	2	2	3	5	6	4	8	1	7	5
SPEEDS 57 58	80	1	1	0	2	2	3	2	1	3	6	9	6
SPEEDS 58 60	218	9	2	1	3	11	9	6	14	12	16	16	10
SPEEDS 60 65	409	7	6	2	12	12	8	15	22	33	27	23	22
SPEEDS 65 70	106	3	2	0	0	3	2	7	5	8	8	7	5
SPEEDS 70 +	11	0	1	0	0	0	1	0	1	0	0	2	0

TIME FROM		12	13	14	15	16	17	18	19	20	21	22	23
TO		13	14	15	16	17	18	19	20	21	22	23	24
	total												
SPEEDS 0 40	5	0	1	0	0	0	1	0	0	0	0	0	0
SPEEDS 40 50	72	3	4	4	13	4	4	3	0	1	0	0	3
SPEEDS 50 53	75	1	3	7	3	5	4	0	2	2	1	2	0
SPEEDS 53 54	66	7	5	3	3	5	2	3	0	2	0	1	1
SPEEDS 54 55	65	6	4	2	5	3	5	1	1	2	2	2	2
SPEEDS 55 56	86	5	3	8	5	2	4	1	1	0	5	2	0
SPEEDS 56 57	96	4	11	5	5	4	4	4	5	3	0	0	3
SPEEDS 57 58	80	3	4	5	5	4	2	2	7	6	2	2	2
SPEEDS 58 60	218	14	12	9	13	9	11	4	5	9	8	5	10
SPEEDS 60 65	409	21	29	31	26	23	23	9	17	9	12	12	8
SPEEDS 65 70	106	8	6	7	9	10	3	4	4	3	0	1	1
SPEEDS 70 +	11	1	0	1	1	2	0	0	1	0	0	0	0

speed-mph	total	0-40	40-50	50-53	53-54	54-55	55-56	56-57	57-58	58-60	60-65	65-70	70 +
no. autos	9547	9	115	138	101	133	151	218	204	691	2863	3530	1394
no. trucks	1332	5	72	75	66	65	86	96	80	218	409	106	11

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 5: Average Gross Weight (0.01 kip increments) of Vehicle by Hour of Day

TIME FROM		0	1	2	3	4	5	6	7	8	9	10	11
TO		1	2	3	4	5	6	7	8	9	10	11	12
	total												
CLASS 4	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	1226	675	2440	0	1654	1956	1287	942	1447	1525	1178	1133	1286
CLASS 6	2928	1428	987	0	1385	2095	2063	3615	2550	4437	3199	3473	2511
CLASS 7	4417	0	0	0	0	0	0	0	0	0	0	0	4417
CLASS 8	2833	3911	3955	2932	3658	0	4128	4076	3152	2991	2346	2718	2805
CLASS 9	5387	5953	5711	5547	5893	6253	5284	5654	5794	5214	5205	4582	5447
CLASS 10	4893	5644	0	0	0	0	0	0	0	0	4002	3211	0
CLASS 11	5490	6523	6561	0	0	5148	0	0	0	5642	5090	0	0
CLASS 12	6442	0	0	0	0	0	0	5903	0	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	3704	3502	0	0	0	0	0	0	4243	0	0	2757	9279
ALL SINGLE	1691	926	1713	0	1600	2015	1545	1323	1709	2107	1594	1835	1880
ALL COMBIN	5019	5827	5673	5329	5815	6223	5172	5328	5089	4928	4835	4296	4837
ALL TRUCKS	3832	5260	5368	5329	5195	5569	4584	4250	4017	3908	3523	3439	3633

TIME FROM		12	13	14	15	16	17	18	19	20	21	22	23
TO		13	14	15	16	17	18	19	20	21	22	23	24
	total												
CLASS 4	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	1226	1262	1334	1195	1208	1229	1065	983	801	1196	1772	1088	1002
CLASS 6	2928	2671	3379	3459	3045	2514	1510	0	3558	2942	0	1569	4220
CLASS 7	4417	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 8	2833	2696	2234	1777	2272	2198	3217	2788	2549	2520	3920	1000	0
CLASS 9	5387	4577	4658	5117	4555	5433	5481	6086	5920	5490	5586	5989	5663
CLASS 10	4893	0	0	0	6715	0	0	0	0	0	0	0	0
CLASS 11	5490	5623	5986	0	5986	5639	4542	4486	5001	0	5604	0	0
CLASS 12	6442	0	0	0	0	0	0	0	0	0	6982	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	3704	0	2060	423	461	3532	0	0	3626	0	6340	0	0
ALL SINGLE	1691	1625	2015	1774	1720	1796	1112	983	1437	1445	1772	1328	1806
ALL COMBIN	5019	4288	4437	4282	3988	4818	5027	5703	5476	4995	5255	5772	5663
ALL TRUCKS	3832	3157	3302	2885	2813	2952	3200	3571	4212	4323	5095	5113	5131

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 6: Weight Distribution by Axle Grouping

Vehicle Group : Single Units

front

kips		#	%	sum%
total		450	0.0	100.0
0	5	192	42.7	57.3
5	6	54	12.0	45.3
6	7	51	11.3	34.0
7	8	46	10.2	23.8
8	9	32	7.1	16.7
9	10	26	5.8	10.9
10	11	14	3.1	7.8
11	12	12	2.7	5.1
12	13	4	0.9	4.2
13	14	3	0.7	3.6
14	15	1	0.2	3.3
15	16	6	1.3	2.0
16	17	7	1.6	0.4
17	18	2	0.4	0.0
18	19	0	0.0	0.0
19	20	0	0.0	0.0
20	21	0	0.0	0.0
21	22	0	0.0	0.0
22	23	0	0.0	0.0
23	100	0	0.0	0.0

single

kips		#	%	sum%
total		328	0.0	100.0
0	5	98	29.9	70.1
5	6	55	16.8	53.4
6	7	22	6.7	46.6
7	8	41	12.5	34.1
8	9	38	11.6	22.6
9	10	24	7.3	15.2
10	11	7	2.1	13.1
11	12	10	3.0	10.1
12	13	9	2.7	7.3
13	14	6	1.8	5.5
14	15	4	1.2	4.3
15	16	5	1.5	2.7
16	17	0	0.0	2.7
17	18	1	0.3	2.4
18	19	2	0.6	1.8
19	20	2	0.6	1.2
20	21	2	0.6	0.6
21	22	0	0.0	0.6
22	23	1	0.3	0.3
23	100	1	0.3	0.0

tandem

kips		#	%	sum%
total		122	0.0	100.0
0	10	20	16.4	83.6
10	12	13	10.7	73.0
12	14	9	7.4	65.6
14	16	6	4.9	60.7
16	18	8	6.6	54.1
18	20	15	12.3	41.8
20	22	13	10.7	31.1
22	24	3	2.5	28.7
24	26	4	3.3	25.4
26	28	7	5.7	19.7
28	30	2	1.6	18.0
30	32	4	3.3	14.8
32	34	1	0.8	13.9
34	36	2	1.6	12.3
36	38	2	1.6	10.7
38	40	11	9.0	1.6
40	42	2	1.6	0.0
42	44	0	0.0	0.0
44	46	0	0.0	0.0
46	200	0	0.0	0.0

triple

kips		#	%	sum%
total		1	0.0	100.0
0	15	0	0.0	100.0
15	18	0	0.0	100.0
18	21	0	0.0	100.0
21	24	0	0.0	100.0
24	27	0	0.0	100.0
27	30	0	0.0	100.0
30	33	1	100.0	0.0
33	36	0	0.0	0.0
36	39	0	0.0	0.0
39	42	0	0.0	0.0
42	45	0	0.0	0.0
45	48	0	0.0	0.0
48	51	0	0.0	0.0
51	54	0	0.0	0.0
54	57	0	0.0	0.0
57	60	0	0.0	0.0
60	63	0	0.0	0.0
63	66	0	0.0	0.0
66	69	0	0.0	0.0
69	300	0	0.0	0.0

Vehicle Group : Multi Units

front

kips		#	%	sum%
total		826	0.0	100.0
0	5	23	2.8	97.2
5	6	1	0.1	97.1
6	7	33	4.0	93.1
7	8	105	12.7	80.4
8	9	195	23.6	56.8
9	10	230	27.8	28.9
10	11	156	18.9	10.0
11	12	57	6.9	3.1
12	13	24	2.9	0.2
13	14	2	0.2	0.0
14	15	0	0.0	0.0
15	16	0	0.0	0.0
16	17	0	0.0	0.0
17	18	0	0.0	0.0
18	19	0	0.0	0.0
19	20	0	0.0	0.0
20	21	0	0.0	0.0
21	22	0	0.0	0.0
22	23	0	0.0	0.0
23	100	0	0.0	0.0

single

kips		#	%	sum%
total		295	0.0	100.0
0	5	70	23.7	76.3
5	6	11	3.7	72.5
6	7	11	3.7	68.8
7	8	16	5.4	63.4
8	9	21	7.1	56.3
9	10	17	5.8	50.5
10	11	20	6.8	43.7
11	12	15	5.1	38.6
12	13	26	8.8	29.8
13	14	18	6.1	23.7
14	15	21	7.1	16.6
15	16	10	3.4	13.2
16	17	12	4.1	9.2
17	18	8	2.7	6.4
18	19	3	1.0	5.4
19	20	2	0.7	4.7
20	21	0	0.0	4.7
21	22	4	1.4	3.4
22	23	0	0.0	3.4
23	100	10	3.4	0.0

tandem

kips		#	%	sum%
total		1420	0.0	100.0
0	10	213	15.0	85.0
10	12	92	6.5	78.5
12	14	117	8.2	70.3
14	16	88	6.2	64.1
16	18	80	5.6	58.5
18	20	74	5.2	53.2
20	22	63	4.4	48.8
22	24	60	4.2	44.6
24	26	74	5.2	39.4
26	28	82	5.8	33.6
28	30	99	7.0	26.6
30	32	123	8.7	18.0
32	34	92	6.5	11.5
34	36	80	5.6	5.8
36	38	48	3.4	2.5
38	40	19	1.3	1.1
40	42	7	0.5	0.6
42	44	5	0.4	0.3
44	46	1	0.1	0.2
46	200	3	0.2	0.0

triple

kips		#	%	sum%
total		6	0.0	100.0
0	15	3	50.0	50.0
15	18	0	0.0	50.0
18	21	0	0.0	50.0
21	24	1	16.7	33.3
24	27	0	0.0	33.3
27	30	0	0.0	33.3
30	33	0	0.0	33.3
33	36	1	16.7	16.7
36	39	1	16.7	0.0
39	42	0	0.0	0.0
42	45	0	0.0	0.0
45	48	0	0.0	0.0
48	51	0	0.0	0.0
51	54	0	0.0	0.0
54	57	0	0.0	0.0
57	60	0	0.0	0.0
60	63	0	0.0	0.0
63	66	0	0.0	0.0
66	69	0	0.0	0.0
69	300	0	0.0	0.0

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 7: Cumulative ESAL Values by Vehicle Classification, GVW and Hour of Day

	flexible esal values		rigid esal values		
	avg	total	avg	total	#
CLASS 4	0.00	0.00	0.00	0.00	0
CLASS 5	0.09	29.52	0.10	32.80	328
CLASS 6	0.49	59.29	0.74	89.54	121
CLASS 7	0.41	0.41	0.70	0.70	1
CLASS 8	0.75	88.50	0.68	80.24	118
CLASS 9	0.90	604.80	1.51	1014.72	672
CLASS 10	0.23	0.92	0.52	2.08	4
CLASS 11	0.86	15.48	0.95	17.10	18
CLASS 12	0.82	1.64	1.00	2.00	2
CLASS 13	0.00	0.00	0.00	0.00	0
CLASS 14	1.21	30.25	1.49	37.25	25
ALL SINGLE	0.20	89.22	0.27	123.04	450
ALL COMBIN	0.88	741.59	1.37	1153.39	839
ALL TRUCKS	0.64	830.81	0.99	1276.43	1289

	flexible esal values		rigid esal values		
	avg	total	avg	total	#
gvw 0 5	0.00	0.00	0.00	0.00	11
gvw 5 10	0.00	0.00	0.00	0.00	154
gvw 10 20	0.03	6.15	0.04	8.20	205
gvw 20 30	0.11	23.32	0.15	31.80	212
gvw 30 40	0.23	38.64	0.31	52.08	168
gvw 40 50	0.34	35.36	0.55	57.20	104
gvw 50 60	0.96	114.24	1.39	165.41	119
gvw 60 70	1.29	144.48	1.97	220.64	112
gvw 70 80	1.85	236.80	3.09	395.52	128
gvw 80 85	2.77	110.80	4.45	178.00	40
gvw 85 90	3.83	53.62	5.70	79.80	14
gvw 90 200	5.78	52.02	7.85	70.65	9

Table 7 continued: Cumulative ESAL Values by Hour of Day

			flexible esal values		rigid esal values		
			avg	total	avg	total	#
hour	0	1	0.98	29.40	1.52	45.60	30
hour	1	2	0.75	19.50	1.30	33.80	26
hour	2	3	0.76	9.12	1.30	15.60	12
hour	3	4	0.99	33.66	1.59	54.06	34
hour	4	5	1.08	48.60	1.79	80.55	45
hour	5	6	0.77	28.49	1.25	46.25	37
hour	6	7	0.90	46.80	1.23	63.96	52
hour	7	8	0.66	44.22	1.04	69.68	67
hour	8	9	0.68	56.44	1.02	84.66	83
hour	9	10	0.78	65.52	1.11	93.24	84
hour	10	11	0.47	41.36	0.75	66.00	88
hour	11	12	0.71	49.70	1.02	71.40	70
hour	12	13	0.32	23.36	0.53	38.69	73
hour	13	14	0.46	37.26	0.73	59.13	81
hour	14	15	0.45	36.00	0.70	56.00	80
hour	15	16	0.43	36.98	0.59	50.74	86
hour	16	17	0.48	34.08	0.70	49.70	71
hour	17	18	0.40	24.00	0.68	40.80	60
hour	18	19	0.55	17.05	0.90	27.90	31
hour	19	20	0.62	26.66	1.01	43.43	43
hour	20	21	0.77	28.49	1.08	39.96	37
hour	21	22	1.04	31.20	1.43	42.90	30
hour	22	23	0.87	23.49	1.49	40.23	27
hour	23	24	0.91	26.39	1.52	44.08	29

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 8: Overweight Trucks by Vehicle Classification and Hour of Day

********** violation on 151 / 1332 trucks **********

TIME FROM / TO	total	0 / 1	1 / 2	2 / 3	3 / 4	4 / 5	5 / 6	6 / 7	7 / 8	8 / 9	9 / 10	10 / 11	11 / 12
CLASS 4	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	4	0	0	0	1	0	0	0	0	1	0	0	0
CLASS 6	17	0	0	0	0	0	0	0	0	3	1	2	1
CLASS 7	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 8	12	0	0	0	0	0	1	2	2	0	1	1	1
CLASS 9	115	3	3	2	6	7	5	7	6	6	11	7	7
CLASS 10	1	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 11	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 12	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	2	0	0	0	0	0	0	0	0	0	0	0	1
ALL SINGLE	21	0	0	0	1	0	0	0	0	4	1	2	1
ALL COMBIN	128	3	3	2	6	7	6	9	8	6	12	8	8
ALL TRUCKS	151	3	3	2	7	7	6	9	8	10	13	10	10

TIME FROM / TO	total	12 / 13	13 / 14	14 / 15	15 / 16	16 / 17	17 / 18	18 / 19	19 / 20	20 / 21	21 / 22	22 / 23	23 / 24
CLASS 4	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	4	0	0	0	0	2	0	0	0	0	0	0	0
CLASS 6	17	1	5	2	2	0	0	0	0	0	0	0	0
CLASS 7	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 8	12	0	0	0	1	0	0	0	0	1	2	0	0
CLASS 9	115	2	5	5	4	5	5	3	4	1	2	2	7
CLASS 10	1	0	0	0	1	0	0	0	0	0	0	0	0
CLASS 11	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 12	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	2	0	0	0	0	1	0	0	0	0	0	0	0
ALL SINGLE	21	1	5	2	2	2	0	0	0	0	0	0	0
ALL COMBIN	128	2	5	5	6	5	5	3	4	2	4	2	7
ALL TRUCKS	151	3	10	7	8	8	5	3	4	2	4	2	7

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 9: Overweight Trucks by Vehicle Classification and Gross Vehicle Weight

********** violation on 151 / 1332 trucks **********

GVW IN KIPS TO	total	0 5	5 10	10 20	20 30	30 40	40 50	50 60	60 70	70 80	80 85	85 90	90 +
CLASS 4	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	4	0	0	0	0	4	0	0	0	0	0	0	0
CLASS 6	17	0	0	0	0	0	1	16	0	0	0	0	0
CLASS 7	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 8	12	0	0	0	0	0	1	5	5	1	0	0	0
CLASS 9	115	0	0	0	0	0	0	0	2	51	40	14	8
CLASS 10	1	0	0	0	0	0	0	0	1	0	0	0	0
CLASS 11	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 12	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	2	0	0	0	0	0	0	0	1	0	0	0	1
ALL SINGLE	21	0	0	0	0	4	1	16	0	0	0	0	0
ALL COMBIN	128	0	0	0	0	0	1	5	8	52	40	14	8
ALL TRUCKS	151	0	0	0	0	4	2	21	9	52	40	14	9

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 10: Overweight Trucks by Vehicle Classification and Amount of Overweight

********** violations **********

overweight kips	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0 +
CLASS 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 6	0	1	1	2	6	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 8	3	0	1	2	2	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0
CLASS 9	19	12	13	4	10	4	9	1	4	4	0	2	4	0	3	1	1	1	0	0
CLASS 10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ALL SINGLE	0	2	2	2	6	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0
ALL COMBIN	22	13	14	6	12	4	10	1	6	5	0	2	4	0	3	1	1	1	0	0
ALL TRUCKS	23	15	16	8	18	6	11	3	6	5	0	2	4	0	3	1	1	1	0	1

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 11: Overweight Trucks by Vehicle Classification and Type of Violation

********** violations **********

	total	1	2	3	4	5	6	gvw
CLASS 4	0	0	0	0	0	0	0	0
CLASS 5	4	4	0	0	0	0	0	0
CLASS 6	17	0	8	0	0	0	0	9
CLASS 7	0	0	0	0	0	0	0	0
CLASS 8	12	11	1	0	0	0	0	0
CLASS 9	115	0	50	1	43	0	0	21
CLASS 10	1	0	0	1	0	0	0	0
CLASS 11	0	0	0	0	0	0	0	0
CLASS 12	0	0	0	0	0	0	0	0
CLASS 13	0	0	0	0	0	0	0	0
CLASS 14	2	0	0	1	0	0	0	1
ALL SINGLE	21	4	8	0	0	0	0	9
ALL COMBIN	128	11	51	2	43	0	0	21
ALL TRUCKS	151	15	59	3	43	0	0	31

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 12: Lane Distribution of Vehicles by Vehicle Classification

	lane 1	lane 2	total
CLASS 4	0	0	0
CLASS 5	314	14	328
CLASS 6	118	3	121
CLASS 7	1	0	1
CLASS 8	112	6	118
CLASS 9	635	37	672
CLASS 10	4	0	4
CLASS 11	17	1	18
CLASS 12	2	0	2
CLASS 13	0	0	0
CLASS 14	19	6	25
ALL SINGLE	433	17	450
ALL COMBIN	770	44	814
ALL TRUCKS	1222	67	1289

Table 13 : Lane Distribution of Vehicles by Gross Vehicle Weight

	lane 1	lane 2	total
GVW 0 5	4	7	11
GVW 5 10	147	7	154
GVW 10 20	199	6	205
GVW 20 30	199	13	212
GVW 30 40	159	9	168
GVW 40 50	103	1	104
GVW 50 60	114	5	119
GVW 60 70	106	6	112
GVW 70 80	124	4	128
GVW 80 85	38	2	40
GVW 85 90	12	2	14
GVW 90 +	7	2	9

Bridge Weigh-in-Motion System

date : 12/11/90
time : from hour 0 to hour 23

Table 14: Distribution of Vehicles by Vehicle Classification and Total Axle Spacing

length	0-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65 +
CLASS 4	0	0	0	0	0	0	0	0	0	0	0
CLASS 5	206	121	0	1	0	0	0	0	0	0	0
CLASS 6	4	69	48	0	0	0	0	0	0	0	0
CLASS 7	0	0	0	1	0	0	0	0	0	0	0
CLASS 8	0	0	0	6	28	22	20	31	10	1	0
CLASS 9	0	0	0	0	3	3	23	182	298	148	15
CLASS 10	0	0	0	0	0	0	0	0	1	2	1
CLASS 11	0	0	0	0	0	0	0	0	0	3	15
CLASS 12	0	0	0	0	0	0	0	0	0	0	2
CLASS 13	0	0	0	0	0	0	0	0	0	0	0
CLASS 14	0	0	1	2	4	6	1	3	4	2	2
ALL SINGLE	210	190	48	2	0	0	0	0	0	0	0
ALL COMBIN	0	0	0	6	31	25	43	213	309	154	33
ALL TRUCKS	210	190	49	10	35	31	44	216	313	156	35

Table 15 : Distribution of Vehicles by Gross Vehicle Weight and Total Axle Spacing

length	0 -20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65 +
GVW 0 5	8	0	0	0	1	1	0	0	1	0	0
GVW 5 10	125	13	0	3	7	4	0	0	2	0	0
GVW 10 20	62	116	7	3	7	5	2	2	1	0	0
GVW 20 30	11	32	22	1	10	6	10	53	51	16	0
GVW 30 40	3	13	12	0	3	7	15	44	42	23	6
GVW 40 50	1	3	4	1	2	3	5	18	44	20	3
GVW 50 60	0	13	3	0	1	1	3	23	37	27	11
GVW 60 70	0	0	0	0	0	0	2	31	45	23	11
GVW 70 80	0	0	0	0	0	0	1	22	67	34	4
GVW 80 85	0	0	0	0	0	0	3	12	15	10	0
GVW 85 90	0	0	0	0	0	0	3	4	4	3	0
GVW 90 +	0	0	1	0	0	0	0	5	3	0	0

APPENDIX C

PIEZOELECTRIC CABLE WIM SPECIFICATIONS AND TABLES

WEIGH-IN-MOTION SYSTEMS USING PIEZOELECTRIC SENSORS

SYSTEM REQUIREMENTS

Description

The two weigh-in-motion systems using piezoelectric sensors shall be provided. Each system shall provide for the in-motion weighing of all vehicles in two adjacent lanes of a highway. Each system will include the following major components:

2 - sets of two piezoelectric sensors
1 - field unit
1 - power supply (rechargeable battery)

--- all necessary cabling, software, and miscellaneous materials and accessories
--- training
--- equipment service support

Additionally, one system shall include a camera monitoring subsystem.

Quantities

An itemized bid proposal shall be submitted. If applicable, a schedule of quantity discounts for specific items should be attached to the bid. Bidder shall specify optional recommended spare parts and their costs.

Construction

All electronic components shall be of solid state design with high noise immunity and low power consumption. Logic and data storage components shall be mounted on firmly replaceable plug in circuit boards. All components shall be mounted and housed so that they will not be damaged by jolts and vibrations encountered in transportation and use. Electronic components shall be protected against overloads, power surges, and transients. All wiring, conduit, and electrical equipment shall conform to state specifications and standards, and local building codes.

Material

Material shall be specified herein. Material not definitely specified shall be of good commercial quality entirely suitable for the purpose. Material shall be free from all defects and imperfections that might affect the serviceability of the finished product.

Standard Products

The equipment shall be essentially standard manufactured products, so that prompt and continuing service and delivery of spare parts may be assured. The component parts of the system need not be products of the same manufacturer.

Piezoelectric Sensors

Piezoelectric sensors shall be grade No. 1 manufactured by Thermocoax or equivalent sensors, mounted in accordance with the sensors tested in the FHWA-DP-88-76-006, "Automated Traffic/Truck Weight Monitoring Equipment (Weigh-In-Motion)." The bidder shall have personnel available on-site to instruct as needed and ensure quality control during the installation of the sensors.

Active lengths of cable shall be 11 feet 6 inches for use in 12-foot lanes or adjusted as necessary for other lane widths.

Feeders shall be of sufficient length to reach roadside electronics without joints. Feeder cables shall be protected by PVC sleeves where they cross joints in or adjacent to the pavement.

VDOT personnel shall install the piezoelectric sensors. Piezoelectric cable mountings shall be permanently installed, flush with the pavement surface along the entire length of each sensor, using Hermetite epoxy adhesive or similar approved materials. The maximum depth of pavement cut for piezoelectric cables shall be two inches. Width of cut shall not exceed two inches.

All work shall be carried out in accordance with approved procedures.

Field Unit

The field unit or electronics subsystem shall be enclosed in a NEMA rated, compact, portable, metal weatherproof housing with carrying handles and lock hasps. The field unit shall couple with the piezoelectric sensors through the cabling and transmit the data to the control unit through a RS 232C port or similar device. The field unit classification shall be capable of monitoring signals from the piezoelectric sensors plus one in-pavement temperature sensor per lane. Each unit shall be capable of monitoring two lanes of traffic simultaneously. Sampling of piezoelectric sensor outputs shall be at a rate of 2 Khz, as a minimum. Charge amplifiers with sealed connectors shall be provided within the electronics subsystem.

The signal processing algorithm shall include provision for automatic zeroing, elimination of pavement bending effects, suppression of noise, detection of wheel passages, digital signal integration, speed compensation and temperature correction.

The system shall contain a facility for self calibration. When selected, the self-calibration algorithm shall periodically change the manually-input calibration factor based on a sample of previously calculated axle weights. Each subsequent sample shall be similarly utilized to readjust the calibration factor by a maximum of one percentage point per adjustment in the direction of the newly-calculated factor.

The field unit shall have the capability of sampling the outputs from the piezoelectric sensors in each lane over the full range of operating speeds.

Power Supply

The field unit shall be designed for low power consumption and continuous operation for a minimum of 7 days on batteries. It shall be capable of operating on 110-120 VAC, rechargeable batteries, and a solar panel.

Monitoring System

The system shall include a high-speed monitoring system capable of displaying individual vehicle records within 1 second of the desired vehicle exiting the system. VDOT shall provide a personal computer.

Camera Monitoring Unit

The system shall be capable of operating in a camera monitoring mode, based around a professional quality 35mm camera system.

In the camera monitoring mode, the camera system shall be activated by a signal transmitted via a cable link from the electronics subsystem. The electronics subsystem shall be capable of transmitting the triggering signal upon detection of user-selectable vehicle classes, axle weights, gross weights, or speeds in excess of user-selectable thresholds. When triggered by the electronics subsystem, the camera system shall produce photographs of the vehicles identified according to the selected parameter thresholds. The photographs shall be of sufficient quality to allow unobscured license plates to be read during normal daylight hours.

The camera system shall include a 250 frame back with a built-in data unit which shall superimpose a date and time on all photographs. The camera system shall also include a motor drive unit and automatic exposure setting. The camera system shall be post-mounted in a roadside equipment cabinet. The equipment cabinet shall be capable of excluding dust and moisture, and shall be resistant to tampering, vandalism, and attempted theft. Installation of the camera system within the equipment cabinet shall be non-permanent, allowing for removal and replacement as required.

The camera monitoring mode shall be capable of operating in conjunction with all operating modes. Additionally, the field unit shall allow for suppression of the camera monitoring mode as required.

Telemetry Units

Telemetry units are an option and costs and description of telemetry units should be included with the bid proposal. Telemetry units shall include a battery-operated telemetry subsystem able to transmit data via an auto-answer modem. The telemetry subsystem shall have a security feature to prevent unauthorized access. Provision shall be made for error trapping and re-transmission of data by a defined and approved protocol. All of the data input parameters shall be capable of being monitored and reset via the telemetry unit.

Software

Each system shall include all necessary software for configuring, calibrating, setting up, diagnosing, and operating the system. Each system shall also include means for directly transferring the data to the following IBM compatible laptop personal computers: (a) IBM PC convertible laptop computer, 512K, two 3.5 inch diskette drives, MS-DOS; and (b) Zenith Supersport 286 laptop computer, 1MB, one 3.5 inch diskette drive, 20MB hard disk, MS-DOS. Specifically, each system:

A. shall be capable of acquiring vehicle data by lane in a fully automatic mode in one or two lanes of traffic.

B. shall display, print and/or store at a minimum, the following periodic (1 hr to 24 hr) summary data for each vehicle classification by lane:

--time period
--fault status
--calibration factor
--vehicle classification count (in FHWA Traffic Monitoring Guide format)
--vehicle speed

plus the following (in FHWA Traffic Monitoring Guide format) for each individual truck:

--vehicle number
--time
--lane number
--speed
--classification
--all axle spacings
--all axle weights

Bidder shall identify data items that are available but not required.

C. shall be capable of in-field processing and simultaneous storage of data.

D. shall complete in-field processing with a maximum headway between vehicles equal to the time needed by a vehicle to exit the system plus 0.05 seconds

E. shall classify vehicles using the 13 classifications of Scheme F of the Federal Highway Administration and in each of the twelve user-defined gross weight bins. The classification code shall be displayed on the vehicle display screen when the truck data are displayed. (Bidders shall identify those items that are optional extras and their individual cost.)

F. shall provide a total vehicle count that includes those vehicles not properly classified in accordance with the classification logic, i.e., total vehicle count shall equal the sum of classified vehicles and others counted but not classified properly.

G. shall provide data for printout or display, including summary reports, and shall provide samples of each. Bidder shall describe extent to which output formats are user modifiable.

H. shall provide sufficient data storage capacity to allow for the continuous collection and storage of two lanes of traffic data over a continuous 7-day period (i.e., 30,000, 3-axle truck records). Bidder shall provide the number of 3-axle truck records that can be stored.

I. shall display digital data using the U.S. Customary Weights and Measures System. Weight shall be 1000s of pounds to 1 decimal place. Spacing shall be in feet and tenths.

J. shall use operator programmable timers as necessary for determining start and ending times for operations and arrival time for individual vehicles.

K. shall provide for a diagnostic check of system hardware and software. Bidders shall briefly describe the procedures and extent of this function.

L. shall provide for changing, adding, or deleting site data such as pavement type, weather, site identification numbers, etc.

M. shall provide full edit capabilities including detection and where possible, correction of questionable data. Bidders shall briefly describe the procedures and extent of this function.

N. shall also include the federal bridge formula table and means for changing any weight limits. The system shall check for compliance with the bridge formula and other axle and gross weight limits and indicate possible violations by type of violation in the display, printout, and storage.

O. shall provide clearly documented software. A software manual, including documentation, will be provided for each WIM system along with any proposed software licensing agreements as part of the proposal.

P. shall provide updates of the software for one year at no cost.

WIM SYSTEM FUNCTIONAL SPECIFICATIONS

The WIM system shall automatically determine within the accuracies specified below the following data for each vehicle by lane of travel for at least a 90% confidence level:

	Systematic or Mean Error	Random Error or Standard Deviation
single axle weight	5%	12%
tandem axle weight	5%	12%
gross weight	5%	12%
axle spacing	± 6 in	12 in
speed	± 1 mph	2.5 mph

Vehicle classification--the system shall accurately classify at least 90% of all vehicles.

Durability--the piezoelectric sensors shall achieve an operating life of at least two years in 80% of cases. The field unit shall achieve an operating life of at least four years in 80% of cases.

USER REQUIREMENT

The vendor shall specify the following user requirements for effective use of the WIM system where applicable:

Site Condition Factors - pavement smoothness, horizontal curvature, longitudinal gradient, cross-slope, width of paved lane
Foundation for Installation
Proper Climatic Environment
Adequate Power

TRAINING OF PERSONNEL

The successful bidder will provide a reasonable and adequate amount of training in Charlottesville and on-site to state personnel in operation, maintenance, trouble shooting, and repairs to the system. Each bidder shall define the recommended level of training to be provided and the cost of that training. At a minimum, 24 hours of training, including at least 8 hours of hands-on field training, shall be provided. The training period shall commence at the discretion of the State. Training is anticipated immediately following delivery of the equipment.

WARRANTIES AND ACCEPTANCE

Warranties

For a period of one year to begin upon notification of acceptance of the system by the State as described below under acceptance procedure, item no. 2, the vendor shall repair or replace at no charge, any component that fails or does not function properly and, if necessary, will provide technical assistance on site to aid in repair or replacement of faulty components. The failed component shall be repaired or replaced within 21 calendar days of delivery of the failed component to the vendor. The vendor shall be responsible for all shipping costs incurred in fulfilling this warranty.

Acceptance Procedure

(1) The vendor shall certify in writing to the State when the system is ready for use by the State. The following conditions must be met before issuing this certification:

--the vendor must have provided sufficient training to enable State personnel to operate the system

--the vendor must provide the State with evidence of a successful system audit performed on the system which demonstrates that the equipment meets minimum design specifications.

(2) Upon the State receiving the above certification, an acceptance testing period of 60 calendar days will begin. The State will notify the vendor in writing at the end of this period of system acceptance or rejection. Acceptance or rejection will be determined through testing and operation of the system for compliance with the specifications contained herein. The vendor shall have the opportunity to remedy the cause(s) for rejection. Payment in full will be made upon acceptance of the equipment.

MAINTENANCE AND TECHNICAL SUPPORT

The vendor must be responsive to equipment problems Monday through Friday between 8:00 a.m. and 4:30 p.m. with 5 work days or less response time.

Bidders shall provide the following information (preferably in a manual):

--escalation policy in regard to equipment repair costs
--maintenance plans available and their costs
--duration and frequency of preventive maintenance
--location of account representative in case of problems and where service would originate
--the dimensions and schematics of each component part and the whole system
--environmental operating requirements for all equipment, including heating, cooling, circuit and grounding requirements
--ongoing technical support policy, practices, and procedures

DELIVERY TIME

Upon award of this contract to a vendor, the complete WIM system must be delivered within 90 days of receipt of the order.

USER MANUALS

The selected vendor shall provide four complete sets of documentation (User Manuals) that describe the capabilities, procedures for set-up, calibration, diagnostic testing, operation and maintenance of the WIM system. One user manual must be included with the Bid and the other User Manuals delivered to the state at least 10 calendar days prior to delivery of the WIM systems and subsequent training period.

SYSTEM COST

Bids shall be provided on an itemized basis and include:

--purchase price for all components and recommended spare parts,
--delivery costs
--software (licensed) costs
--training costs
--total cost
--other appropriate costs

AWARD

The contract will be awarded to the vendor on the basis of an evaluation of the total bid with respect to system design, compatibility with bid specifications, and costs.

NON-PERFORMANCE OF VENDOR

Failure of the vendor to fulfill any commitment made by the vendor within the scope of the contract agreement may, at the option of the State, result in the termination of the contract agreement and the assessment of damages to be paid to the State by the vendor.

In the event that the State determines that such failure to fulfill a commitment has occurred, the State shall provide written notification to the vendor. Upon receipt of such notification, the vendor shall have five (5) working days to remedy the failure or to propose a remedy which will be satisfactory to the State, in which case the right to terminate shall not be invoked.

Addendum to the Piezoelectric Cable WIM

- o self calibration as an option to switch on and off
- o 1 battery recharger
- o software that generates summary tables directly and at a minimum be the eight tables generated by the weigh mat system
- o omit off scale sensors
- o install sensor 3/16 in below the pavement surface
- o omit off-scale sensors.

Installation Procedures

1 A group of four operatives is required for the safe and efficient installation of the equipment - two persons for loop cutting, a general laborer and a supervisor. Weather conditions must be dry, with pavement temperatures preferably in the range 50 degrees F to 80 degrees F. On arrival at the site, personnel should proceed in accordance with approved traffic control practices. The site should be coned well into the second lane, without undue detriment to passing traffic, to protect personnel when working at the edge of the array.

2 The proposed positions of the sensors should be marked on the pavement with paint. It is essential that the sensors are positioned parallel to one another, perpendicular to the edge of the pavement.

3 Surface conditions such as rut depth should then be checked to confirm that a suitable site has been chosen. If a double-blade diamond saw slot cutter is to be used, which is the preferred method of operation, a single straight line should be drawn indicating one edge of the sensor. If a single blade cutter is to be used then the sensors should be laid alongside the first line and a second line drawn. In such a case it is preferable to cut just inside the line to avoid having too wide a hole for the sensor.

4 Having marked the positions of the sensors, the trench between the edge of the pavement and the site of the control cabinet or hut into which ducting will be laid for the feeder cables should be excavated. The ducting should have an internal diameter of at least 1 1/2".

5 If a twin blade cutter is adopted for the piezo installation, the space between the blades should be set to the specified distance, typically 1 3/8". The depth of cut needs also to be set, typically to 1 1/4". A height control should be provided on the cutting blade to indicate the necessary depth of cut. A single slot is also required from the coaxial cable feeder to each piezo sensor.

6 Having cut the twin slots for the piezo sensors, the intervening material should be carefully broken out to avoid damaging the pavement surface at the edge of the hole. A hammer and stone chisel are required, breaking-out along the length of the cut. Having brushed out most of the debris, an air blower should be used to drive out finer material and some of the remaining water. A flame gun should then be used to dry out the holes completely.

7 A false top should be fitted to each sensor, to be removed once the sensor is installed. This should avoid the need to chip away any excess material covering the sensor following installation. This top may be in the form of a rubber strip or adhesive PVC tape which can be peeled off the sensor while the epoxy is setting, bringing with it any excess material. The strip or tape will need to be strong enough to resist tearing when it is removed from the top of the sensor.

8 The sensors should now be placed in their respective holes to identify isolated high spots which should be broken out. The sensors should then

be laid alongside the holes to identify high and low points across the pavement profile. These positions should be marked on the sensors. Where the pavement is high, steel plates should be attached to the top of sensors using wire or plastic cable straps. Where the pavement is low, plates should be laid across the sensor after it is installed and weights applied to hold it down to the pavement profile while the epoxy adhesive acquires the necessary strength.

9 The bottom and sides of the sensors should then be cleaned using a proprietary solvent. The epoxy adhesive, prepared in accordance with the manufacturer's instructions, is then poured in the slot and spread up the sides. Only one sensor should be installed at a time. Typically 14-20 lbs. of epoxy adhesive is required for each sensor, depending on the final dimensions of the hole.

10 During summer months, it is desirable to maintain the epoxy adhesive at a temperature of 45-55 degrees F before use. This should avoid the adhesive running downhill before setting. If this is impracticable, it would be prudent to install the sensors early in the day when the ambient temperature is low. During Spring or Fall, the opposite approach may be necessary, keeping the epoxy at room temperature prior to installation.

11 The sensor should be lowered into the slot starting from one end, so that the bow-wave of epoxy adhesive produced will ensure contact along its whole length. If necessary a scraper should be used to spread adhesive down the sides of the sensor. Extra adhesive may be necessary to fill the sides of the slot before weighing down the sensor. The untied plates should be repositioned at the locations previously marked on the sensor and weights placed to hold the sensor to the profile of the road.

12 The feeder cable should then be passed through the ducting to the control housing. Feeder wires should be tagged to identify individual sensors. Where feeders pass through joints in the pavement, PVC sheaths should be placed around the cable to minimize damage from movement along the joint. A second or subsequent sensor can now be installed.

13 Excess epoxy adhesive should be removed while still wet. The actual time required for the adhesive to set depends on the ambient temperature. Initial cooling may be necessary if the weather is hot but the manufacturer's instructions and specification should first be checked. On cold days, setting times can be much longer than normal.

14 When the epoxy adhesive is hard, the weights and plates should be removed. Any excess fixant should be carefully removed using a hand grinder and low spots filled with further adhesive. It is essential that epoxy is not left on top of the sensors. Cold fill macadam or similar, sealed as necessary, should be used to cover the feeder cables where they enter the ducting in the verge.

15 The cables should then be connected to test equipment and the sensors tested by striking lightly with a hammer, or similar. Given suitable signals, the trench to the control housing should be backfilled. The site should then be cleared and the dimensions of the array, as installed, should be noted and recorded for future reference. The traffic control signs and cones should finally be removed and the sensors tested using random vehicles before commissioning the equipment.

09:00 03/12/91
Lane 1 Axle calibration factor = 58%

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	Tot
	1	134	31	1	5	2	1	5	16	0	0	0	0	196

Speed	<30	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	>94
(mph)	11	1	3	1	4	41	91	41	3	0	0	0	0	0	0

Weight	4994	9988	14982	19976	24970	29964	34958	39952	44946	49940	54934	59928
(lbs)	133	31	5	1	2	6	5	3	1	1	2	6

09:00 03/12/91
Lane 2 Axle calibration factor = 63%

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	Tot
	1	284	43	4	6	2	0	7	14	1	0	1	0	363

Speed	<30	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	>94
(mph)	3	0	2	21	18	79	130	94	7	2	0	0	0	0	0

Weight	4994	9988	14982	19976	24970	29964	34958	39952	44946	49940	54934	59928
(lbs)	291	41	6	4	2	5	1	3	2	3	2	12

10:00 03/12/91
Lane 1 Axle calibration factor = 58%

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	Tot
	1	146	45	3	11	5	0	4	14	0	0	0	0	229

Speed	<30	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	>94
(mph)	1	0	0	7	18	59	95	45	5	0	0	0	0	0	0

Weight	4994	9988	14982	19976	24970	29964	34958	39952	44946	49940	54934	59928
(lbs)	135	52	6	8	6	5	5	2	2	0	3	6

10:00 03/12/91
Lane 2 Axle calibration factor = 63%

Class	1	2	3	4	5	6	7	8	9	10	11	12	13	Tot
	2	156	42	3	7	2	0	3	21	0	0	0	0	236

Speed	<30	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	>94
(mph)	1	0	0	5	4	38	113	70	3	1	0	0	0	0	0

Weight	4994	9988	14982	19976	24970	29964	34958	39952	44946	49940	54934	59928
(lbs)	164	37	5	1	2	4	3	7	2	1	2	9