Testing of the French Piezo-Electric Cable Weigh-in-Motion (WIM) Truck Scale

WA-RD 141.1

Final Report
December 1987

Washington State Department of Transportation
in cooperation with the
United States Department of Transportation
Federal Highway Administration

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16. ABSTRACT

This report documents the testing of a piezo-electric cable weigh-in-motion (WIM) truck scale. The equipment tested was developed by the French national laboratory, Laboratorie Central des Ponts et Chausees. Tests were made on the accuracy of the system's static weight estimates, its estimates of vehicle speed, and its classification of vehicles. Speed and vehicle classification estimates were quite good. Weight estimates did not meet the proposed HELP system specifications. The standard deviation of the difference between WIM and static gross vehicle weights was approximately 20 percent.

Tests were also performed to examine the effects of tire pressure, speed and lane position on the voltage output of the cable. Of these variables, tire pressure was determined to most highly effect cable voltage output. Reduction of tire pressures from 105 psi to 75 psi had a statistically significant effect on cable voltage output.

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DISCLAIMER

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TESTING OF THE FRENCH PIEZO-ELECTRIC CABLE WEIGH-IN-MOTION (WIM) TRUCK SCALE

EXECUTIVE SUMMARY

This report documents the testing and research performed on the French piezo-electric cable high speed truck scale by the Washington State Transportation Center (TRAC) for the Washington State Department of Transportation. This work was carried out as a part of the WSDOT research program, in conjunction with the Heavy Vehicle Electronic License Plate (HELP) project.

INTRODUCTION

Within the state of Washington, as well as nationally, increases in the number and weight of trucks have resulted in concern over the effect of heavy vehicles on the life of existing pavements and bridge decks and on the design of new pavements and bridges. The data collection equipment and techniques currently used do not allow vehicle weights to be adequately measured and monitored on most highways. One reason is that many trucks of both legal and illegal weights by-pass conventional static scales. Another is that the dynamic forces felt by the pavement or deck can be very different from the static loadings measured at conventional scales. Furthermore, operation of conventional scales is labor intensive. Consequently, the collection of truck weight data via conventional equipment can be both biased and costly. For the past three years WSDOT has been examining the use of different low and medium cost, high speed truck scales to overcome these limitations. This project is part of that effort.

As a result of a competitive bidding process, a system developed by the French government at the Laboratorie Central des Ponts et Chausses (LCPC) was selected for testing in Washington and Oregon. This system was installed at two sites, a high speed site in Washington and a medium speed site in Oregon.

Project Objective

The research described in this report had three major objectives:

- to examine the feasibility and reliability of an existing piezo-electric cable WIM system for conditions extant in Washington,
- to determine if piezo-electric cable WIM systems could be used for collecting tire pressure information, and
- to evaluate piezo-electric technology for use in other applications such as bridge response computations, pavement loading history computations, and automated control and sorting of trucks.

Equipment Tested

The equipment used during the project included one SAFT (Station D'Analyse Fine Du Trafic) scale system, leased for two months, and one purchased AP-16 scale. The SAFT is a medium priced scale system developed in 1983 for collecting axle load and vehicle classification information for a variety of uses within France. The devices are portable and can be attached to roughly 200 sets of piezo-electric cables imbedded in pavement throughout France. The system's electronic components, which collect, amplify and interpret the piezo-electric signal, are located in a standard equipment rack.

The SAFT equipment is capable of collecting and storing the data required to meet the HELP WIM specifications. Data on each vehicle crossing the cables are recorded on removable, 5-megabyte Bernouli cartridges. Data stored for each vehicle include

- individual axle weights (individual axles of tandem and tridems, too),
- the time between axle pulses,
- the speed of the vehicle,
- and the date and time of the vehicle's passage.

The current price for the equipment is roughly 228,000 French francs, or $37,000 at current exchange rates. This exceeds the price goal of the Iowa/Minnesota piezo-electric cable project but is competitive with many other scale systems currently available in the United States.

The AP-16 is a low cost cable system that collects axle loading information. The AP-16 does not classify vehicles but simply records the weight of each axle in a series of definable axle weight categories.

Equipment Installation

The installation of the cables required roughly five hours at each site. This estimate includes curing time for the resin. A six-person crew was used for the installation, although with a small amount of practice a crew of three could probably perform an installation in roughly six hours. The lane that was instrumented had to be closed to traffic throughout the installation process.

To perform the installation, two channels were cut in the road surface. The channels were each 7 cm (2.75 in) wide, 5 cm (2.0 in) deep, and 3.7 m. (12 ft) long. The two cables were located 65 cm (25.6 in) apart. The "bar" containing the piezo-electric cable was then placed in each channel using a device provided with the cables. The device set the cable at the desired height below the road surface (roughly 1 cm). A resin mixture was then poured over and around the cable to secure the device to the pavement.

Testing

After the cables were calibrated with two test vehicles, roughly 100 trucks were weighed at the Washington static and WIM sites. Comparisons of dynamic and static single axle, tandem axle and gross vehicle weights for the 100 trucks are described under "Test Results," below.

The original plan was to weigh between 150 and 200 vehicles, but a series of different computer failures increased the non-operational project time and therefore, the limited project budget reduced the total number of vehicles that could be weighed. The project team believes the computer failures were primarily related to fluctuations in the power supply caused in part by the use of a gasoline powered generator and the need to convert American power (110 volt, 60 hertz) to European power (220 volts, 50 hertz). (Because the system tested was leased for the project, it was equipped with European wiring. A purchased SAFT would be built with American power capabilities.)

In Oregon, a test vehicle made a series of passes so that the effects of tire pressure and lane position on the cable signal output could be examined. In these tests a three-axle, single unit truck loaded with 10,300 pounds on the front axle and 29,200 pounds on the rear tandem (14,750 on the second axle, 14,450 pounds on the third axle) was driven over the cable at a constant speed. The tires on the vehicle were initially inflated to 105 psi. Fourteen passes of the cable were made at a speed of 25 miles per hour.

The pressure in both tires on the front axle was then reduced to 75 psi. Eight passes were then made with the vehicle crossing the cable in the left-hand portion of the lane. Eight passes were made in the right-hand portion of the lane, and twelve passes were made at an increased speed of 35 miles per hour.

TEST RESULTS

Single and Tandem Weight Estimates

The WIM system did not provide axle weight estimates within the accuracies desired by WSDOT. A tabular summary of the test results for single and tandem axle weight estimates made at the Washington site is shown in Exhibit E-1. Exhibits E-2 and E-3 show system errors (defined as WIM weight minus static weight) compared against the static weight of single and tandem axles.

Two separate phenomenon are apparent in these exhibits. The first is that the WIM estimates include a systematic error. (In Exhibits E-2 and E-3, the data points would be centered around 0 tons of error if no systematic error were present.) The second is that the random error in the data is too large. This is demonstrated by the spread of the data about the centerline.

For tandem axles, the system starts to show significant underestimation after 9 tons (20,000 pounds). For single axles, underestimation starts to occur after 7 tons (15,000 pounds).

Gross Vehicle Weight Estimates

For all vehicles weighed at both the static and WIM scales, the systematic error for the system was determined to be 1 percent, with a standard deviation of that error of 19.5 percent. The size of the

Exhibit E-1
Summary of WIM Accuracy
Single Axle Estimates

	Mean Error (pounds)[1]	Std. Dev. of Error	Mean Percentage Error[2]	Std. Dev. of Percentage Error
All Single Axles	-980	2,430	-3.3%	26.1%
Steering (Front) Axles	-1,770	1,580	-17.2%	13.4%
Non-Steering Axles	-330	2,800	8.2%	28.4%

Tandem Axles and GVW Estimates

	Mean Error (pounds)[1]	Std. Dev. of Error	Mean Percentage Error[2]	Std. Dev. of Percentage Error
Tandem Axles	-590	4,900	4.9%	26.7%
Gross Vehicle Weights	-140	9,810	1.0%	19.5%

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[1] computed as $\sum_{0}^{N}$ (WIM - static)/n

[2] computed as $\sum_{0}^{N}$ ((WIM - static)/static)/n

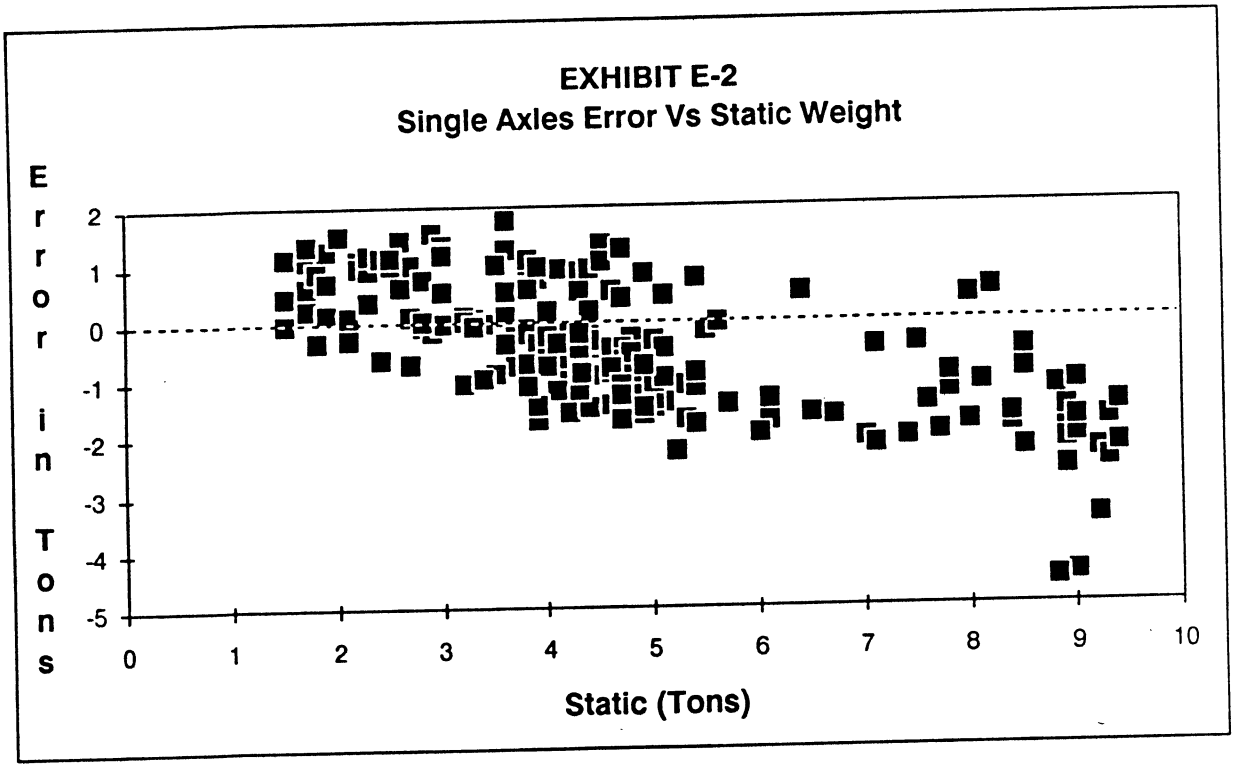
EXHIBIT E-2
Single Axles Error Vs Static Weight
Error in Tons
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10
Static (Tons)

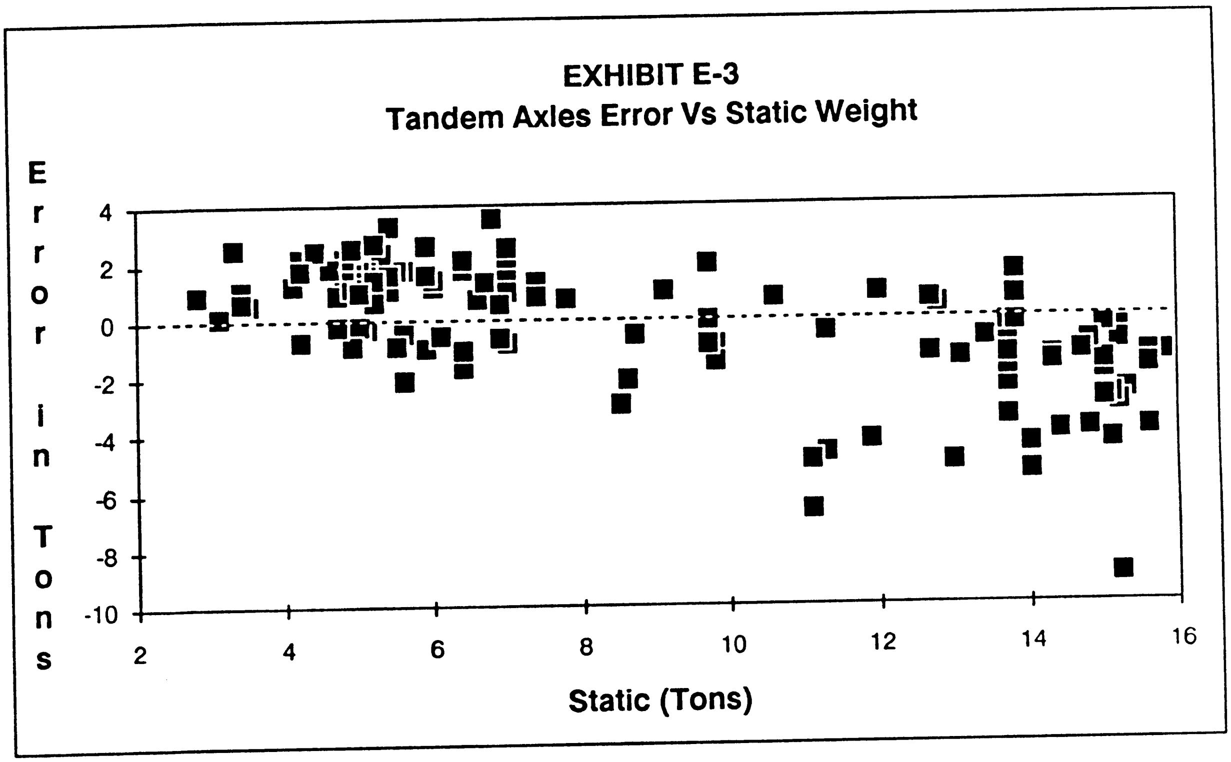
EXHIBIT E-3
Tandem Axles Error Vs Static Weight
Error in Tons
4
2
0
-2
-4
-6
-8
-10
2
4
6
8
10
12
14
16
Static (Tons)

systematic error varied depending on the mix of heavy and light vehicles in the traffic stream. This is discussed in the main text.

The weight estimates are not good. Exhibit E-4 is a plot of WIM versus static weight. Exhibit E-5 is a plot of the error, defined as WIM weight minus static weight, versus static weight. Both graphs include only data collected at the Washington test location.

Apparent in Exhibit E-5 is that the system tends to underestimate the weights of heavy vehicles and overestimate the weights of light vehicles. For 22 of 26 vehicles (85 percent) over 30 tons (66,000 pounds) GVW were underestimated, while for 37 of 53 vehicles (70 percent) under 20 tons (44,000 pounds) GVW values were overestimated.

Effects of Tire Pressure and Lane Position

The voltage outputs from the Oregon tire pressure tests showed the following.

- Lowered tire pressure produced a lowered voltage spike from the piezo-electric cable.
- The lowered voltage spike was significantly different at a confidence level of 99.5 percent.
- The differences in voltage output were between 11.8 and 16 percent.
- In some but not all cases, the lateral position of the vehicle affected output voltage.

Each of these findings is described in more detail in the main text.

CONCLUSIONS

The following are the preliminary conclusions from this evaluation effort.

- The French piezo-electric truck scale system (SAFT) tested does not currently meet the performance standards required by the Washington State Department Of Transportation (WSDOT), Oregon Department Of Transportation, or the Heavy Vehicle Electronic License Plate project (HELP).

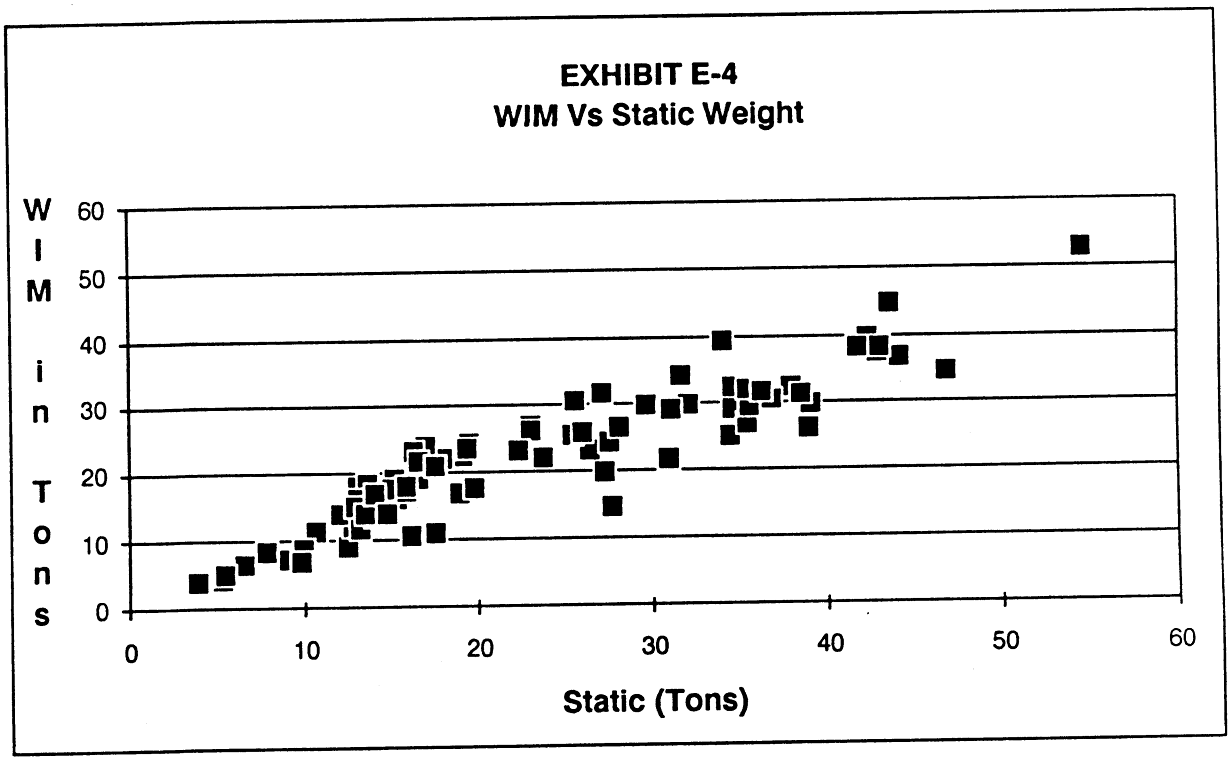
EXHIBIT E-4
WIM Vs Static Weight
WIM in Tons
60
50
40
30
20
10
0
0
10
20
30
40
50
60
Static (Tons)

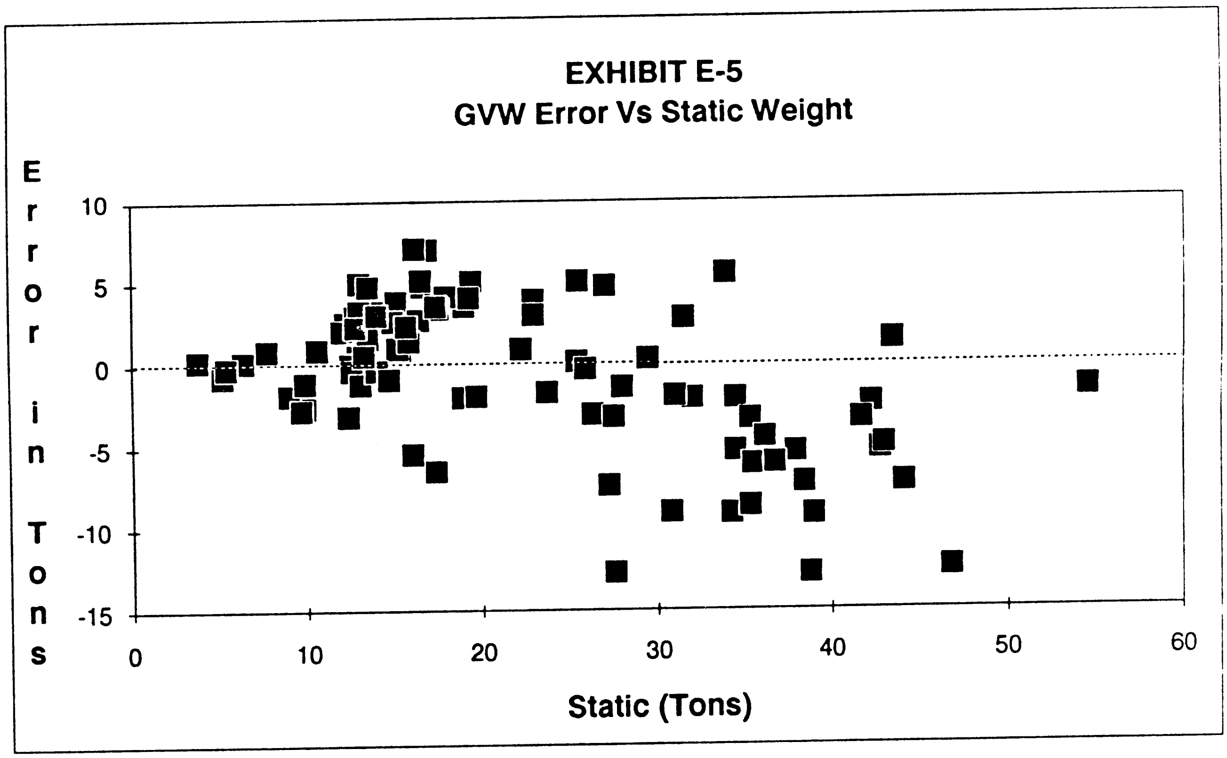
EXHIBIT E-5
GVW Error Vs Static Weight
Error in Tons
10
5
0
-5
-10
-15
0
10
20
30
40
50
60
Static (Tons)

- The system did perform reasonably well under controlled conditions. However, under normal operating conditions the differences between WIM axle and gross vehicle weight estimates and static weights were too large for normal usage in WSDOT data collection efforts.
- The accuracy of the axle weight estimates was affected by the static weight of axles being weighed.
- The system tended to underestimate heavy axle weights and overestimate light axles weights.
- The response for steering axles was different than that for non-steering axles, although the difference was not statistically significant.
- Lowering tire pressure produced a statistically significant reduction in the voltage output of the cable system for equal axle loadings.

  Lowered voltage output translated directly into a lowered axle weight estimate by the French piezo-electric WIM system.
- The possible causes of the differences between the observed static and dynamic weights were not clear, but included the following:
  - the algorithms used to estimate weights,
  - the functioning of the cable itself (i.e., the electrical charge produced),
  - differing tire pressures, or
  - the differing dynamics of various vehicle types and loading conditions.
- The tests performed led the author to believe that piezo-electric cable technology can be used to develop a sensor that would indicate the presence of imbalanced loads or significantly different tire pressures on two tires on the same axle.
- Considerable development of software and hardware (including new cable installation research) are necessary before such a system could be built.

- The use of both axle sensors to weigh vehicles, as opposed to using only one sensor for weighing (the second is used only for speed estimation) would improve the accuracy of the system considerably.
- If both axle sensors were used, the distance between sensors would have to be stretched to a value that would help compensate for the response characteristics of typical American trucks.
- The French WIM system was not designed for operation at low speeds (below 20 miles per hour) and did not function well under those conditions.

RECOMMENDATIONS

The following are recommendations, based on the foregoing conclusions, the funding available for the coming biennium, and the state of the art in WIM technology at this time, for future research and implementation of WIM technology by WSDOT.

- Additional testing of the existing French cable WIM system is not desirable.
- Additional research is warranted into the use of piezo-electric cable sensors for weighing axles, including the use of sensors that need not be permanently installed in the pavement.
- Any additional research should be conducted with more advanced French systems, the Iowa/Minnesota system being marketed by GK Instruments, or some other similar system.
- The research should center on the following aspects of cable mounting.
  - How important is the depth of the senor to cable sensitivity?
  - Can cables from different manufacturers be used with different companies' electronics?
  - What are the important installation tolerances for the cable and the road surface in which it is placed?

- Is it better to slightly bend the cable to more closely match the pavement profile, or place the cable horizontally and let the distance between the cable and the road surface vary?

- Additional research into the response of piezo cables installed in pavements to different tire pressures, tire widths, and the length of tire footprints could significantly improve the accuracy of piezo-electric cable WIM systems.

New WIM systems should be expected to exhibit considerable burn-in difficulties during their first two years of operation.

- If the on-going HELP project does not demonstrate that one low cost WIM system is clearly superior to others, the WSDOT should consider testing available cable systems.
  - WSDOT should provide for the labor, materials and vehicles to test the equipment;
  - manufacturers should provide their equipment free of charge for testing; and
  - the most highly ranked system should then be selected as the equipment to be purchased for installation at SHRP and HELP locations within the state.

The final recommendation from this effort is that initial laboratory research on the use of these sensors for bridge response measurements should be begun with two of the four remaining piezo cable sensors. This laboratory work would demonstrate the potential for this type of application using these sensors. The remaining two piezo cables should be reserved for use in testing the effects of depth of the cable on WIM system accuracy, or for use with another WIM system's electronics.

TESTING OF THE FRENCH PIEZO-ELECTRIC CABLE WEIGH-IN-MOTION (WIM) TRUCK SCALE

INTRODUCTION AND BACKGROUND

This report documents the testing and research performed on the French piezo-electric cable high speed truck scale by the Washington State Transportation Center (TRAC) for the Washington State Department of Transportation. This work is carried out as a part of the WSDOT research program, in conjunction with the Heavy Vehicle Electronic License Plate (HELP) project.

Introduction

Within the state of Washington, as well as nationally, increases in the number and weight of trucks have resulted in concern over the effect of heavy vehicles on the life of existing pavements and bridge decks and on the design of new pavements and bridges. The data collection equipment and techniques currently used do not allow vehicle weights to be adequately measured and monitored on most highways. One reason is that many trucks of both legal and illegal weights by-pass conventional static scales. Another is that the dynamic forces felt by the pavement or deck can be very different from the static loadings measured at conventional scales. Furthermore, operation of conventional scales is labor intensive. Consequently, the collection of truck weight data via conventional equipment can be both biased and costly. For the past three years WSDOT has been examining the use of different low and medium cost, high speed truck scales to overcome these limitations. This project is part of that effort.

Piezo-electric ceramic technology provides one potential means of developing a low cost sensing device that can unobstructively collect unbiased truck weight information. Experiments have been conducted with this technology for several years in several countries, the majority of work having been done in France and Great Britain. Until recently, little of this work had been done in the United States. However, within the last year one major piezo-electric scale system development project has been introduced in Iowa and Minnesota, and several private corporations are in the process of developing additional systems. The results of the Iowa/Minnesota project are intended to provide hardware and software designs for the public domain that can be manufactured by competing companies.

In Washington WSDOT decided that existing scale systems used in other countries and/or recently developed should be examined in addition to the Iowa/Minnesota work.

As a result of a competitive bidding process, a system developed by the French government at the Laboratorie Central des Ponts et Chausses (LCPC) was selected for testing in Washington and Oregon. This system was installed at two sites, a high speed site in Washington and a medium speed site in Oregon. (A description of the installation is included in the "Location" section.) Tests were then made at those installations to evaluate the performance of the system.

Project Objective

The research described in this report had three major objectives:

- to examine the feasibility and reliability of an existing piezo-electric cable WIM system for conditions extant in Washington,
- to determine if piezo-electric cable WIM systems could be used for collecting tire pressure information, and
- to evaluate piezo-electric technology for use in other applications such as bridge response computations, pavement loading history computations, and automated control and sorting of trucks.

Project Equipment

The equipment obtained from LCPC included one SAFT scale system, leased for two months, and one purchased AP-16 scale. The SAFT is a medium priced scale system developed in 1983 for collecting axle load and vehicle classification information for a variety of uses within France. Currently five SAFT systems are being used within that country. The devices are portable and can be attached to roughly 200 sets of piezo-electric cables imbedded in pavement throughout France. The system's electronic components are located in a standard equipment rack. For these tests, the equipment was kept in a University cargo van (equivalent to an eight passenger van) and driven to the various test locations. At the test locations, the equipment was attached via BNC connectors to two piezo cables buried in the asphalt roadway (see "Installation"). Set-up time was roughly 10 minutes at each site, once the cables were permanently installed. Set-up time included starting of a portable generator, boot-up of the system's computer and attachment of the various pieces of the system via cable.

The SAFT was designed to run unattended, although in this project an operator was always on site. For proper operation, the system requires electric power. Battery power operation is possible but only for very limited periods of time.

The SAFT equipment is capable of collecting and storing the data required to meet the HELP WIM specifications. Data on each vehicle crossing the cables are recorded on removable, 5-megabyte Bernouli cartridges. Data stored for each vehicle include

- individual axle weights (individual axles of tandem and tridems are also collected),
- the time between axle pulses,
- the speed of the vehicle,
- and the date and time of the vehicle's passage.

A series of computer programs supplied with the electronics processes the data records to provide a variety of summary reports. Some of these computer programs would need to be changed to aggregate data into the vehicle configurations requested by FHWA, but these modifications would be relatively minor.

The current price for the equipment is roughly 228,000 French francs, or $37,000 at current exchange rates. This exceeds the price goal of the Iowa/Minnesota piezo-electric cable project but is competitive with many other scale systems currently available in the United States.

The AP-16 is a low cost cable system that collects axle loading information. The AP-16 does not classify vehicles but simply records the weight of each axle in a series of definable axle weight categories. This type of device is considerably useful for maintaining the actual loading history of a pavement in order to track the performance of that pavement against expectations. It is also an inexpensive means of analyzing seasonal and or temporal pavement loading patterns when vehicle classification issues are not important.

The current price of the AP-16 is approximately 40,000 French francs, or roughly $6,700. The AP-16 is capable of monitoring traffic in two lanes simultaneously. This cost is roughly equivalent to that for the Iowa/Minnesota system specifications, although the AP-16 is a much more limited device.

Location of Equipment

Piezo-electric cables were installed at two locations, one in Washington and one in Oregon. The Washington site was located in the right-hand lane of Interstate 5, southbound, just north of the Nisqually static scale location. Vehicles traveling over the scale were measured at between 55 and 60 miles per hour. The piezo scale was set far enough upstream of the off-ramp to the static scale that truck speed over the cables was not affected by operation of the static scale.

The pavement at the Washington site was in good condition. Rutting in the pavement was nearly 10 mm deep. No significant cracking in the pavement was visible. The test section of road had no horizontal or vertical curvature and had a side slope of 0.0156 ft per foot. A vertical profile of the pavement leading to and surrounding the WIM site is included in this report as Appendix B.

The Oregon site was located within the northbound Woodburn static weigh station. The piezo-electric cables were placed immediately following the existing medium speed sorting scale. The project team intended for vehicles to travel over the scale at between 30 and 40 miles per hour. During testing, however, the truck drivers were so busy watching the project team personnel that they consistently traveled over the scales at below 15 miles per hour. In addition, trucks crossing the Oregon scales were not driving at constant speeds. Most of the trucks passing the Oregon site location were either braking or accelerating at some point while they were over the scale system.

The pavement at the Oregon site was in worse condition than the pavement at the Washington site. While no horizontal or vertical curvature was present in the road surface, ruts were 15 to 20 cm deep. The side slope of the pavement was also greater than in Washington, 0.0246 ft per foot.

As a result of the higher side slope of the pavement, the resin mixture used to secure the cables to the pavement was slightly different at the Oregon site than the Washington site. In Oregon, a higher ratio of sand per pound of resin was used in the installation. This caused the resin to be stiffer and kept it from flowing out of the pavement cut before it hardened.

REVIEW OF PREVIOUS STUDY

As noted previously, the French scale system was originally developed in 1983. LCPC claimed that tests performed in France resulted in a coefficient of variation of 15 percent for axle weights on roads with asphalt pavements in good condition. (This value was specified in bid documents submitted by the LCPC in response to the UW/WSDOT request for proposals included in Appendix A.)

A British company, Weighwrite, is currently marketing a piezo-electric scale through the American firm CMI-Dynamics, Inc. Testing of the Weighwrite scale at the Transportation and Road Research Laboratory in England* resulted in gross vehicle weight estimates with a standard deviation of 15 percent (i.e., the standard deviation of the difference between static gross vehicle weight and the measured dynamic weights).

As noted above, the states of Iowa and Minnesota are currently developing a piezo-electric scale as part of a Federal Highway Administration/HELP project. Initially published results indicate weight estimates with systematic errors of about 0.1 percent and random errors of 8.7 percent (one standard deviation) for individual axles. Gross vehicle weights produced by the system are slightly better than this, with systematic errors of roughly 0.1 percent and random errors of 6.3 percent.

The preliminary Iowa tests showed that there is a statistically significant difference in systematic error when light axles (below 10,000 pounds/4.5 metric tons) are compared with heavy axles (over 20,000 pounds/9 metric tons). Lightly loaded axles tended to be overweighed by roughly 1.5 percent, while heavily loaded axles tended to be underweighed by roughly 1 percent.

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*A copy of these results was furnished to TRAC by CMI-Dynamics. It is not clear whether the results have been published.

HELP Specifications

The HELP project is coordinating the development of design criteria and a test and acceptance plan for WIM scale systems. HELP is establishing these controls so that equipment operated by different states produces results that are valid and whose accuracy is within desired limits. The provisional HELP WIM scale specifications state that for low cost installations

- systematic standard errors in weight measurement shall not exceed the greater of 500 pounds or 5 percent for any weight range for single axles, and
- random standard errors in axle measurement shall not exceed 1200 pounds or 12 percent for any weight range.

For gross vehicle weight estimates, the HELP specifications require low cost WIM systems to provide weight estimates within 8 percent, or within 800 pounds, for any weight range.

PROCEDURES

As a result of the competitive bidding process, the French systems described above were selected for testing. (A copy of the bid specification is included in this report as Appendix A.) The equipment was provided by the LCPC through an agreement with the firm Map S.a.r.l. In addition to the SAFT and AP-16, the contract with Map included piezo electric cables mounted in a "bar" for placement in the road surface, assistance with installing the cables, and the material required for performing the installation (i.e., the resin).

Installation

The installation of the cables required roughly five hours at each site. This estimate includes curing time of the resin. A six-person crew was used for the installation, although with a small amount of practice a crew of three could probably perform an installation in roughly six hours. The lane that was instrumented had to be closed to traffic throughout the installation process.

To perform the installation, two channels were cut in the road surface. The channels were each 7 cm (2.75 in) wide, 5 cm (2.0 in) deep, and 3.7 m. (12 ft) long. The two cables were located 65 cm (25.6 in) apart. The "bar" containing the piezo-electric cable was then placed in each channel using a device provided with the cables. The device set the cable at the desired height below the road surface (roughly 1 cm). A resin mixture was then poured over and around the cable to secure the device to the pavement.

The resin required roughly one hour to set. The setting time is included in the five hour estimate mentioned above. The setting time of the resin varies according to the ambient air temperature. Temperatures in the upper 60s and lower 70s (F) existed during both the Oregon and Washington installations. Installation of the cables in cooler weather would require a longer resin set-up time.

The directions for the cable installation indicated a need for dry weather with temperatures above 60 degrees (F). While the French engineers indicated that installations could be performed in poorer weather conditions, the difficulty in properly installing the cable under adverse weather conditions should prohibit installation from being scheduled in periods of expected harsh weather. Because the properties of the resin change when it is contaminated by water, the pavement cut must be dry before the cable is installed. In inclement weather, a temporary shelter should be constructed to protect the cut from moisture until the resin set.

Calibration

After the resin had set, the SAFT was attached to the cables for calibration. An oscilloscope was then attached to the SAFT to monitor the shape and height of the cable signal. The cable was also tested before calibration began by striking the sensor with a hammer and observing the resulting signal on the oscilloscope.

Two trucks were used at each site to calibrate the equipment. The test trucks were run repeatedly over the cables (roughly 20 times each) at two speeds, 20 miles per hour and 40 miles per hour. The electronic gain provided by the SAFT was then tuned so that the voltages measured by the device resulted in an estimation approximating the axle weights of the test vehicles.

For both test sites, after the cables were calibrated, the traffic lanes containing the scales were opened to regular traffic. Traffic was weighed both by the piezo scale and at a static scale immediately downstream from the piezo-electric WIM site. Statistical comparisons were made between the weights obtained from the piezo cable system and the static scales to test the calibration.

These tests showed the initial calibration of the system for the Washington site was incorrect, and an adjustment was made to correct the calibration. The calibration adjustment was based on the differences between observed static gross vehicle weights and those gross vehicle weights estimated by the WIM equipment.

The cause of the observed differences in the initial calibration and the actual weight estimates was not completely clear (see "Test Results"). Some of the most likely causes were the following:

- all axles on the test vehicles were reasonably heavily loaded (between 5 and 9 tons), while the system was determined to have systematic biases between heavy and light axle weights,
- vehicles in normal operation were experiencing a greater amount of dynamic movement than the test vehicles, which operated under more constrained conditions, and
- the dynamic suspension conditions of the test vehicles may have differed from those of the truck population as a whole.

Testing

After final calibration, roughly 100 trucks were weighed at the Washington static and WIM sites. Originally the plan was to weigh between 150 and 200 vehicles, but a series of different computer failures and a limited project budget reduced the total number of vehicles that could be weighed. The project team believes the computer failures were primarily related to fluctuations in the power supply caused in part by the use of a gasoline powered generator and the need to convert American power (110 volt, 60 cycles) into European power (220 volts, 50 cycles). Because the system tested was leased for the project, it was equipped with European wiring. A purchased SAFT would be built with American power capabilities.

Comparisons of dynamic and static single axle, tandem axle and gross vehicle weights for the 100 trucks are described under "Test Results," below.

Because initial results showed that the cable was providing axle weight estimates with larger errors than were anticipated, a second set of tests were performed at both the Washington and Oregon sites. In these tests, a test vehicle was run over the cable with varying lateral lane positions and speeds. In addition, in Oregon the effects of two different tire pressures were examined.

In Washington a chart recorder was used to measure the signal output from the cable to determine if the cable was responding differently as a result of speed and lane position. Results of these tests showed definite effects due to lane position and possible effects due to speed. Because of limitations in the strip chart recorder, a more accurate digital oscilloscope was used during the Oregon tests.

In Oregon the sensitivity of the cable to tire pressure was examined by running a test vehicle with tire pressures of 70 and 105 psi over the cables. The test vehicle made runs at a constant speed of roughly 25 miles per hour, with one set of runs at 35 miles per hour. As in Washington, the test vehicle was also moved laterally both to the left and right portions of the lane so that it hit the cable but was on the extreme outer edges of the cable installation.

The AP-16 suffered a power system failure during its initial testing and was returned to France for warranty repairs. The AP-16 uses a process similar to that used by the SAFT and can be considered to have very similar accuracies and limitations.

TEST RESULTS

This section describes the results of the tests performed with the French piezo-electric cable WIM system. The section is divided into the following subsections:

- single and tandem axle weight estimates,
- gross vehicle weight estimates, and
- effects of tire pressure, lateral position and speed.

Single and Tandem Weight Estimates

The WIM system did not provide axle weight estimates within the accuracies desired by WSDOT. A tabular summary of the test results for single and tandem axle weight estimates is shown in

Exhibit 1. Exhibits 2 and 3 show system errors (defined as WIM weight minus static weight) compared against the static weight of single and tandem axles.

Two separate phenomenon are apparent in these exhibits. The first is that the WIM estimates include a systematic error. (In Exhibits 2 and 3, the data points would be centered around 0 tons of error if no systematic error were present.) The second is that the random error in the data is too large. This is demonstrated by the spread of the data about the centerline.

For tandem axles, the system showed significant underestimation for loads of more than 9 tons (20,000 pounds). For single axles, underestimation occurred after 7 tons (15,000 pounds). In an attempt to correct for this systematic error, a linear regression line was fitted to the data with the WIM estimate as the independent variable and the static weight as the dependent variable. The linear regression correction provided minor reductions in the systematic error of the system but provided only minimal improvements to the overall random error (as denoted by the standard deviation of the error) of the system. The results of the linear regression equation are presented in Exhibit 4.

Because front axle tires tend to be wider than tires for trailing axles, the study team was concerned that the wider tire width would create errors in weight estimates from piezo-electric systems. (The wider tire increases the contact area on the cable, decreasing the pressure per inch on the cable from a specified load.) The data collected showed that front axles were measured slightly differently than other axles for all trucks. However, this difference was not statistically significant. The observed difference appeared to be due more to the location of the front axles on the Error vs Static weight line (see Exhibit 5) than to the nature of the steering axle tire design.

Tests done using the strip recorder in Washington also showed some unusual effects of different tire widths and vehicle suspensions. In the strip chart recorder tests, the test vehicle was originally loaded with 16,100 pounds on the front axle and 36,000 pounds on the rear tandems (18,480 lbs on axle #2, 17,520 lbs on axle #3). The average output of the recorder under these conditions is shown as line A in Exhibit 6. After a series of runs at the initial weights, 10,460 pounds of sand were unloaded from the test truck. The new axle weights became 15,800 pounds on the steering axles, and 25,540 pounds on the

Exhibit 1
Summary of WIM Accuracy
Single Axle Estimates

	Mean Error (pounds)[1]	Std. Dev. of Error	Mean Percentage Error[2]	Std. Dev. of Percentage Error
All Single Axles	-980	2,430	-3.3%	26.1%
Steering (Front) Axles	-1,770	1,580	-17.2%	13.4%
Non-Steering Axles	-330	2,800	8.2%	28.4%

Tandem Axles and GVW Estimates

Tandem Axles	-590	4,900	4.9%	26.7%
Gross Vehicle Weights	-140	9,810	1.0%	19.5%

[1]computed as (drop) (WIM - static)/n

[2]computed as (drop) ((WIM - static)/static)/n

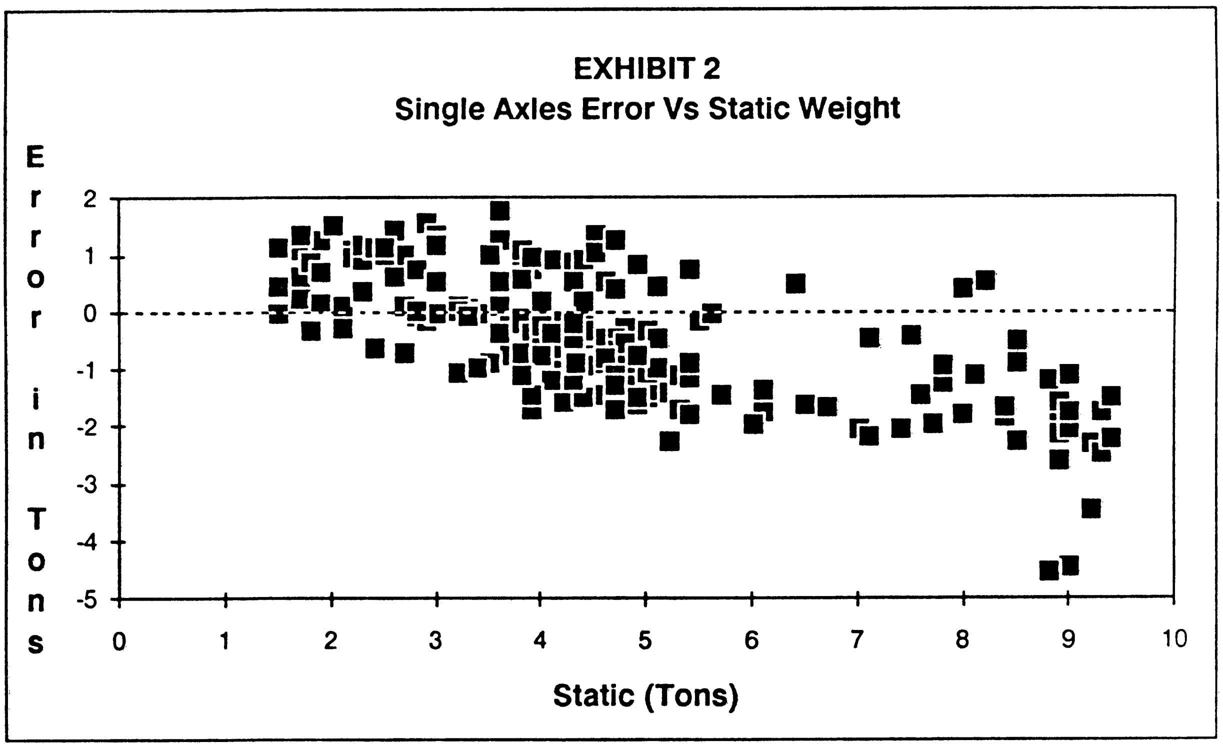


EXHIBIT 2
Single Axles Error Vs Static Weight
Error in Tons
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10
Static (Tons)

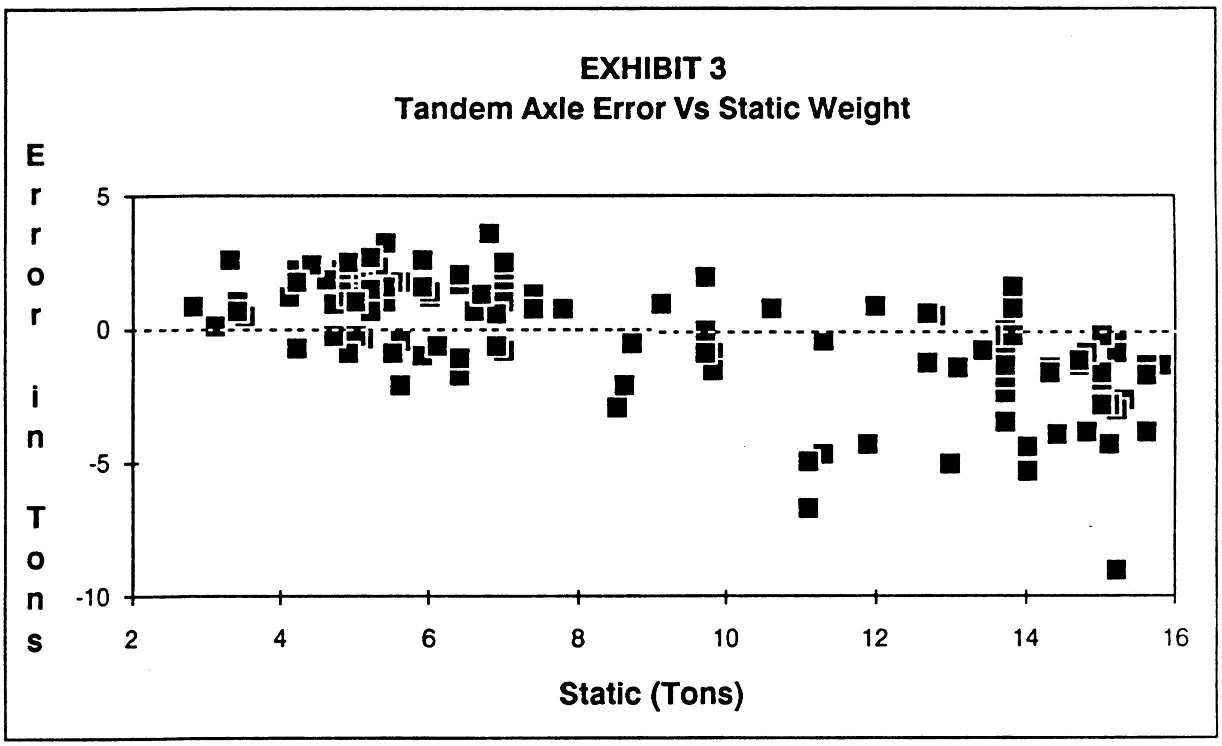


EXHIBIT 3
Tandem Axle Error Vs Static Weight
Error in Tons
5
0
-5
-10
2
4
6
8
10
12
14
16
Static (Tons)

Exhibit 4
Effects of Regression Analysis

	With Regression Correction	Without Regression Correction
Non-steering Single Axles		
Mean Error (pounds)[1]	50	-330
Mean Error (percentage)[2]	5.6%	+8.2%
Standard Deviation (pounds)	2,620	2,800
Standard Deviation (percentage)	25.7%	28.4%
Tandem Axles		
Mean Error (pounds)[1]	50	-590
Mean Error (percentage)[2]	6.6	4.9%
Standard Deviation (pounds)	4,820	4,900
Standard Deviation (percentage)	26.9%	26.7%

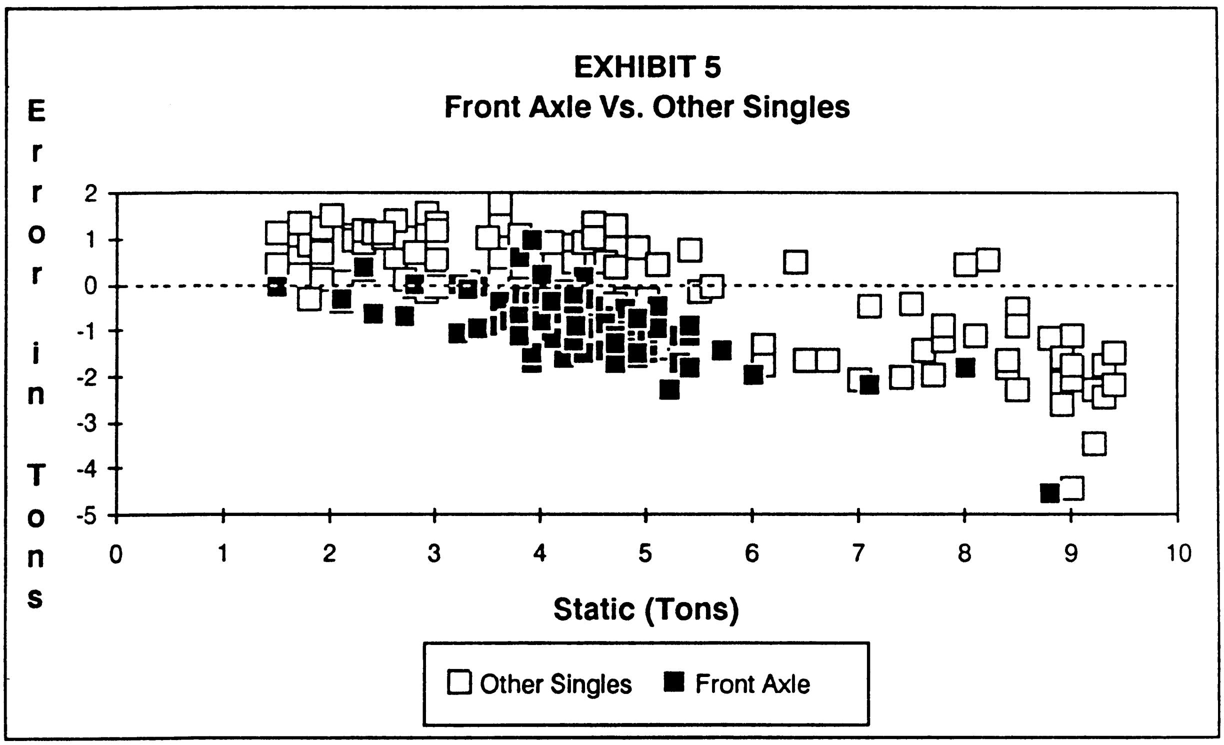
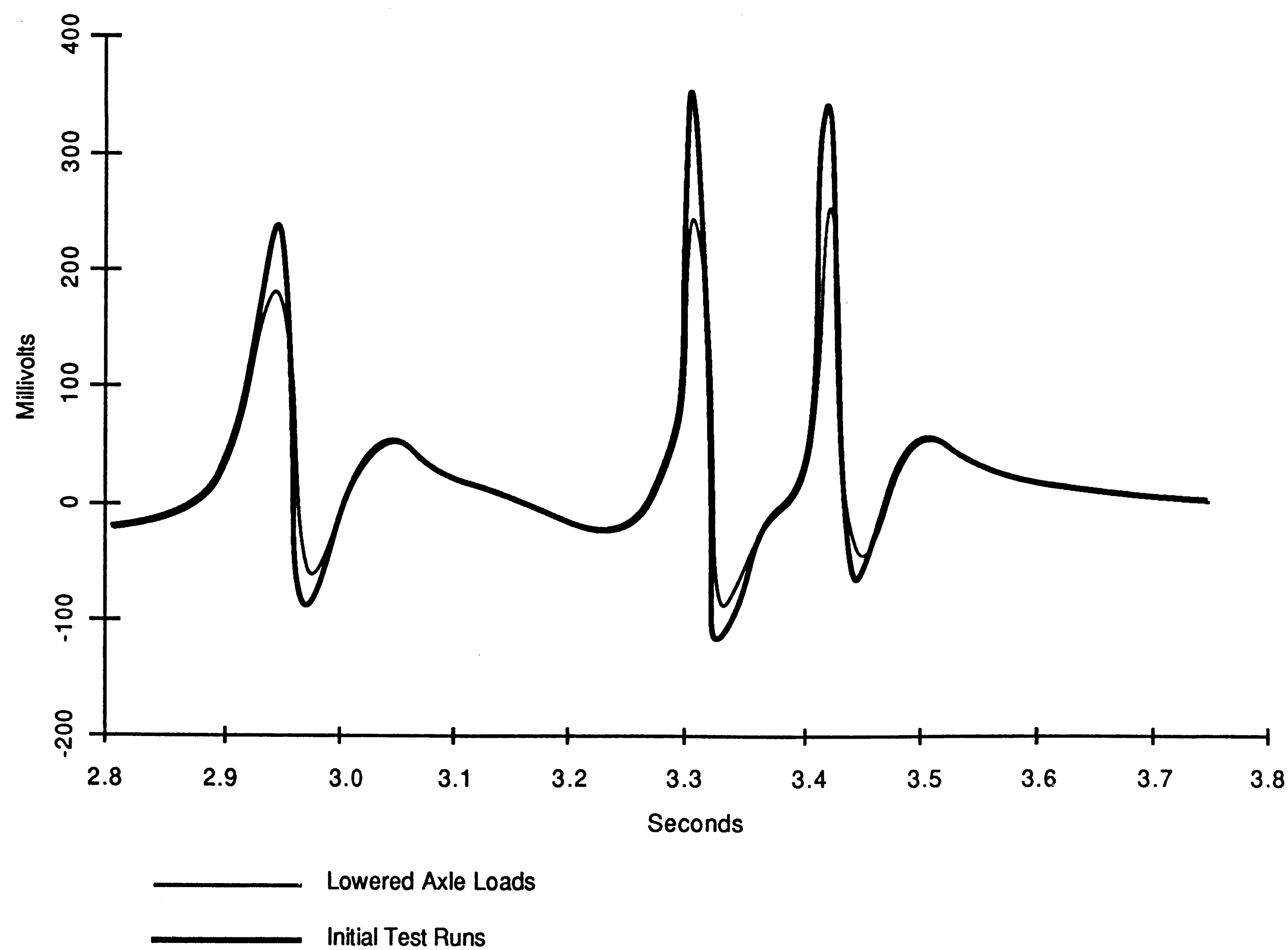


EXHIBIT 5
Front Axle Vs. Other Singles
Error in Tons
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
8
9
10
Static (Tons)
Other Singles
Front Axle

Exhibit 6

Effects of Tire Pressures on Cable Response



tandem (13,200 lbs on axle #2 and 12,340 lbs on axle #3). The resulting signal pattern is shown as Line B in Exhibit 6.

The surprising aspect of the differences in these two lines is that the individual axles of the tandem experienced continued higher signal peaks than the front axle, in spite of the fact that the individual rear axles had less weight than the steering axle and more tire area. (The front axle had two 11-inch tires, each rear axle had four 8-inch tires.) The author can not explain this phenomenon except that it is most likely caused by a combination of vehicle dynamics, flow of pavement due to axle loads, damping of the cable signal, and cable characteristics under dynamic impact loads. The importance of the above finding is that it shows the complexity of the interacting forces on the cable and some of the limitations of using a simple amplitude measurement for estimating axle weights.

Gross Vehicle Weight Estimates

For all vehicles weighed at both the static and WIM scales, the systematic error for the system was determined to be 1 percent, with a standard deviation of that error of 19.5 percent. The size of the systematic error varied depending on the mix of heavy and light vehicles in the traffic stream. This is discussed below.

The gross vehicle weight estimates were not good. Exhibit 7 is a plot of WIM versus static weights. Exhibit 8 is a plot of the error, defined as WIM weight minus static weight, against the static vehicle weight.

Apparent in Exhibit 8 is that the system tended to underestimate the weights of heavy vehicles and overestimate the weights of light vehicles. For 22 of 26 vehicles (85 percent) over 30 tons (66,000 pounds) GVW were underestimated, while for 37 of 53 vehicles (70 percent) under 20 tons (44,000 pounds) GVW values were overestimated.

The errors in estimating GVW were directly related to the errors in estimating single axle weights. Normally gross vehicle weight estimates are better than individual axle weights because the random errors of the individual axle estimates are averaged out during the calculation of GVW. However, systematic error for axle weights tends to be retained and sometimes even compounded for

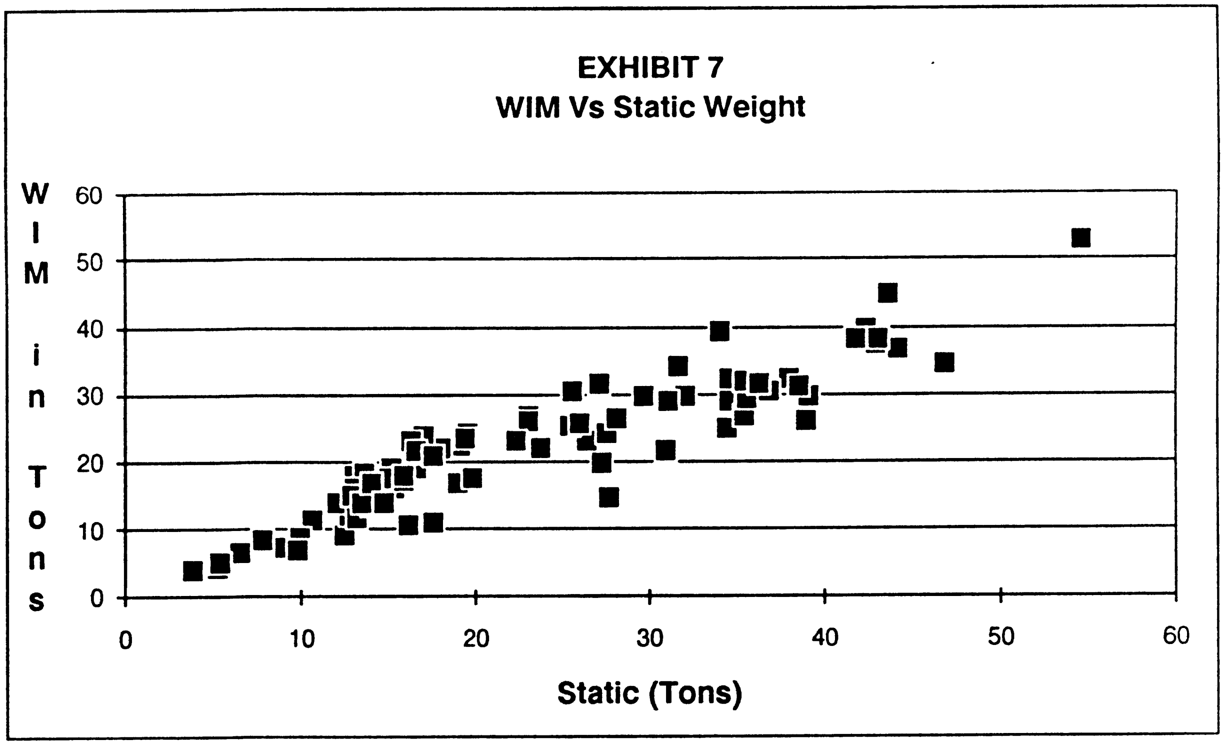


EXHIBIT 7
WIM Vs Static Weight
WIM in Tons
0
10
20
30
40
50
60
Static (Tons)

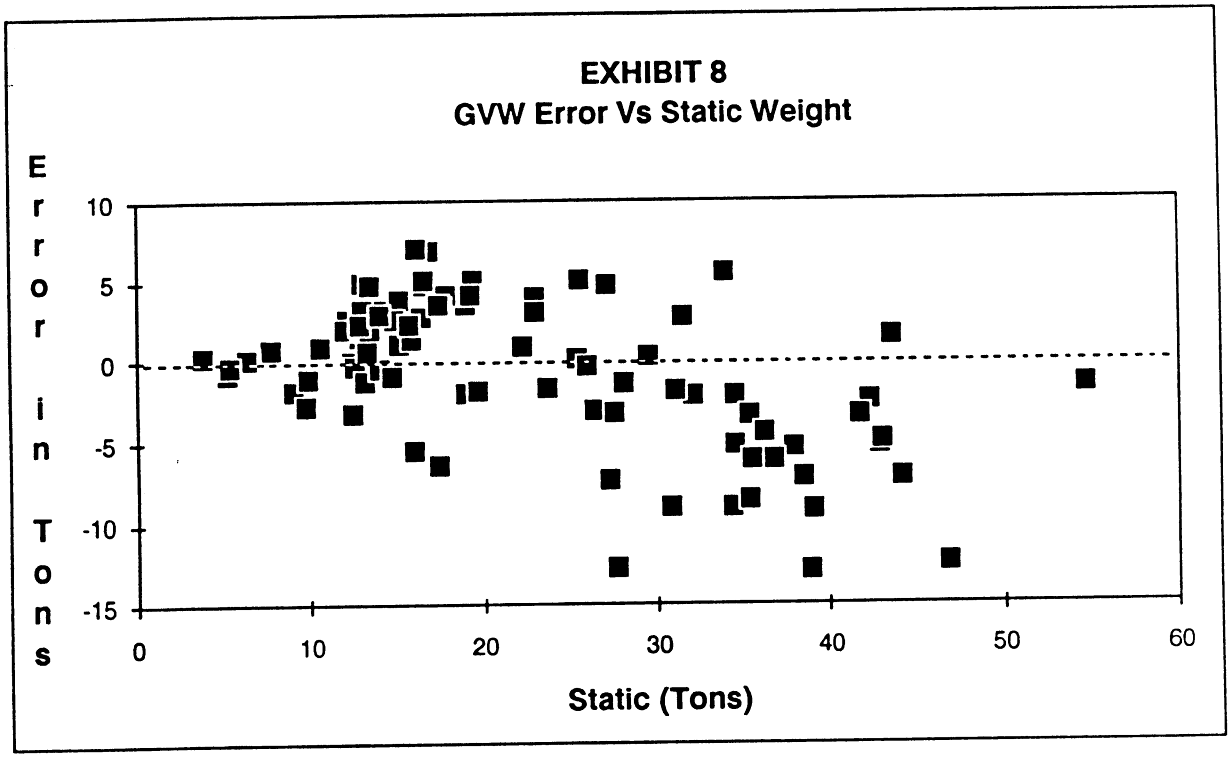


EXHIBIT 8
GVW Error Vs Static Weight
Error in Tons
10
5
0
-5
-10
-15
0
10
20
30
40
50
60
Static (Tons)

gross vehicle weights. Most vehicles have either a series of heavy axles or a series of light axles (they are loaded or unloaded). A vehicle with all heavy axles, which tend to be underweighed, is likely to have an underweighed gross vehicle weight. Conversely, vehicles with light or no loads tended to have all axles except steering axles overweighed. The result is an overestimated gross vehicle weight.

The system will produce systematic errors in vehicle weights whenever the traffic mix of heavy and light vehicles does not correspond to the traffic mix used to calibrate the system. Thus, if the traffic stream has more light vehicles than used in calibration, the system will produce a mean vehicle weight that is higher than the true mean. The opposite will be true if the vehicle mix contains more heavy vehicles.

Effects of Tire Pressure, Lateral Position and Speed

The tests done in Oregon indicated that tire pressure does have a statistically significant effect on voltage output of the piezo-electric cable and consequent weight estimates using the French system. (The French system measures the amplitude of the voltage spike caused by tires impacting the piezo-electric cable and converts this estimate directly into an estimate of axle weight.)

During the Oregon tire pressure tests, a three-axle, single unit truck loaded with 10,300 pounds on the front axle and 29,200 pounds on the rear tandem (14,750 pounds on the second axle, 14,450 pounds on the third axle) was driven over the cable at a constant speed. The tires on the vehicle were initially inflated to 105 psi. Fourteen passes of the cable were made at a speed of 25 miles per hour.

The pressures in both tires on the front axle were then reduced to 75 psi. Eight passes were then made with the vehicle crossing the cable in the left-hand portion of the lane, eight-passes were made in the right-hand portion of the lane, and twelve passes were made at an increased speed of 35 miles per hour.

Comparison of the voltage outputs from these runs produced the following results.

- Lowered tire pressure produced a lowered voltage spike from the piezo-electric cable.
- The lowered voltage spike was significantly different at a confidence level of 99.5 percent.

- The differences in voltage output were between 11.8 and 16 percent.
- In some, but not all cases, lateral position of the vehicle affected output voltage.
- Changes in speed had little or no effect on output voltage.

Each of these findings is described in more detail below.

Tire Pressure by itself reduced cable voltage output by between 11 and 16 percent. Three different methods were used to measure the voltage amplitude created by the test vehicles. In the first method, the maximum positive voltage ("A" in Exhibit 9) was used as the output voltage. For the second measure, the minimum leading voltage was added to the maximum positive voltage ("B" in Exhibit 9). In the third measure, the maximum trailing voltage was added to the maximum positive voltage ("C" in Exhibit 9).

In all three cases, the difference in the output voltage of the cable was statistically significant at the 99.5 percent confidence level.

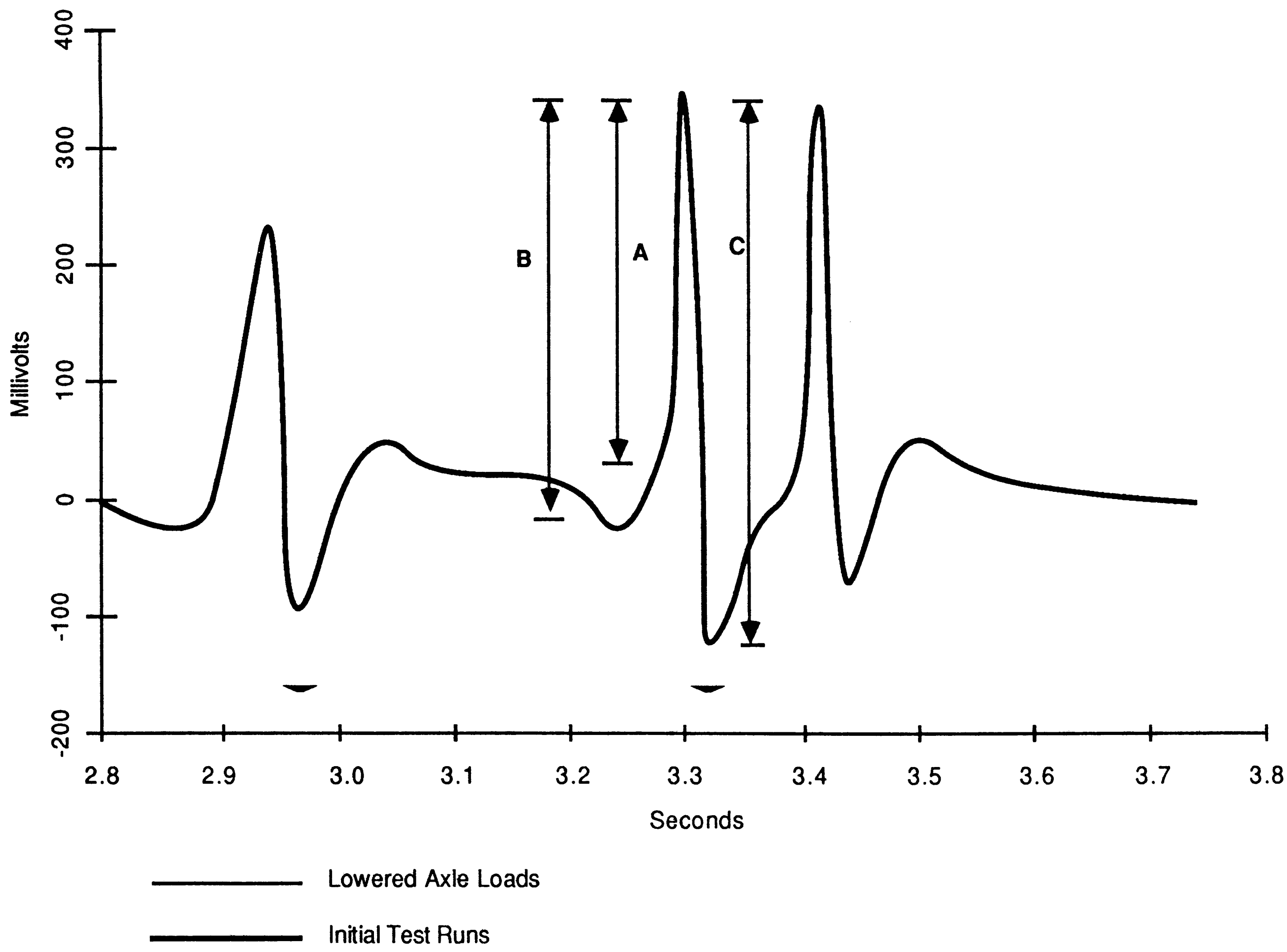
The effects of lateral position were mixed. Each of the two tests were performed using all three measurements of output voltage amplitude. Use of the third method indicated a significant difference with the vehicle moved to the right of the lane. Use of the first method indicated a significant difference with the vehicle moved to the left of the lane. The remaining four tests showed no statistically significant difference. Given the relatively low number of test runs, these results indicate that lane position does have an effect on the voltage output and thus on the weight estimate, but at a lower level than does tire pressure.

The variability due to lateral position probably contributed to the high standard deviation of the errors in the system's static weight estimates. Lateral position did not appear to effect systematic error unless a portion of the tire missed the cable entirely.

Speed has little effect on cable voltage output. The effects of speed on voltage output showed a statistical difference in only one of the three tests (Method 1). As with lane position, it was difficult to conclude with confidence that speed had a significant impact on the voltage output of the piezo-electric cable. However, a reasonable conclusion is that the cable's reaction to different speeds does add to the

Exhibit 9

Methods For Measuring Amplitude



variability of the results it produces. Furthermore, since speed affects the dynamics of vehicles (particularly lightly loaded vehicles) higher speeds may create a slightly higher degree of variation in the measured dynamic forces produced on the cable. These forces would still center on the mean static weight of the axle.

The above conclusions support the findings made by comparing weight estimates with speed results acquired using the WIM system. In that analysis, no statistically significant link was found between WIM/static weight errors and vehicle speed.

APPLICATION AND IMPLEMENTATION

The results from this series of tests show that the French system would need to be modified significantly to meet the WIM requirements of the WSDOT. Discussions with the French engineers that assisted in the installation and testing of the equipment, Mr. Bill McCall, who is directing Iowa DOT's piezo-cable research, and a variety of university personnel, led to a list of possible hardware modifications that might improve the performance of the French system and consequently its ability to meet WSDOT requirements. These include the following:

- using at least the second piezo-electric sensor, and possibly additional sensors, for weighing as a means of limiting the effects of dynamic vehicle motion;
- increasing the distance between the two sensors collecting weight information to more effectively reduce the effects of vehicle motion (dynamic oscillation);
- providing for better lane control, perhaps by using a sensor that indicates an on scale/off scale condition; and
- reducing the size and cost of the electronic components.

One major software change that was discussed was the use of an integration technique for analyzing the piezo-electric cable signal in place of the signal amplitude technique used currently. (The Iowa system uses integration.) The French engineers felt that the integration technique would result in improvements of roughly 5 percent in accuracy. Other researchers have suggested informally that an integration technique might result in more significant improvements. Changing to such a system would require major changes in the processing software, as well as the data collection hardware and speed of the microprocessor performing the calculations.

While exhaustive tests of the various system components could not be performed as part of this project, the project team believes that refinements of the piezo-electric cable technology can make the system operate within the desired limits. The French system tested would require modification before it achieved that accuracy.

APPENDIX A
BID SPECIFICATION

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

Purchasing Department, ND-10
Telephone: (206) 543-5810

May 7, 1986

86-002

University of Washington, Purchasing Department; 3917 University Way NE; Seattle, Washington 98105; Attn: Barbara Stephens, Buyer.

66---- The University of Washington is currently inviting bids for a Piezo-Electric Cable Truck Scale System.

This project is being funded by the Washington State Department of Transportation to demonstrate the accuracy and limitations of piezo-electric cable technology for vehicle classification and estimating axle and gross vehicle weights, while operating at highway speeds and conditions.

Bid opening is scheduled for June 17, 1986. Requests to be included on the bid list must be made in writing and should be directed to the University using Reference No. BS 86-2. Phone inquiries may be directed to Barbara Stephens, (206) 543-5827.

THIS IS NOT AN ORDER

INVITATION TO BID

APPLY ENCLOSED STICKER ON FACE OF ENVELOPE CONTAINING YOUR BID

Purchaser:
University of Washington — Purchasing Department
3917 University Way N.E., Seattle, Washington 98105
Purchasing Information (206) 543-5810

Bid to be opened: June 17, 1986 (DATE)

Requisition No.: BS 86-2

Buyer's name: Barbara Stephens

INVITATION

Sealed invitations to bid for furnishing the supplies, equipment or services described below will be received by the University of Washington's Purchasing Department. TO RECEIVE CONSIDERATION FOR AWARD, THE BID WILL BE SUBMITTED ON THIS FORM IN ORIGINAL AND ONE (1) COPY, SIGNED IN FULL IN INK, AND RECEIVED IN UNIVERSITY'S PURCHASING DEPARTMENT TO HAVE A DATE/TIME STAMP AFFIXED, ON OR BEFORE THE DATE AND TIME SHOWN FOR THE BID OPENING. Prices will be based on units specified. Bidders will enter the delivery date or time for each item contained herein. The University reserves the right to accept or reject bids on each item separately or as a whole, to reject any or all bids, to waive informalities or irregularities and to contract as best interest of the University may require. BIDS ARE SUBJECT TO THE GENERAL TERMS AND CONDITIONS AS PRINTED ON THE REVERSE SIDE HEREOF AND AS SET FORTH HEREIN.

DATE	DELIVERY IS REQUIRED NO LATER THAN	DEPARTMENT REQUISITION NO.	BIDS OPEN AT 2:00 P.M.	BIDDER MUST ENTER DELIVERY DATE FOR EACH ITEM BID
4 29 86 lw		BS 86-2	June 17, 1986	

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	EXTENDED PRICE	DELIVERY DATE
	NOTICE: Bidders are to pay particular attention to the attached "Special Requirements for Minority and Women's Business Enterprise (MWBE) Participation": revised 1/85. The goals for this solicitation are:					
	MBE 15% <u>or</u> WBE 15%					
	First priority for award will be given to the bidder who proposes to meet or exceed these MWBE goals and whose bid is within 5% or $5,000, whichever is less, of the otherwise lowest responsive bid. (See Award Procedure section on the "Special Requirements" attachment for further information about making awards.) The attached Vendor's MWBE Response Form must be signed and submitted with the bid.					
	Invitation to Bid for a Piezo-Electric Cable Truck Scale System per the attached specifications, instructions and terms and conditions.					
	ATTACHMENTS					
				TOTAL:		

OFFER

To the Purchasing Department, University of Washington:

In compliance with the above, the undersigned offers and agrees, if this offer is accepted within ______ calendar days (30 calendar days unless a different period is inserted by the purchaser) from the bid open date, specified above, to furnish any or all items upon which prices are offered, at the price set opposite each item, delivered at the designated point(s), within the time specified.

Bidder guarantees shipment from ____________

Via ____________ (CARRIER) within ____________ days

FOB ____________ after receipt of order at address shown.

TERMS ____________

Bidder name ____________

By ____________ (MUST BE SIGNED IN FULL IN INK)

Street address ____________

City and state ____________ ZIP ____________

Date ____________ 19 ______ Phone ____________ (area code)

'8

GENERAL TERMS AND CONDITIONS

1. **CHANGES:** No alteration in any of the terms, conditions, delivery, price, quality, quantities, or specifications of this order will be effective without written consent of Purchaser's Purchasing Department.

2. **PACKING:** No charges will be allowed for special handling, packing, wrapping, bags, containers, reels, etc., unless otherwise specified herein.

3. **DELIVERY:** For any exception to the delivery date as specified on this order, Vendor shall give prior notification and obtain approval thereto from Purchaser's Purchasing Department. With respect to delivery under this order, time is of the essence and the order is subject to termination for failure to deliver on time.

The acceptance by Purchaser of late performance with or without objection or reservation shall not waive the right to claim damage for such breach nor constitute a waiver of the requirements for the timely performance of any obligation remaining to be performed by Vendor.

4. **PAYMENTS AND ASSIGNMENTS:** All payments to Vendor shall be remitted by mail. Purchaser shall not honor drafts, nor accept goods on a sight draft basis. Furthermore, the provision of monies due under this contract shall only be assignable with prior written consent of Purchaser.

5. **SHIPPING INSTRUCTIONS:** Unless otherwise specified, all goods are to be shipped prepaid, FOB Destination. Where specific authorization is granted to ship goods FOB Shipping Point, Vendor agrees to prepay all shipping charges, to route cheapest common carrier, and to bill Purchaser as a separate item on the invoice for said charges, less federal transportation tax. Each invoice for shipping charges shall contain the original or a copy of the bill indicating that the payment for shipping has been made. It is also agreed that Purchaser reserves the right to refuse COD Shipments.

6. **REJECTION:** All goods or materials purchased herein are subject to approval by Purchaser. Any rejection of goods or material resulting because of nonconformity to the terms, conditions, and specifications of this order, whether held by Purchaser or returned, will be at Vendor's risk and expense.

7. **IDENTIFICATION:** All invoices, packing lists, packages, shipping notices, instruction manuals, and other written documents affecting this order shall contain the applicable order number. Packing lists shall be enclosed in each and every box or package shipped pursuant to this order, indicating the content therein. Invoices will not be processed for payment until all items invoiced are received.

8. **INFRINGEMENTS:** Vendor agrees to protect and save harmless Purchaser against all claims for patent, trademark, copyright, or franchising infringement arising from the purchase, installation, or use of material ordered on this order, and to assume all expense and damage arising from such claims.

9. **NONWAIVER BY ACCEPTANCE OF VARIATION:** No provision of this order, or the right to receive seasonable performance of any act called for by the terms, shall be deemed waived by a waiver by Purchaser of a breach thereof as to any particular transaction or occurrence.

10. **WARRANTIES:** Vendor warrants articles supplied under this order conform to specifications herein and are fit for the purpose for which such goods are ordinarily employed; except if stated in a Special Condition, the material must then fit that particular purpose.

11. **CASH DISCOUNT:** In the event that Purchaser is entitled to a cash discount, the period of computations will commence on the date of delivery, or receipt of a correctly completed invoice, whichever is later. If an adjustment in payment is necessary due to damage, the cash discount period shall commence on the date final approval for payment is authorized. If a discount is made part of the contract, but the invoice does not reflect the existence of a cash discount, Purchaser is entitled to a cash discount with the period commencing on the date it is determined by Purchaser that a cash discount applies.

12. **TAXES:** Unless otherwise indicated, Purchaser agrees to pay all State of Washington sales or use tax. No charge by Vendor shall be made for federal excise taxes and Purchaser agrees to furnish Vendor, upon acceptance of articles supplied under this order, with an exemption certificate.

13. **LIENS, CLAIMS, AND ENCUMBRANCES:** Vendor warrants and represents that all the goods and materials delivered herein are free and clear of all liens, claims, or encumbrances of any kind.

14. **RISK OF LOSS:** Regardless of FOB Point, Vendor agrees to bear all risks of loss, injury, or destruction of goods and materials ordered herein which occur prior to delivery, and such loss, injury, or destruction shall not release Vendor from any obligation hereunder.

15. **SAVE HARMLESS:** Vendor shall protect, indemnify, and save Purchaser harmless from and against any damage, cost, or liability for any or all injuries to persons or property arising from acts or omissions of Vendor, his employees, agents, or subcontractors, howsoever caused.

16. **PRICES:** If price is not stated on this order, it is agreed that the goods shall be billed at the price last quoted or paid, or the prevailing market price, whichever is lower.

17. **TERMINATION:** In the event of a breach by Vendor of any of the provisions of this contract, Purchaser reserves the right to cancel and terminate this contract forthwith upon giving oral or written notice to Vendor. Vendor shall be liable for damages suffered by Purchaser resulting from Vendor's breach of contract.

18. **QUALITY STANDARDS:** Special brands, when named, include the standard of quality, performance, or use desired. Bids on Vendor's equal may be considered provided Vendor specifies brands, model, and necessary descriptive literature. In the event Purchaser elects to contract for a brand purported to be an equal by the bidder, the acceptance of the item will be conditioned on Purchaser's inspection and testing after receipt. If, in the sole judgment of Purchaser, the item is determined not to be an equal, the material shall be returned at Vendor's expense and the contract terminated.

19. **OFF-SHORE ITEMS:** In accordance with RCW 39.25 *et seq.* upon completion of this order, Vendor shall furnish a certified statement setting forth the nature and source of off-shore items in excess of $2,500 which have been utilized in the performance of this contract.

20. **ACCEPTANCE:** This order expressly limits acceptance to the Terms and Conditions stated herein. All additional or different terms proposed by Vendor are objected to and are hereby rejected, unless otherwise provided in writing by Purchaser's Purchasing Department.

21. **NONDISCRIMINATION:** Unless exempt by Presidential Executive Order 11246 and applicable regulations thereunder, Vendor (1) certifies that it does not and will not, maintain segregated facilities, nor permit its employees to work at locations where facilities are segregated on the basis of race, color, religion, national origin, age, or sex; (2) agrees that for all orders in excess of $10,000, an Equal Opportunity Clause contained in the University of Washington Board of Regents Equal Opportunity Compliance Certification, as may be amended from time to time, is hereby incorporated by reference; and (3) for all orders in excess of $50,000, agrees to furnish the University of Washington with a written Affirmative Action Compliance Program within 120 days.

22. **OSHA / WISHA:** Vendor agrees to comply with the conditions of the Federal Occupational Safety and Health Act of 1970 (OSHA), the Washington Industrial Safety and Health Act of 1973 (WISHA), and the standards and regulations issued thereunder and certifies that all items furnished and purchased under this order will conform to and comply with said standards and regulations. Vendor further agrees to indemnify and hold harmless Purchaser from all damages assessed against Purchaser as a result of Vendor's failure to comply with the Acts and the standards issued thereunder and for the failure of the items furnished under this order to so comply.

23. **LAW:** The laws of the State of Washington shall govern this order and the venue of any action brought hereunder shall be in the Superior Court, County of King, State of Washington.

24. **AFFIRMATIVE ACTION FOR HANDICAPPED:** Vendor certifies that he will comply with Section 503 of the Vocational Rehab Act of 1973.

25. **AFFIRMATIVE ACTION FOR VETERANS:** Vendor certifies that he will comply with Section 2012 and 2014 of the Vietnam era Veterans' Readjustment Act of 1974.

26. **ANTITRUST ASSIGNMENT CLAUSE:** Vendor and Purchaser recognize that in actual economic practice, overcharges resulting from antitrust violations are in fact usually borne by the Purchaser. Therefore, Vendor hereby assigns to Purchaser any and all claims for such overcharges as to goods and materials purchased in connection with this order or contract, except as to overcharges which result from antitrust violations commencing after the price is established under this order or contract and which are not passed on to the Purchaser under an escalation clause.

27. **PRICE WARRANTY FOR COMMERCIAL ITEMS:** Vendor warrants that prices charged to Purchaser are based on Vendor's current catalog or market prices of commercial items sold in substantial quantities to the general public and prices charged do not exceed those charged by Vendor to other customers purchasing the same item in like or comparable quantities.

SECTION I INFORMATION AND INSTRUCTIONS TO BIDDERS

1.1 Scope of Contract

The University of Washington herewith solicits bids to furnish, install, calibrate and operate Piezo-Electric Cable Truck Scales, as specified herein. The truck scales are to be located at two sites.

1.2 Discription of Use

The scales will be used in research activities conducted by the University of Washington (UW). The UW, acting under contract for the Washington State Department of Transportation (WSDOT), plans to purchase a truck scale system utilizing piezo-electric cable technology. The selected truck scale system must be capable of collecting and processing sufficient information to correctly classify and weigh in real time vehicles currently operating on state highways in the states of Washington and Oregon, while those vehicles travel at highway speeds. The primary objectives of this project are the following:

1. To acquire for current and later use by the UW and WSDOT, at least one and the, and possibly two, piezo-electric cable weigh-in-motion truck scales.

2. To demonstrate the accuracy and limitations of existing piezo-electric cable systems while operating in conditions common to the Pacific Northwest states. This demonstration includes classifying vehicles, and estimating axle and gross vehicle weights.

3. To determine whether existing piezo-electric cable technology can be used to estimate truck tire pressures, while trucks operate at highway speeds.

1.3 Background

The WSDOT, like the rest of the nation's highway departments, lacks accurate, unbiased truck weight information for vehicles using the state's highways. As a result, many WSDOT analyses, including pavement design and pavement rehabilitation, are not as accurate as they should be. This is particularly important given the $460,000,000 annually spent by WSDOT on the construction, repair and maintenance of the state highway system.

A major reason for this lack of unbiased weight information is the high cost of collecting vehicle weight data. Truck weighing devices currently used or available to Washington and most other states usually suffer from one or more of the following difficulties:"

high initial capital cost,
high manpower levels needed for operation,
extensive, expensive site preparation,
high visibility to passing motorists,
inability to operate in all lanes of traffic, or
inaccuracies generated from high traffic volumes

As a result, WSDOT and the UW are interested in exploring the capabilities of new technology for inconspecuously collecting truck weight information. Previous research, performed primarily in Europe, has indicated that piezo-electric cable technology can be used to acceptably estimate vehicle weights. This technology requires the placement of one or two piezo-electric cables in the roadway surface, and the attachment to those cables of electronic equipment for interpreting output from those cables. Several companies and foreign governments laboratories have demonstrated in controlled tests the ability of this type of equipment to perform the tasks required in the project. Nowhere in the U.S.A. has a demonstration of this technology been attempted prior to this time by a state transportation agency.

The states of Iowa and Minnesota are currently attempting to <u>develop</u> a piezo-electric system that will sell for under $5,000 per location. WSDOT and the UW are interested in demonstrating <u>available</u> equipment, as opposed the attempting to develop or refine a <u>prototype</u> system capable of meeting a specific cost range. The French Laboratoire Regional des Ponts et Chausees at Trappes has such equipment available.

1.4 Submission of Bids

Two copies of the Bid must be submitted to:

University of Washington
Purchasing Department ND-10
3917 University Way N.E.
Seattle, WA 98195 USA

Attn: Barbara Stephens

on or before 2:00 p.m. June 17, 1986. Any Bid received after that date and time will not be considered.

1.5 Timetable

The timetable pertinent to this Bid is given below:

Event	Date
a. Closing date for inquiries	June 10, 1986
b. Open bids	June 17, 1986
c. Announce apparent successful Vendor	July 15, 1986
d. System delivered and ready for installation	August 15 - Sept. 15, 1986

1.6 Bid Documents

All bids must include the following documents. The documents are found in Section IV. BIDDERS FAILING TO COMPLY WITH REQUIREMENT WILL BE CONSIDERED NON-RESPONSIVE AND WILL NOT BE ELIGIBLE FOR AWARD.

Bid document #1 -- Statement of Warranty
Bid document #2 -- Response to Technical Specifications
Bid document #3 -- Financial Information
Bid document #4 -- Test Result Submittals

1.7 Bidders Obligations

By signing and submitting a bid as a response to this Invitation to Bid, the bidder acknowledges that they have read and understand the entire Invitation to Bid and that they have not found any omissions or sections needing further information or clarification.

1.8 Interpretations

All inquiries concerning this Invitation to Bid shall be addressed in writing to:

Barbara Stephens
University of Washington
Purchasing Department ND-10
3917 University Way N.E.
Seattle, Washington 98105 U.S.A.
(206)543-5827

1.9 Optional Configurations

Bids that do not meet the Manditory requirements set for in Section II, will not be considered. Purchaser encourages vendors to respond with optional configurations that meet as many of the desirable features as possible.

1.10 Prior to commencement of work/service/operations, vendor shall provide the University of Washington a certificate of insurance pursuant to Section IV, Appendix, Attachment A.

SECTION II TECHNICAL SPECIFICATIONS

The following manditory specifications must be met in order for a bid to be considered.

2.1 Equipment

2.1.1. Piezo-electric cable for instrumenting eight full lanes of traffic. Four lanes of traffic will be on outside roadways (i.e., next to a shoulder). Four lanes of traffic will be on inside roadways (i.e,, in the middle of three lanes of traffic, or on the inside of two lanes of traffic [in one direction] where no median exists).

2.1.2. Vendor awarded this contract must supply all electronic processing equipment (computers, signal processors, etc.) necessary for processing piezo-electric cable signals for two adjacent lanes simultaneously. This equipment requirement can be met by either one or more piece of equipment (i.e., one or two truck scales). At least one complete set of equipment, capable of weighing vehicles in one lane of traffic, will become the property of the UW/WSDOT. Additional pieces of equipment may be leased to the UW/WSDOT for the duration of this contract.

Note: More than one type of equipment can be included to meet the above specification. For example, a manufacturer may supply one type of scale system for data collection in one lane, and a second type of data collection equipment for the second lane (e.g., a less sophisticated, less expensive model).

2.1.3. Software for performing the processing required must be included. This includes a hard copy of the source code for the processing routines, as well as executable modules.

2.1.4. The electronics processing equipment must be constructed in such a way that it can be moved from site to site. (Cables will stay imbedded in the pavement at each site.) A van will be provided by WSDOT for housing the equipment during the demonstration.

2.2 Services

In addition to the above equipment the successful bidder awarded this contract must provide the services listed below.

2.2.1. The bidder must provide on-site assistance for installing, calibrating and operating the equipment.

Bid Document #2

RESPONSE TO TECHNICAL SPECIFICATIONS

The vendor shall respond in the space provided below to each paragraph number and shall indicate whether the system bid complies fully with the specification or does not comply. For a system that complies fully, the vendor shall list the paragraph and state "complies fully". As apropriate, the vendor is asked to discuss vendor's capacity to exceed the specification.

For a system that does not comply fully with the specification, vendor shall list by paragraph number "complies partially" or "does not comply". Vendors should discuss fully the reason for non-compliance and why vendor believes system bid would still meet the purchaser's overall requirments.

Bid Document #3

FINANCIAL INFORMATION

The requested system will be purchased by the University of Washington. The vendor must specify the cost of the proposed system including any calibration, installation, shipping and insurance charges. If the proposed system is comprised of subassemblies that are normally price separetely by the vendor, list the prices of each sub-assembly, and total the individual prices to provide a total system price. Alternatively, the vendor may quote a package price. All applicable costs for which the purchaser will be charged must be clearly listed. Since vendors may opt to offer some equipment as a rental, rather than a purchase (see the technical specifications), vendors must clearly indicate if any of the prices are for rental or lease of equipment.

Equipment Offered	Purchase or Lease?	Price

State hourly rates for on-site assistance in excess of 40 hours per site.____________________

State hourly rates for technical assistance via telephone for assistance in excess of 40 hours.______________________

Bid Document #4

TEST RESULT SUBMITTALS

Vendors are requested to submit test results evidencing prior, successful testing of the equipment bid, including evidence of the accuracy and the reliability of that equipment.

Submit with bid

VENDOR'S MWBE RESPONSE FORM

This solicitation includes goals for MWBE participation. If the Vendor has been certified by the Office of Minority and Women's Business Enterprises (OMWBE), please complete Part 1 below. If the Vendor is proposing to subcontract or joint venture with certified MBEs or WBEs, please respond to Part 2. If the Vendor proposes no MWBE participation in its bid, please so indicate in Part 3.

1. MWBE IDENTIFICATION:

Vendor is certified by the OMWBE. ____Yes ____No

a. Vendor is a certified MBE. _____
b. Vendor is a certified WBE. _____
c. Vendor is certified as a minority female ("Both"). _____
d. Vendor is certified as a "Combination", owned 50% by a minority male and 50% by a non-minority female. _____

2. MWBE PARTICIPATION: The goals for MWBE participation in this contract are established in the attached solicitation. Vendor proposes to include the following certified MBEs or WBEs in the contract if awarded:

Certified MBE Participation:

Name(s) of Participation MBEs: ______________________________
Description of Participation: ______________________________
Amount of Participation: $______________

Certified WBE Participation

Names(s) of Participating WBEs: ______________________________
Description of Participation: ______________________________
Amount of Participation: $______________

3. NO MWBE PARTICIPATION PROPOSED:

No certified MWBE participation is proposed by this vendor. _____

____
Signed: Vendor or authorized representative

The OMWBE's directory of certified MWBEs may be purchased from that office or from the U.W. Purchasing Department located at 3917 University Way N.E., Seattle, Washington, 98105. A reference copy is available at the Purchasing Department reception desk.

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SPECIAL REQUIREMENTS FOR MINORITY AND
WOMEN'S BUSINESS ENTERPRISE (MWBE) PARTICIPATION

GENERAL REQUIREMENTS

In accordance with state law established by the Washington State Legislature, it is the policy of the State "to provide the maximum practicable opportunity for increased participation by minority and women-owned businesses in participating in public works and the process by which goods and services are procured by state agencies and educational institutions from the private sector." This solicitation is subject to the legislation.

Chapter 120, Laws of 1983, established the Office of Minority and Women's Business Enterprises (OMWBE) located in Olympia, Washington. A primary function of the OMWBE is to certify minority-owned business enterprises (MBEs) and women-owned business enterprises (WBEs). Only those MWBEs certified by OMWBE will be elgible for participation in this program. Information about certification or certified businesses may be obtained from the OMWBE at 406 South Water, Mail Stop FK-11, Olympia, Washington 98504; Telephone (206) 753-9693.

DIRECTORY OF CERTIFIED FIRMS

The OMWBE has published a directory identifying certified firms. A copy of the OMWBE directory may be purchased from the OMWBE. A reference copy of the directory is available for review at the OMWBE and at the University's Visitor's Information Center.

MWBE PARTICIPATION REQUIREMENTS

MWBE participation requirements for this contract are incorporated in the accompanying solicitation documents. Either certified MBEs or WBEs may participate unless the solicitation specifically restricts participation to one category. Certified minority and women-owned businesses are encouraged to bid directly, to subcontract, or to enter into a joint venture with other firms. Bidders who are not certified as MWBEs must subcontract or joint venture with certified firms to meet the MWBE requirements. Joint ventures must be approved in advance by the University. Requests for joint venture approval must be made by the bidder in accordance with the WAC 326-40-100, and be submitted to the University's designated buyer at least five business days before the bid opening.

VENDOR'S MWBE RESPONSE FORM

All bidders must sign and submit the enclosed Vendor's MWBE Response Form. Bidders proposing to meet the MWBE requirements through subcontracting or joint venturing must identify on this form the certifed MBE or WBE who will participate in their contract, include a brief description of the work to be performed by the MBE or WBE, and specify the dollar amount associated with the participation. Upon award, the designated MWBE participation amount will be considered an enforceable part of the contract terms.

COUNTING MWBE PARTICIPATION

Where a firm owned by a minority woman participates as a vendor or subcontractor/joint venturer on a solicitation, the bidder must advise the Purchaser that the participating firm is certified as both an MBE and a WBE. Participation by this type of firm may be counted toward either the MBE or WBE goals. (See WAC 326-30-100).

The OMWBE may also certify a business that is 50% owned by a non-minority female and 50% owned by a minority male as a "combination" MWBE. Participation by a combination MWBE will be counted toward the contract's MWBE goals by applying half the participation toward the MBE goal and half toward the WBE. If the contract designates only an MBE goal or WBE goal, then only one half of the dollar value of the combination MWBE's participation will be counted toward the goal. (See WAC 326-30-100).

AWARD PROCEDURES

Where a contract for the purchase of goods, services, or equipment is to be awarded as a result of a competitive process and includes requirements for MWBE participation, the following process will be utilized to evaluate the vendor responses:

1) All vendors meeting the goals established in the solicitation will be evaluated and the lowest cost vendor meeting all solicitation requirements will receive the award if the bid is within 5% or $5,000, (whichever is less), of the lowest otherwise responsive bid. The "lowest otherwise responsive bid" is the lowest bid responsive to all specifications other than MWBE requirements. (See WAC 326-40-010).

2) If no vendor meets the established MWBE goals, the award will be made to the lowest cost vendor whose bid includes MWBE participation meeting or exceeding the average MWBE participation of all competitive bidders, so long as that vendor's bid is within 5% or $5,000 of the otherwise responsive bid. A "competitive bid" is defined to include all otherwise responsive bids that are within 25% of the lowest otherwise responsive bidder. If no bidder meets or exceeds the average MWBE participation proposed by the other bidders and is within 5% or $5000, whichever is less, of the lowest bid as described above, an award will be made to the lowest otherwise responsive bidder. (See WAC 326-40-020).

SUBCONTRACTOR REPORTS

Prior to final payment by the University under the contract, or periodically if requested, the vendor must send the notarized MWBE Subcontractor Report, along with the vendor's invoice, to the University's Accounts Payable Office. The University will furnish the vendor with the MWBE Subcontractor Report form upon contract award. The vendor must complete a Subcontractor Report form for each participating MWBE, and identify the amount paid to each under the contract. Both the vendor and subcontractor's signatures must be notarized.

TERM CONTRACT REPORTS

On term contracts, the vendor will be required to submit a quarterly activity report to the University's MWBE Officer, indicating the total sales volume of orders placed under the contract. This report must be accompanied by a certification statement from the participating MWBEs describing their participation and the dollar amount received. The quarterly report must be submitted no later than the twentieth day of the month following the end of the quarterly period. Quantity figures in term contracts are estimates only, and the vendor will be required to achieve the established MWBE goals on the actual volume purchased by the University. If the vendor fails to meet the quarterly MWBE goals, or to submit the required reports, the University will withhold payment until the requirements are met. These requirements will also apply to options to extend when the requirements are included in the option terms.

SUBSTITUTION OF SUBCONTRACTORS

If the proposed MBE or WBE is de-certified or is unable or unwilling to perform after submission of the bid, the bidder will comply with the substitution alternative set out in WAC 326-30-080. The successful vendor may find a certified replacement subcontractor at no additional cost to the Purchaser. If substitution cannot be made by the vendor, then the Purchaser reserves the right to terminate the contract at no additional cost to the purchaser by giving 60 days written notice.

SANCTIONS AND PENALTIES

If the Vendor provides fraudulent information about an MWBE participating in the contract, the contract may be immediately terminated without additional cost to the Purchaser. If the vendor fails to make payments to the MWBE or fails to achieve the stipulated MWBE participation requirements on the contract, the University may terminate the contract, require the vendor to pay the MWBE in accordance with the contract, or pursue appropriate legal remedies. Willful, repeated violations may disqualify the vendor from further participation in state contracts for a period of one year.

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University of Washington
Attachment to
Invitation to Bid

IN-STATE PREFERENCE -- RECIPROCITY

This Invitation to Bid is subject to RCW 43.19.702 which requires exercising a penalty against those firms who bid from states which grant a preference to their in-state business firms. Firms bidding from addresses in the following states will, for bid evaluation purposes, be penalized the percentage indicated:

ALASKA	5%	LOUISIANA	5%	OHIO	5%
ARKANSAS	5%	MASSACHUSETTS	2%	OKLAHOMA	5%
CALIFORNIA	5%	MONTANA	3%	SOUTH CAROLINA	2%
HAWAII	3%	NEW MEXICO	5%	WEST VIRGINIA	2%

In determining the lowest responsive bidder, the buyer will add an amount equal to the above percentage to each bid submitted by a firm bidding from an address listed in any of the above-listed states.

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2.2.2. The bidder will provide a maximum of one week's on-site assistance at each location. In the event on-site assistance in excess of one 40 hour week is required, bidders are to indicate hourly rates in section IV, Bid Document #3.

2.3.3. WSDOT and the Oregon Department of Transportation (ODOT) will provide highway crews and equipment for cutting pavement and assisting in the installation of the cables under the supervision of the bidder. The bidder must supply all necessary material for installing cables for eight traffic lanes, although they will be responsible only for the installation of cable at two sites. Both installations will be made in asphalt road surfaces.

2.2.4. WSDOT and ODOT will provide vehicles of known weight for calibrating the equipment.

2.2.5. One site will be near Olympia, Washington. The second site will be near Salem, Oregon.

2.2.6. In addition to the two weeks on-site, the bidder will provide without additional charges periodic technical advice and assistance via telephone for one year. Assistance will be required for a miniumum 40 hours of analysis time.

3.1 Introduction

A full evaluation of all qualified vendor's bids will be made. During the evaluation, personnel involved in the selection process may meet with the vendors for clarification of technical points or interpretation of substitute terms and conditions contained in vendor's bids.

3.2 Evidence of Qualification

Upon request of the Purchaser, a Vendor whose bid is under consideration for the award, shall submit promptly, satisfactory evidence of sufficient:

a. financial resources
b. technical resource personnel
c. relevant experience
d. equipment available for the performance of the contract
e. other relevant information

3.3 Financial Evaluation

Financial evaluation will be based on the total cost to acquire the system. After evaluating the bids received from this ITB according to the cited criteria, the award will be made based upon the best value to the University of Washington. The University reserves the right to determine the configuration that best meets its needs.

Total cost will be based on the following:

a. basic cost bid for system and vendor support service
b. any installation costs
c. equipment shipping and insurance costs
d. customs and duty charges, if applicable
e. any other applicable costs

3.4 Technical Evaluation

Initial screening and technical evaluation of bids will be based upon the ability of the Vendor and proposed equipment to meet the mandatory requirements. For a bid to be considered, it must meet all mandatory specifications in Section II, Technical Specifications. If, during the evaluation process, the Purchaser determines that a particular mandatory requirement may be modified or waived and still allow the Purchaser to obtain a system that substantially meets the intent of this ITB, the mandatory requirement will be modified or waived for all vendors, and all vendors' bids will be re-evaluated in light of the change.

Further technical evaluation will be based on the ability of the vendor and the proposed system to exceed mandatory specifications and provide desired features. If a vendor does not provide a particular desired feature as part of the proposed system, but is capable of providing the feature as a field installatble option if the purchaser so desires at some later time, this will be regarded as a positive consideration in favor of the proposed system.

Technical evaluation will be based on the degree to which the bidder and the equipment meet the requirements identified in the Technical Specifications. This technical evaluation will be performed using the criteria and scoring plan described in the following section.

3.5 Basis for Award

After the total cost and the total technical evaluation score for each responsive bid are determined, a dollar cost per evaluation score point ratio will be calculated for each bid. This value will then be used to rank the bids in the final order of desirability to the University.

The University of Washington reserves the right to award the contract on the basis of a) suitability of the equipment bid for meeting the needs of the University; b) adherence to the specification details; c) quality of the merchandise offered and the results of testing; d) delivery and installation schedules; 3) net total cost to the University of Washington; f) information supplied by references; g) capability of the proposed; h) any other factors which are pertinent as may be determined by the University of Washington.

Each bid will undergo a technical evaluation using the criteria stated below to determine their suitability to the described research activities. Each criterion has been assigned a point value. Each vendor's bid will be scored. Any bid which receives a zero (0) under any criterion associated with a stated mandatory requirement shall be disqualified from further consideration, because it is unresponsive to the University's requirements.

3.6 Technical Evaluation Criteria

Criterion	Weight
Meet all manditory specifications	30 points
Evidence of prior, successful testing with an error rate not to exceed $\pm$ 15% with a 90% confidence interval.	35 points
Ownership of all equipment necessary to do the work described in this ITB (as opposed to some of the equipment being leased or rented).	15 points
Dual inductance loops, and information storage capacity by number of trucks	20 points

STATEMENT OF WARRANTY

All vendors are to define their warranty in the space provided below. Included in the statement of warranty shall be the commencement, duration, parts and/or labor covered and the dates of service.

The vendor makes the following warranty:

APPENDIX B
ROAD PROFILE

EXHIBIT B—1

Vertical Road Alignment