Weigh-in-Motion Needs and Potential Data Collection Plans

WA-RD 182.1

Final Report
June 1989

Washington State Department of Transportation
Planning, Research and Public Transportation Division

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

Final Report

Research Project GC 8286, Task 37
WIM — PLAN DEVELOPMENT

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION WEIGH-IN-MOTION NEEDS AND POTENTIAL DATA COLLECTION PLANS

by

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Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

June 1989

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. WA-RD 182.1	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE WASHINGTON STATE DEPARTMENT OF TRANSPORTATION WEIGH-IN-MOTION NEEDS AND POTENTIAL DATA COLLECTION PLANS		5. REPORT DATE June 1989
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Mark E. Hallenbeck		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Transportation Center (TRAC) University of Washington, JE-10 The Corbet Building, Suite 204; 4507 University Way N.E. Seattle, Washington 98105		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. GC8286, Task 37
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, KF-10 Olympia, Washington 98504		13. TYPE OF REPORT AND PERIOD COVERED Final Report
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This report outlines the Washington State Department of Transportation's truck weight data needs and the potential plans that might be used to meet those needs. It summarizes the requirements of HELP, SHRP, the *Traffic Monitoring Guide*, and special state needs, and recommends alternative plans for purchasing and deploying weigh-in-motion equipment within the state.

17. KEY WORDS weigh-in-motion, WIM, traffic data collection, weight monitoring, SHRP data collection	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	38	

DOT FORM 310-022 (11/86) -1216-

DISCLAIMER

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WEIGH-IN-MOTION NEEDS
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This paper outlines the WSDOT's truck weight information needs and the potential data collection plans that might be used to meet those needs. It summarizes the requirements of the Heavy Vehicle Electronic License Plate project (HELP), the Strategic Highway Research Program (SHRP), the Data Rationalization Study, and the Traffic Monitoring Guide (TMG). It describes the various technologies that can be used to collect truck weight data and the advantages and disadvantages inherent in each of those technologies. Finally, it discusses a series of WIM equipment and deployment strategies that might meet the Department's needs at a variety of costs. The pros and cons of each of these data collection strategies are also discussed.

The intent of this paper is to provide sufficient background to the Department's Weigh-in-motion Technical Advisory Committee (WIM TAC) so that the committee can make the necessary decisions regarding the appropriate direction of the Department's WIM program.

DATA COLLECTION NEEDS

The Department's data collection needs result from four areas:

- HELP,
- SHRP,
- the Traffic Monitoring Guide, and
- the Data Rationalization Study.

The sections below describe the principal requirements and needs of each of these programs and/or studies. These descriptions are highly summarized to reduce the amount of material the WIM TAC must review. Additional information concerning any of these programs can be obtained by calling Kris Gupta at the Transportation Data Office at

SCAN 234-6167 or Mark Hallenbeck at the Washington State Transportation Center (SCAN 323-6261).

HELP

For the HELP demonstration, the Department has committed to installing weigh-in-motion on Interstate 5. The Department has not committed to a specific number of WIM stations, but it has proposed a maximum of five potential locations to the HELP Executive Committee. A minimum of one station should be installed during the next year, and as many as three should be installed in the next five years. From a HELP perspective, five stations would be desirable, but for purposes of the HELP demonstration, I believe that five stations are not necessary to demonstrate the ability of the HELP equipment to weigh and identify vehicles as they travel the I-5 corridor.

The five potential HELP locations include

- Vancouver port-of-entry,
- Kelso,
- Ft. Lewis (Nisqually),
- Sea-Tac, and
- Bow Hill.

All five sites are currently Washington State Patrol (WSP) enforcement stations. Only the Bow Hill weigh station has been designed with WIM in mind, although both the Sea-Tac station and northbound Ft. Lewis station (which is currently being rebuilt) have the potential to benefit from some kind of sorting operation as they are currently designed.

The HELP study prefers scales that operate on a continuous basis year-round. HELP has not specified that the WIM sites operate in both north- and south-bound directions, although the HELP Executive Committee would prefer this situation.

The use of existing weigh station sites for HELP would be reasonable, since each site is already connected to power and telephone lines. The existing facilities would reduce the cost of site preparation for WIM installation. WIM could be installed inside of

the weigh stations (off of the mainlanes) that are open 24 hours a day (Vancouver and Bow Hill). For those weigh stations that open and close periodically, the WIM sensors would need to be in the mainline freeway lanes, although the computer hardware, power, and telephone installation could still be located within the static scale site. In this latter case, it could be advantageous to have sensors both inside and outside the weigh station. In this manner, a comparison of the differences between weights of vehicles passing the scales when they were open and when the scales were closed would be easy. Such information would allow the effectiveness of the enforcement process to be analyzed and would provide very valuable information from which to compare the functioning of the mainline scales.

An alternative WIM configuration that would provide the same information would be to place the mainline scales either before or immediately after the enforcement station. This configuration would also require careful tracking of the times when the static scale was in operation to ensure that vehicles passing the scale when it was closed could be adequately separated from those that passed through the open weigh station. With this latter configuration, it would also be possible to compare the accuracy of the WIM scale by comparing the weights measured by the static scale with those measured by the WIM device. The disadvantage of this configuration would be that it would require extra conduit to bring the WIM sensor signal to the power and telephone capability of the existing weigh station.

- **SHRP**

SHRP has three minimum traffic data requirements.

- Vehicle classification data are to be collected for a minimum of 365 continuous days at some point in the next four years at each SHRP site (Washington has approximately 23 SHRP sites[1]).
- At each site, WIM data are to be collected for 48 consecutive hours during the weekdays and 48 consecutive hours during the weekends for each "truck season."[2] This data collection must be performed only once during the four remaining years of the current SHRP funding period.
- SHRP will select a series of "Master" or "Regional" WIM locations (operating continuously 365 days per year) to study the seasonal, daily, and hourly fluctuations in truck traffic. The sites will also be used to factor the short duration WIM counts to represent "average annual conditions."

SHRP has also requested additional vehicle classification and weigh-in-motion data from the sites if data collection resources permit this additional effort. These requirements mesh well with the needs of the HELP demonstration program and the Traffic Monitoring Guide. They do not match the locations of the existing static enforcement scales.

The SHRP sites are geographically spread around the state. There are eight interstate sites, 11 primary arterials, three minor arterials, and one collector. They are split between six urban locations and 17 rural locations. Only two SHRP sites are reasonably close to existing WSP static scales. Both of these sites are on I-5 (near Kelso and Bow Hill).

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[1]The number of SHRP sites in Washington is uncertain at this time. It has fluctuated around the number 23 for several months, and this report assumes that the final number f SHRP sites will be 23.

[2]"Truck Season" is defined as any time when the character (weight or normal classifications) of truck traffic changes during the calendar year. (For example, in agricultural areas there may be a different truck season for each of the crop harvest seasons. In other areas, there may be only one season.

SHRP specifications indicate that the weighing operation does not have to take place within the SHRP section but must be done on a roadway that experiences the "same traffic stream" as the SHRP section. This means that the WIM site may be located up- or down-stream of the SHRP section, but the intervening highway should not contain an intersection that significantly alters the number or composition of trucks traveling on that facility.

Traffic Monitoring Guide

The FHWA Traffic Monitoring Guide (TMG) specifies that 90 measurements be used in collecting WIM data for each three-year HPMS submittal. The individual state may select a combination of different locations to make up the 90 measurements, or take up to 90 different seasonal weighings at the same location. This allows each state to best match the weighing process with the particular spatial pattern of the state, that state's equipment capabilities, and the state's need for personnel utilization.

The intent of the TMG is to provide a statistically representative measure of vehicle weights. To do this, the TMG requires some stratification of weighing between functional classes, seasons, and geographic areas. However, the statistical basis for the TMG procedure is limited by the inability to cost-effectively install and operate weigh-in-motion equipment on a statistically valid sample of locations and times. (That is, weighing equipment does not work accurately in many physical locations that might be selected as the result of a truly random sample, and it is very cost-inefficient to schedule personnel in a way that randomly distributes counts both geographically and temporally.) The result is a compromise counting program that encourages the distribution of counts across functional classes and geographic regions while making cost-effective use of staff and equipment.

While the TMG requests 90 "sites," the technical specifications for the TMG were not nearly this precise. The number 90 resulted from the need to give more specific instructions to states about the appropriate level required to perform adequate truck

weighing, given the limited data available to most states on truck weight variability. The number 90 was a close approximation to the number of sites deemed necessary to meet reasonable precision levels for the five test states examined in the testing of preliminary TMG designs. This number of sites would also provide a high probability of getting good seasonal and geographic representation from the weighing sample. Finally, note that the 90 site guideline is actually 30 sites per year, as the 90 sites must be measured over a three-year period.

The combined needs of the SHRP and HELP efforts come close to fulfilling the requirements of the TMG. The necessary geographic distribution is met as a result of the distribution of SHRP sites within the state. However, the SHRP sites primarily cover the rural upper functional classifications and ignore the lower functional classes and urban areas. This means that additional weighing will be required on those roads that are not well represented in the SHRP sample. While the SHRP sites were not chosen randomly, they were selected primarily as a result of pavement type rather than by traffic level (SHRP pavements include a variety of traffic levels). Thus, bias problems inherent in selecting only high volume truck routes are not a significant problem with the SHRP sample.

The SHRP sites will require roughly six to eight weighings of 48-hour duration over the next four years. This equals 161 sessions over the next four years, [23 sites X (4 sessions per weekday + 4 sessions per weekend)] or 46 sessions per year. This effort alone exceeds the number of counts required by the TMG, although an insufficient number of measurements would be taken on the lower functional classes and in urban areas. The SHRP program also explicitly takes seasonality and weekday/weekend differences into account, while the TMG does so only through guidelines on site selection, guidelines on selecting time periods for weighing, and the large TMG sample size.

By adding a limited number of weighing sites on lower functional class and urban roadways to the existing SHRP locations, the state can easily accomplish the intent of the TMG with only a marginal addition in effort. These additional weighing sessions are necessary to ensure a reasonable understanding of loading profiles for all types of state highways in all portions of the state.

Data Rationalization Study

This study, published in 1986, reviewed the Department's traffic data needs and presented a traffic monitoring program to meet those needs. The study concluded that 15 locations needed to be weighed each year. In addition, the study recommended weighing 200 vehicles of a specific type at each location, rather than staying at that location for a given period of time. These decisions were based on available data and the assumption that truck volumes did not vary significantly through the course of the day.

Data collected under this data collection procedure are still being analyzed, and it is currently unclear whether the assumption of constant weights per vehicle type across hours in a day is valid. The selection of 15 sites per year was based on the variability of the weight data reviewed during the study and the capabilities of the weighing equipment assumed to be available to the Department. There is still considerable uncertainty as to whether the 15 sites provide sufficient geographical spread to the truck weight database.

Weight data collection within the Data Rationalization study was intended to meet the state's needs for input to the pavement management system, design procedures, and various related analyses. Data collected beyond the levels recommended in the Data Rationalization study should improve the accuracy of these analyses, but it is not possible to measure that improvement mathematically.

PROPOSED PLAN OUTLINE

The proposed WIM plan is closely related to the existing WSDOT traffic counting program and also closely resembles the SHRP weighing effort. The plan is an attempt to

integrate the various needs described above while also considering the staffing limitations of the Department. Essentially, the plan starts with the SHRP data collection effort as a base and adds measurement requirements to meet the HELP, TMG, and other Departmental needs. Further, the plan attempts to balance the high initial cost, low recurring staff needs, and high data availability from fixed locations against the lower capital costs, higher staffing requirements, and added flexibility inherent in portable equipment. Thus the plan strikes a balance between fixed and portable equipment.

The proposed plan consists of two elements:

- geographically spread, short duration counts, and
- a limited number of permanent, continuously operating weigh stations.

The plan is designed to be implemented over time, and its actual implementation may change as different equipment is brought onto the market.

Short Duration Counts

The recommended short duration program consists of the SHRP weighings plus five to ten additional weighings on lower functional class and/or urban highways per year.

The basic data collection needs of SHRP were described earlier on pages 3 and 4 of this report. Data collection at the SHRP sites should be concentrated on specific SHRP sites each year, rather than at all sites within one year. (That is, the weighing sessions required at a specific SHRP site should all be taken within one year.) Roughly one-quarter to one-third of all SHRP sites should perform weighings during any one year. This will reduce the number of calibration efforts required for the WIM equipment and will allow the "easier" WIM sites to be addressed first, while providing additional time to pass (and additional equipment improvements to be made) before the more difficult sites are addressed.

For the lower rural functional class roads, weights at 15 different locations should be measured over the next three-year period. This plan represents an effort of five

locations per year, only one less than the number that a strict reading of the TMG calls for. It should result in precision estimates very similar to those expected by the TMG, given differences in actual truck weight variation between the national average and the state of Washington's truck populations.

Unlike the SHRP sites, only one weighing per location (rather than seasonal weighings) is required at these sites. For lower functional class roads, the small number of sites and the relatively high number of lane miles of highway (although low vehicle-miles of travel) mean that extra geographic distribution is more important for statewide (and TMG) needs than additional seasonal data at relatively few low volume sites. In addition, as part of this effort, some emphasis should be placed on weighing some vehicles in the agricultural and timber cutting areas of the state, because of the high impact trucks in these regions have on pavement damage.

Ideally, five urban sites should be weighed each year in addition to the SHRP and rural weighings mentioned above. While such a data collection effort is roughly half of what might be required under a strict interpretation of the TMG, the difficulty of weighing accurately in urban areas and the additional information that should be available from the two SHRP counts on urban interstates make this a reasonable trade off.

Accurate weighing in urban areas is often difficult because of equipment limitations, pavement conditions and street layouts. On high volume urban roads it is often difficult to place portable WIM sensors, let alone calibrate them or isolate heavy vehicles from the surrounding traffic stream to accurately weigh them.

Given the resources available to the Department and the large number of lane miles of rural roads (in comparison to urban roads under state jurisdiction), the urban weighing should be limited to SHRP sites until more resources become available or priorities change within the Department. When resources allow the weighing of vehicles at urban sites, the Department should consider the use of permanent and semi-permanent scale systems (i.e., those systems whose sensors are permanently embedded in the

pavement but which may not always be operating.) The cost of these permanent installations may be high initially, but the long-term cost should be lower than use of portable equipment, particularly for urban interstates, where traffic control problems significantly limit the opportunities for using WIM equipment.

The Department may also want to set aside resources to examine weights at specific trouble spots identified through the regular planning process or at the request of the WSP. The recommended WIM plan does not directly impact the enforcement of weight violations, although the data collected using this plan should provide a reasonable estimate of the severity of the overweight vehicle problem on state highways (at least within the limitations of equipment accuracy).

The availability of portable equipment will allow the Department to weigh vehicles at sites that are suspected of suffering from large numbers of vehicle overloads; however, current staffing levels may not be sufficient to meet the needs of both the regular weighing program and additional "troublespot" weighings.

Continuously Operating Weigh Stations

One of the biggest shortcomings in the field of truck weighing is the lack of good data on the temporal and seasonal patterns associated with truck weights. It is important that the state install and operate permanent WIM equipment at a limited number of sites to monitor the size of these fluctuations.

The greater the number of continuously operating stations that are available, the more complete will be the picture of vehicle weights within the state. However, the cost of installing permanent systems is high, and the volume of data generated by continuous WIM sites will be very large.

The recommended program for long-term weighing would start with one station on Interstate 5. This would help satisfy the HELP demonstration needs while also providing information that could be used by SHRP, FHWA, and the Department. During the next four years, a minimum of two more permanent stations should be installed. This

would provide high quality, year-round data on the two highest volume interstates and provide for one additional station to meet other needs. Additional permanent sites should be encouraged if funds and weighing technologies permit this expansion.

Interstate 90 should be the site of the second permanent WIM site, followed by either a second I-5 site (for HELP) or a site off of the interstate system. Site selection for these stations needs considerable input from the various members of the WIM TAC. Logical sites for additional WIM equipment would be the SHRP locations, where the additional information available from the greater data collection capabilities would provide the greatest benefit to the largest number of users.

The number of continuously operating sites the Department should operate is a direct function of the technology to be selected, the budget that is available, and the degree to which the state wishes to meet the SHRP traffic data request. Finally, note that the greater the number of permanent WIM sites, the better the state's ability to examine seasonal changes in truck weights, truck axle configurations, and truck volumes. All of these data are of interest and importance to the Department.

EQUIPMENT CONSIDERATIONS

A variety of equipment styles and technologies exist for collecting WIM data. Each technology has its own advantages and drawbacks. The accuracy of all WIM technologies is seriously affected by the road condition immediately before and after the WIM sensors. The rougher the pavement, the more poorly the WIM device will estimate the static axle loads of the measured trucks, regardless of the technology used. No available WIM system will work accurately in a deteriorated pavement.

The more poorly the WIM device estimates the static weights of the truck axles, the ESALs calculated from those data will be erroneous. Thus, significant errors in the weight estimates will likely result in very significant errors in the pavement depth calculations made with those data. The more expensive WIM technologies usually

provide more reliable weight estimates than the less expensive technologies. However, selection of those technologies will mean an increase in cost to the Department, or a decrease in the number of sites at which data can be collected.

The WIM technologies being considered by the Department include

- bending plate,
- strain gage load cell,
- piezo-electric cable,
- capacitance pad, and
- bridge weighing system.

Each of these systems is briefly described below.

Bending Plate

Two manufacturers currently market bending plate WIM scales in the U.S., PAT Equipment Corporation and Streeter Amet Corporation. This system uses strain gages attached to a steel plate embedded in the road surface to estimate the load applied by passing vehicle axles. These systems are usually permanent (i.e., the plates are installed in the pavement and left operating, or at least left in place), although the plates may be moved from location to location, provided frames have been placed in the ground at all the locations at which they will be used.

The bending plate system has been used actively for several years in the U.S. It has a good reputation and has consistently performed well in WIM system tests. Given the permanent nature of the installation process, and the relatively high cost of the system (approximately $35,000 per lane), the system is usually installed in concrete pavement in excellent condition with a smooth approach to the scale sensor. This partially explains its reliability and consistently good results.

These scales can be placed in asphalt pavement, but the scale life in asphalt is lower than that in concrete, since the rutting in the asphalt decreases system accuracy over time.

When it is placed in a prepared pit, the bending plate system operates unattended. Installation of the sensors when the bending plate operates as a portable system requires a minimum crew of three. The instrumented lane must be closed to traffic while the sensor is mounted in the pavement.

Extensive use of bending plate systems by the Department will require an increase in planned expenditures, or a decrease in the number of instrumented sites currently planned.

Strain Gage Load Cell

Strain gage load cells are made and marketed by CMI Dynamics in the U.S. This system is designed only as a permanent station. The individual axle sensors weigh over 2,000 pounds a piece, and moving them between locations is not practical.

The CMI scales have also proved to be quite accurate. A number of enforcement sorter scales around the nation use CMI scales, and in the recent HELP and Maine WIM tests, the CMI system showed excellent results. The CMI system costs roughly $50,000 per lane plus installation costs. Installation is more expensive than that for bending plate systems, since the CMI system requires a 3-foot excavation for scale installation, while the bending plate system needs only a 5-inch cut.

This system operates unattended. A crew of six or more is usually needed to install the system.

Piezo-Electric Cable

Piezo-electric systems use a piezo-ceramic cable sensor placed in the pavement to measure axle loadings. This system is still reasonably new, and tests carried out by three states (Washington, Iowa, and Minnesota) have shown mixed results. The best results, (from Iowa, using a system built by G.K. Instruments placed in concrete pavement) are comparable to the accuracies achieved with bending plate and strain-gage load cell systems. The poorer results found in Minnesota (G.K. Instrument system in asphalt) and

Washington (a French system in asphalt) showed error results roughly twice as high as those commonly found in "traditional" WIM scales.

Piezo-cable systems are less expensive than "traditional" systems ($10,000 per lane). Piezo-cable is also the best choice of permanent axle sensor currently on the market. Additional research is necessary to determine the reliability of the cables as WIM sensors and under which conditions the cables can be used.

The cables commonly used are not portable, but the low cost of the sensors ($2,000 per lane) allows agencies to install them in several locations and move only the electronics from site to site. Once installed, the piezo-system is usually left unattended. Installation requires a crew of at least three persons, and lane closure of from 4 to 8 hours, depending on the resin mixture used to place the cable and the weather conditions.

New developments in piezo technology are rapidly advancing its potential uses. A British firm has started to market a portable piezo-based WIM sensor, although this sensor has not been tested and its reliability is completely unknown. In addition, a piezo-film axle sensor is actively being marketed in the U.S. The first major series of installations of this sensor are taking place in Texas this spring and summer. Piezo-film is also somewhat experimental, and its use within the context of this project is not certain at this time.

Capacitance Pad

The capacitance pad (or mat) is the most portable of the available WIM systems. It consists of a 6-foot-wide mat that is placed in the right-hand wheel path of a highway lane. When a tire crosses the mat, the capacitance of the pad changes. This change is interpreted by the electronics to estimate the axle weight. The capacitance pad is not available as a permanent system. It is only used as a temporary system.

The pad is the least accurate of the WIM devices reviewed. There are two reasons for this. The first is that the pad lies on top of the road surface (rather than being placed in a cut or pit). This creates a bump in the road and increases the dynamic action of the

vehicles being weighed. This increase in dynamics results in a decrease in system accuracy.

The second factor that hinders system accuracy is that the pad is so portable that it can be placed on almost any highway section. This fact leads many agencies to place the mat in locations from which weight data are needed but where site conditions are less than optimal for weighing. The result is that the agency gains some knowledge of the weights being experienced at that location, but the WIM estimates are often very different from the actual static weights passing that location.

A crew of three is usually needed to install the pad in the highway lane. A lane must be closed to traffic for 30 minutes or so to install or remove the sensor. A one-person crew is usually on-site at all times to monitor the pad and prevent vandalism to the system.

Bridge Weighing System

There are two versions of the bridge system. Both consist of strain gages attached to the underside of a highway bridge, two axle sensors per lane, and a computer to monitor and interpret the sensor information.

The "commercial" bridge system has been tested and used by several states with varying degrees of success. This system usually works as a portable system, and removable strain gages and electronics are moved from bridge to bridge as needed. A motor home is usually necessary to transport the system and house the equipment.

Results with this system have shown that some bridges work well as scale platforms (mostly short span, simply supported steel girder bridges), while others do not work well (complex concrete bridges, bridges with high skews, and bridges with very high traffic volumes). Tests in Washington with an early version of the system were not favorable, although its use on low volume rural roads (which have better operating conditions than the urban bridges used in the Washington test) might be feasible.

A low cost bridge WIM system is currently being designed as an NCHRP project. This system was originally intended to be mounted on a bridge and left in place; however, additional work has been done to allow this system to be portable, similar to the traditional system described above. Testing of this system should begin this summer. The low cost system should have the same limitations as the traditional system, but will require a lower capital investment and will be more conducive to 365-day operation.

In most cases, two persons are required to set up and take down the system, but only one person is needed full time to operate the "commercial" system. The operator must monitor the generator and ensure that the temporary axle sensors are not displaced by passing traffic. The low cost system is designed to operate unattended.

ALTERNATIVE DATA COLLECTION PLANS

This section of the report describes a number of alternative scenarios for collecting weight data within the state. The different scenarios assume different mixes of weighing equipment and different numbers of permanent versus portable equipment sites. Exhibit 1 shows a summary of the costs of these alternative plans, along with their major pros and cons. Appendix A explains the assumptions used to estimate these costs.

The nine alternatives considered are as follows:

A. **Five bending plate systems with 18 vehicle classifiers and two capacitance pad systems.**

B. **Six bending plate systems with 17 vehicle classifiers and two capacitance pads.**

C. **Three bending plate systems with 20 vehicle classifiers and two capacitance pads.**

D. **Three bending plate systems and 20 piezo-electric systems.**

E. **Five bending plate systems with 18 piezo-electric systems.**

EXHIBIT 1
SUMMARY OF ALTERNATIVE DATA COLLECTION PLANS

Scenario Number	Scenario	Cost For SHRP	Cost Plus HPMS	Pros	Cons
A	5b, 18v,2c	$1,515,000	$1,588,000	Good mix of permanent and portable systems Can expand the number of sites easily..	Requires that pads work well Requires a large staff to operate
B	6b, 17v, 2c	$1,628,000	$1,701,000	Same as above	Same as above
C	3b,20v,2c	$1,290,000	$1,363,000	Same as above	Same as above Not as strong a permanent system
D	3b, 20 p	$1,230,000	$1,718,000	Low SHRP cost Lots of weight data	Relies heavily on piezo technology
E	5b, 18p	$1,464,000	$1,952,000	Lots of weight data Good permanent scales	Relies heavily on piezo technology
F	5b, 5p, 13 v, 1c	$1,494,000	$1,567,000	Has many permanent sites Good flexability in operational requirements Could use bridge in place of piezo	Requires maintenance of many types of equipment
G	8b, 23 eb, no v	$1,752,000	$2,137,000	Excellent permanent system	Not easily moved High cost System not easily expanded Does not meet SHRP needs
H	8b, 23 eb, 6v	$1,816,000	$2,202,000	Same as above Meets SHRP veh. class. needs	Same as above (except SHRP)
I	5b, 10 eb, 8 v, 1 c	$1,496,000	$1,569,000	Gives best possible accuracy at 15 sites.	Does not allow permanent WIM for HELP demonstration

b = bending plate, p = piezo-electric, eb = bending plate frames without electronics, c = capacitance pad, v = permanent veh. classifiers

F. **Five bending plate systems with five piezo-electric systems, 13 vehicle classifiers and one capacitance pad.**

G. **Eight bending plate systems for use in a semi-portable operation at all 23 SHRP sites**

H. **Eight bending plate systems for use in a semi-portable operation at all 23 SHRP sites, plus six vehicle classifiers.**

I. **Five bending plate systems with ten additional bending plate pits (for portable operation), eight classifiers for the remaining sites, and one capacitance pad.**

The advantages and disadvantages of each of these scenarios are discussed below.

A. **A scenario of five bending plate systems with 18 vehicle classifiers and two capacitance pad systems** would provide a good mix of "higher quality" permanent sites with a strong portable weighing capability. Year-long counts would be performed with the bending plate systems. All remaining counts would be performed with the two capacitance pads. The use of five bending plate systems would equip two WIM sites on I-5, with three other sites spread around the remainder of the state. By using the capacitance pad systems for the remainder of the SHRP program, it would be easy to expand the weighing effort to include the 30 additional HPMS sites that would help balance out the weighing program for smaller roads.

The disadvantage of this scenario is that there would be a high reliance on the capacitance pad. The use of the pad has a strong impact on the quality of the expected weight results. In addition, use of the pad is labor intensive. The pad requires round the clock observation and vandalism protection. This would result in a larger need for FTEs than in several other scenarios.

B. **The scenario of six bending plate systems with 17 vehicle classifiers and two capacitance pads** is essentially the same scenario as the first alternative. The only difference is the number of permanent weigh stations. The added bending plate system would result in better information for the Department, but at a cost of over $100,000 over the previous alternative (including labor saved by not using the capacitance pad).

C. **The scenario of three bending plate systems with 20 vehicle classifiers and two capacitance pads** is similar to the first two alternatives, but includes the minimum recommended number of "high quality" permanent systems. The combination would save dollars by using fewer permanent systems but at the expense of a loss of information.

D. **A scenario of three bending plate systems and 20 piezo-electric systems** assumes that the piezo-cable systems would work reasonably well at all necessary locations, and consequently makes the marginal upgrade from vehicle classifiers to WIM. The big advantage of this scenario is that it would provide the greatest number of permanent systems.

The cost for this alternative would be the lowest of any of the alternatives for the collection of SHRP and HELP data. However, the collection of WIM data for the remaining 30 HPMS locations would increase the cost of this alternative substantially because of the need to install additional cables and purchase one more set of electronics. One alternative to the use of additional piezo-cable sites would be to purchase a capacitance pad for collecting measurements at the non-

SHRP HPMS sites. (The capacitance pad alternative is not included in the cost estimates.)

(One other alternative for this scenario would be to substitute a low cost bending plate system, as bid by the PAT corporation, in place of the piezo-electric technology. Such a system would cost slightly more than the estimated piezo system but would be less risky in terms of system accuracy . The bridge system is not considered an alternative to the piezo-cable system for this alternative because of the difficulty in finding appropriately configured bridges at the necessary SHRP sites.)

E. **A scenario of five bending plate systems with 18 piezo-electric systems** is similar to the previous alternative but with a slightly greater number of "high-quality" permanent systems.

F. **A scenario of five bending plate systems with five piezo-electric systems, 13 vehicle classifiers and one capacitance pad** would provide a few of each kind of system. It would increase the number of permanent WIM locations, while not relying as heavily on the piezo technology as the previous two scenarios and also maintaining the capacitance pad capability. Finally, it would allow the low cost expansion of the weighing process to include the needed HPMS urban and minor rural roadways without the need for additional capital expenditure.

The primary drawback to this scenario is the fact that it would require the Department to maintain three disparate weighing systems and their spare parts.

Unlike Scenario D, both the low cost bending plate and bridge WIM systems might be used in place of the piezo-electric technology for this alternative.

Because this scenario would only require five piezo systems, WSDOT would be more likely to find five bridges where the bridge system could operate effectively.

G. **The scenario including eight bending plate systems for use in a semi-portable operation at all 23 SHRP sites** assumes that the piezo and capacitance pad systems would not function accurately enough for acceptable use. It is the "lowest cost" option of the all bending plate scenarios. It assumes that the Department would not meet the vehicle classification needs of SHRP but would make up for that with better WIM data. This scenario also assumes that the bending plate system would work as well in lesser quality asphalt roadways as it does in concrete roadways (or at least that it would work better than the piezo or capacitance systems.)

The primary drawbacks to this alternative are the high cost of the system, the lack of portability, and the lack of any year-round vehicle classification information. Unlike the capacitance pad, the bending plates cannot be placed on any road to "get a feel" for the traffic loadings, as the system requires a pit in the pavement for installation.

H. **A system of eight bending plates for use in a semi-portable operation at all 23 SHRP sites, plus six vehicle classifiers** is the same as the previous alternative but includes the necessary equipment to fulfill the SHRP vehicle classification request. Consequently, it would eliminate the disadvantage of not having the vehicle classification information required by SHRP but would add $60,000 in capital costs to provide the minimum SHRP vehicle class data.

I. **The scenario of five bending plate systems with 10 additional bending plate pits (for portable operation), eight classifiers for the remaining sites, and one capacitance pad** would place five bending plate systems at a different site each of three years. The remaining locations would get a classifier, and weighing would be performed with a capacitance pad. The capacitance pad would be reserved for use on the smaller roadways (two-lane, two-way facilities) in the SHRP data collection effort and on the 30 additional HPMS locations.

The rotation of the five bending plate systems would limit the use of any one site as a "permanent" WIM location within SHRP or HELP, but it would provide a strong database for use by the Department. This system would provide an easy phasing mechanism for the Department (pits could be built immediately before use, thus spreading out their construction over three years), as well as good seasonal information at each of the 15 sites. It would also limit the number of times that traffic lanes would have to be closed for plate installation.

The use of the capacitance pad would allow true portable operation on the remainder of the SHRP and HPMS sample sections, as well as provide the Department with the ability to easily weigh at any location in the state, if the need arose. The cost for this alternative would fall in the middle of the possible scenarios.

RECOMMENDATIONS

It is impossible to make adequate decisions concerning WIM without a better understanding of the accuracy and reliability of the competing WIM systems. Research indicates that the bending plate system is the most reliable (and likely the most accurate) of the alternatives, but it is also the most expensive to buy, install, and operate. The piezo

system is the least expensive (along with the new low-cost bridge system), but it is essentially an unknown quantity, having produced mixed results in previous tests. The capacitance pads are the most portable but probably the least accurate of the systems (given their portable nature and the fact that they create their own "bump" in the road), and they too have produced mixed results when tested by different agencies under a variety of conditions.

Given uncertainties in equipment operation, the alternatives are listed in rank order of acceptability in Exhibit 2. A summary of the reasons for this ordering is presented below. Because the selection of any of these scenarios rests on the acceptable performance of the selected equipment, the Department must be convinced that the equipment will work correctly.

Consequently, the recommended course of action for the Department is to start implementation slowly, while carefully testing the available equipment. This will allow the Department to become satisfied with the performance of the equipment before committing the majority of its resources. This "go slow" philosophy can be taken because most of the scenarios share a number of similarities in equipment usage.

Rank Order of the Scenarios

If all of the technologies functioned well, the "best" alternative for the weight data collection would be Scenario F. This scenario is the second lowest cost option for SHRP and HPMS data collection and is in the middle range of costs for SHRP data collection alone. This option would have the advantage of not being tied to a specific WIM technology, and it would provide a mix of the extra data collection capabilities of permanent WIM sites with the flexibility of the capacitance pads. This option would provide the second highest number of permanent WIM stations of all the scenarios, without sacrificing the budget to weigh vehicles on the smaller functional class roads.

The primary limitation of this scenario is that the Department would be required to maintain several different types of WIM equipment. This would increase the staff

EXHIBIT 2

RANK ORDER OF ALTERNATIVE DATA COLLECTION PLANS

Scenario Number	Scenario	Cost Plus HPMS
F	5b, 5p, 13 v, 1c	$1,567,000
D	3b, 20p	$1,718,000
A	5b, 18v,2c	$1,952,000
C	3b, 20v, 2c	$1,363,000
B	6b, 17v, 2c	$1,701,000
I	5b, 10eb, 8 v, 1c	$1,569,000
H	8b, 23eb, 6v	$2,202,000
E	5b, 18p	$1,952,000
G	8b, 23eb	$2,137,000

where:

b = bending plate

eb = bending plate frames, but no electronics

p = piezo-electric cable WIM

v = permanent vehicle classification

c = capacitance pad

training costs and the system maintenance costs, as well as increase the inventory required for spare parts.

The second ranked data collection scenario is alternative D, the piezo-cable system. For SHRP data collection alone, this scenario would cost the least amount of money. It would require little staffing to maintain and operate, and it would provide the most data, with 23 permanent WIM sites. The resulting database on the seasonal and temporal patterns of vehicle class and weights within the state would be unequaled.

Alternative D has two major drawbacks, the cost of collecting HPMS rural and urban information, and the dependence on the piezo-electric cable technology. If the remaining 30 non-SHRP sites were instrumented with piezo-electric cable, the cost for this scenario would escalate quickly. (This cost increase could be greatly reduced if WSDOT crews did the installation.) Another alternative would be to use the recently purchased capacitance pad to perform these additional measurements. This action would eliminate the need for 30 additional site installations and would result in a cost savings of about $300,000. The other significant drawback to this alternative would be its reliance on a technology that has functioned poorly in two of the three tests made in the U.S. (particularly in asphalt). A final limitation with an all piezo-cable scenario would be the inability of the Department to easily move the sensors around the state to additional locations where weights were of interest. (To weigh vehicles, additional cables would have to be laid and then calibrated.) As with the HPMS measurements, this limitation would be eliminated by using capacitance pads, (not included in the cost of this scenario).

If the piezo-cable systems proved to be inadequate (i.e., the technology could not be made to work satisfactorily), the next best alternative would be either Scenario A or C. These scenarios are also very similar to scenarios B, consisting of a limited number of bending plate systems, two capacitance pad systems, and vehicle classifiers for the remaining sites. These scenarios would provide a reasonable coverage of temporal and

seasonal weight changes, but would rely extensively on the capacitance pads for weight data at most of the sites.

These alternatives are reasonable only if the capacitance pads worked well. If the pads were not more accurate than the piezo-cables, the increased level of staffing required for this alternative and the decrease in the amount of data that could be collected would rank all three alternatives below Scenario D. Choosing among Scenarios A, B, and C is difficult. Selecting among these scenarios is simply a judgment about whether additional permanent WIM data are worth the added cost of high quality WIM equipment. In the rankings, Scenario A is rated above Scenario C and then Scenario B. Scenario C provides the least seasonal weight information of all of the scenarios, and the total lack of seasonal weight data makes the added cost of the additional two stations worthwhile. The added cost of the sixth WIM station does not appear to be worth the additional cost.

The next best alternative is Scenario I. This alternative would place a heavier reliance on the bending plate technologies than the earlier scenarios, while limiting both the cost of the required bending plate equipment and the number of capacitance pad systems required. The capacitance pads used with the system would allow the necessary flexibility in adding new sites to the weighing plan, but would also result in a substantial decrease in accuracy if they did not work well. Using the bending plates in a portable operation would also reduce the effectiveness of the Department's participation in the HELP demonstration.

The last recommended system is Scenario H. This system would provide the most reliable data of all of the scenarios, but it would also be the most expensive of the alternatives. The additional scale pits should be built only during the years when the system is to be installed (rather than building all of the pits at the same time.) This would reduce the impact of asphalt pavement deformation on scale accuracy. Because the WIM equipment would be moved from site to site, it would not be possible to collect a

complete year of data at each site, and therefore a limited number of vehicle classifiers would be required to provide the remaining SHRP data.

The remaining two scenarios are not considered acceptable alternatives. Scenario E is not acceptable because it costs more than Scenario D while providing little or no additional information and relying on the same technologies. Scenario G is considered unacceptable because it can not provide the data requested by SHRP.

Recommended Actions

The recommended actions for the Department are listed below:

- Install an initial bending plate system on I-5.
- Test a new generation cable system at one SHRP location, using those cables for vehicle classification if they don't work for weights.
- Install and test the low cost bridge system at another SHRP site.
- Purchase and test a capacitance pad system.
- If the piezo-cable tests are positive, begin implementation of Scenario F by purchasing weighing grade piezo-cables and installing them (five sets of cable maximum).
- If Piezo-cable tests are negative, buy classification grade cable or piezo-film and install it for use as a permanent classifier.
- Select sites for the remaining bending plate systems.
- Make the final selection among the alternatives, on the basis of the results of acceptance tests, and purchase and install remaining equipment.

Use of the Data

After the data collection plan has been implemented, the truck weight data can be used in the same manner as the TMG recommended. The SHRP sites are assumed to be randomly selected, and as a result, the formulae used in Chapter 2 of Section 5 of the TMG are valid, although permanent SHRP sites may produce so much data that additional considerations of seasonal effects may be necessary for some analyses.

APPENDIX A

REVISED ASSUMPTIONS USED IN THE WIM COST CALCULATIONS

The values below were used to calculate the estimated cost of installing the various WIM systems. After the results of the RFP were reviewed, it was determined that the cost of system installation performed by an outside contractor was roughly twice that of installation performed by the Department. Thus, the costs below have been doubled from the original estimate.

The other major change resulting from the RFP responses was a change in the estimated cost of piezo-electric cables. As with the installation costs, the piezo-electric cable estimates bid were roughly twice the cost originally estimated. The new estimate is $2,000 per weight grade cable. Estimates for vehicle classifying piezo-cable were left at $1,000 apiece to reflect the possibility of using piezo-electric file (at $300 per lane) in place of traditional piezo cable.

INSTALLATION COSTS

4 lane piezo WIM installation = $16,750 * 2 = $33,500

based on $6,750 of labor and travel + 8 * $1,000 for cables + 4 * $500 for misc. expenses.

2 lane piezo WIM installation = $8,000 * 2 = $16,000

based on $3,000 in labor + 4 * $1,000 for cables + 2 * $500 for misc. expenses.

4 lane bending plate installation = $26,700 * 2 = $53,400

based on $13,500 for labor + 4 * $2,800 for frames + 4 * $500 for misc. expenses.

2 lane bending plate installation = $18,600 * 2 = $37,200

based on $12,000 for labor + 2 * $2,800 for frames + 2 * $500 for misc expenses.

Bridge WIM is considered comparable in cost to piezo cable systems.

COST OF ELECTRONICS

Piezo WIM = $8,000 (must be doubled for 4 lane systems)

Vehicle classifier = $ 2,500

Capacitance pad (one set of electronics and two pads) = $50,000

Two capacitance pad systems (two sets of electronics and four pads) = $75,000

Bridge WIM assumed equal to piezo cable

Bending plate system 4 lanes = $105,000

Bending plate system two lanes = $65,000

PORTABLE SYSTEM MANPOWER NEEDS

Manpower estimated at $162 per day with five persons needed per crew (traffic control for set-up and take down equals two persons for 1/2 day for both set-up and take-down. These are included as part of the crew cost.

Each crew is needed for two days at each site.

Each crew must make two trips to each site for each season.

Four seasons are monitored at each site.

A multiplier of 1.5 is applied to account for travel costs.

APPLICATION OF COST ESTIMATES

The list of SHRP sites and characteristics used in calculating the WIM costs is shown on the following page. In general, the higher quality, more permanent stations were assumed to be placed on the larger facilities (i.e., those at the top of the page.) This allows the measurement of truck weights on all lanes of the majority of highways, in that the portable equipment can not always be placed on multiple lanes of a facility.

Finally, for permanent stations, all lanes of a facility are assumed to be instrumented. While SHRP requires only the instrumentation of the right-hand lane of one direction, it is assumed that the Department would prefer the collection of data in both directions and all lanes, to allow a variety of other analyses.

SHRP Approved Site Details List

SR	Location Type	Location	City	FC	Lanes each way	Divided?	Phone	County	R/U	Pavement
90	13.06-16.64	SR 901 E of ECL	Bellevue	I	4	D	Y	King	U	A
5	33.41-36.19	1.2 mi S of Kelso SCL	Kelso	I	3	D	Y	Cowlitz	R	A
405	18.84-21.87	NE 116th St off ramp	Kirkland	I	3	D	Y	King	U	A
2	104.72-114.08	Jct SR 97	Cashmere	P	2	U		Chelan	R	A
5	258.01-262.21	Bakerview Rd Off-ramp	Bellingham	I	2	D	Y	Whatcom	U	A
5	72.29-73.28	Newulum Rvr Brdige	Chehalis	I	2	D	Y	Lewis	R	C
14	3.93-11.86	Evergreen Blvd	Camas	P	2	D	Y	Clark	U	C
20	53.2-55.1	N of Bayview, La Conner Rd	Burlington	P	2	D	Y	Skagit	R	A
82	103.19-118.48	Goose Gap Rd Off ramp	Kennewick	I	2	D	Y	Benton	R	C
82	54.84-72.6	Granger ECL	Sunyside	I	2	U	Y	Yakima	R	C
90	208.16-218.03	E of jct SR21	Ritzville	I	2	D	Y	Adams	R	A
195	86.22-89.78	S of Stentz Rd	Spokane	P	2	D	Y	Spokane	R	C
195	91.55-94.39	Spokane SCL	Spokane S	P	2	D	Y	Spokane	R	A
12	372.85-376.36	E of jct SR126	Dayton	P	1	U	Y	Columbia	R	A
14	16.1-19.6	Jct SR 140	Washougal	M	1	U		Clark	U	A
97	248.96-253.59	Wells Dam	Wells Dam	P	1	U	Y	Okanogan	R	A
167	21.56-26.01	S 212 St off Ramp	Renton	P	1	D	Y	King	U	A
195	0-8.6	Idaho St Line	Colton	P	1	U	Y	Whitman	R	A
195	22.85-25.82	Lct Wawawai Rd	Pullman	P	1	U	Y	Whitman	R	A
215	0-6.21	Jct SR20	Okanogan	M	1	U	Y	Okanogan	R	A
221	5.91-13.53	Lenzie Rd	Prosser	M	1	U	Y	Benton	R	A
522	15.3-20.81	SR 134 Uxing	Monroe	P	1	U		Snohomish	R	A
903	0-7.62	Jct SR 970 W Cle Elum	Roslyn	C	1	U	Y	Kittitas	R	A

COST ESTIMATE BREAKDOWN

Scenario								
5b, 18v,2c	6b, 17v, 2c	3b,20v, 2c	8b, 23 eb, no v	8b, 23 eb, 6v	5b, 10 eb, 10 v,1 c	5b, 5p, 13 v, 1c	3b, 20 p	5b, 18p
Installation								
695000	714900	655200	881400	927400	789400	695000	65520	655200
Vehicle Classification Equipment Cost								
45000	42500	50000	0	15000	20000	32500	0	50000
Manpower for WIM pad								
174960	165240	194400	0	0	97200	126360	0	0
Manpower for portable WIM (non-pad systems)								
0	0	0	30618	34020	14580	0	0	0
WIM Equipment Cost								
600000	705000	390000	840000	840000	575000	640000	575000	759000
Total WIM Cost (sum of WIM equipment and WIM manpower costs)								
774960	870240	584400	870618	874020	686780	766360	575000	759000
TOTAL (3 YEAR PERIOD) (Sum of installation, vehicle class and WIM costs)								
1514960	1627640	1289600	1752018	1816420	1496180	1493860	1230200	1464200
Cost of extra HPMS Counts								
72900	72900	72900	385290	385290	72900	72900	488000	488000