1477

Technical Report Documentation Page

1. Report No. FHWA/VA-92-R17	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Using the <u>Traffic Monitoring Guide</u> to Develop a Truck Weight Sampling Procedure for Use in Virginia*		5. Report Date June 1992
		6. Performing Organization Code
7. Author(s) B. H. Cottrell, Jr.		8. Preforming Organization Report No.
9. Performing Organization Name and Address Virginia Transportation Research Council Box 3817, University Station Charlottesville, Virginia 22903-0817		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 2646–081
12. Sponsoring Agency Name and Address Virginia Department of Transportation 1401 E. Broad Street Richmond, Virginia 23219		13. Type of Report and Period Covered Final Report Nov. 1989–Sept. 1991
		14. Sponsoring Agency Code

15. Supplementary Notes

In cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The *Traffic Monitoring Guide* (*TMG*) provides a method for the development of a statistically based procedure to monitor traffic characteristics such as traffic loadings. Truck weight data in particular are a major element of the pavement management process because there is a strong relationship between pavement deterioration and truck weights. Because truck weight data collected by weigh-in-motion (WIM) systems are more representative of actual traffic loadings and are more efficient than enforcement and static weight data, the use of the *TMG* and WIM systems together provide improved monitoring of truck weights.

The objective of this research was to develop a plan for VDOT to implement a truck weight sampling procedure using the *TMG* and WIM systems.

Four alternatives from the *TMG* that were based on different schemes for multiple measurements at permanent WIM sites were evaluated. A truck weight sampling plan was developed for the preferred alternative. Truck weight sample sites, data collection procedures, cost and resources estimates, data from permanent WIM sites, and data management information are included in the plan.

17. Key Words traffic monitoring, truck weight data, truck weight sampling, weigh-in-motion, traffic monitoring guide		18. Distribution Statement No restrictions. This document is available to the public through NTIS, Springfield, VA 22161	
19. Security Clasif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 41	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

147c

FINAL REPORT

USING THE *TRAFFIC MONITORING GUIDE* TO DEVELOP A TRUCK WEIGHT SAMPLING PROCEDURE FOR USE IN VIRGINIA

B. H. Cottrell, Jr.
Senior Research Scientist

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

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

June 1992
VTRC 92-R17

TRAFFIC & PLANNING RESEARCH ADVISORY COMMITTEE

L. C. TAYLOR, Chairman, Salem District Traffic Engineer, VDOT

B. H. COTTRELL, JR., Executive Secretary, Research Scientist, VTRC

M. G. ALDERMAN, Regional Sign Shop Co-ordinator, VDOT

W. S. BLACK, Fredericksburg District Traffic Engineer, VDOT

J. BROWN, Bowling Green Resident Engineer, VDOT

J. L. BUTNER, Traffic Engineering Division Administrator, VDOT

J. CHU, Transportation Engineer Program Supervisor, VDOT TMS Center

B. R. CLARKE, Assistant Transportation Planning Engineer, VDOT

C. A. CLAYTON, Transportation Engineer Program Supervisor, VDOT—Traffic Engineering

D. E. COLE, Bristol District Traffic Engineer, VDOT

G. R. CONNER, Assistant Rail & Public Transportation Administrator, VDOT

J. C. DUFRESNE, Culpeper District Traffic Engineer, VDOT

Q. D. ELLIOTT, Williamsburg Resident Engineer, VDOT

D. L. FARMER, Chief Transportation Planner, Hampton Roads Planning District Commission

C. F. GEE, State Construction Engineer, VDOT

C. D. HALL, Assistant State Traffic Engineer, VDOT

J. T. HARRIS, Transp. Eng. Program Supervisor, VDOT—Location & Design

S. D. HENSHAW, Suffolk District Traffic Engineer, VDOT

K. J. JENNINGS, Senior Transportation Engineer, VDOT—Maintenance Division

T. A. JENNINGS, Safety/Technology Transfer Co-ordinator, Federal Highway Administration

Y. LLORT, Northern Va. District Planning & Operations Engineer, VDOT

T. W. NEAL, JR., Chemistry Lab Supervisor, VDOT

R. L. SAUVAGER, Assistant Urban Division Administrator, VDOT

W. W. WHITE, District Tunnel & Tolls Engineer, VDOT

ABSTRACT

The *Traffic Monitoring Guide* (*TMG*) provides a method for the development of a statistically based procedure to monitor traffic characteristics such as traffic loadings. Truck weight data in particular are a major element of the pavement management process because there is a strong relationship between pavement deterioration and truck weights. Because truck weight data collected by weigh-in-motion (WIM) systems are more representative of actual traffic loadings and are more efficient than enforcement and static weight data, the use of the *TMG* and WIM systems together provide improved monitoring of truck weights.

The objective of this research was to develop a plan for VDOT to implement a truck weight sampling procedure using the *TMG* and WIM systems.

Four alternatives from the *TMG* that were based on different schemes for multiple measurements at permanent WIM sites were evaluated. A truck weight sampling plan was developed for the preferred alternative. Truck weight sample sites, data collection procedures, cost and resources estimates, data from permanent WIM sites, and data management information are included in the plan.

148.3

TABLE OF CONTENTS

FINAL REPORT

USING THE *TRAFFIC MONITORING GUIDE* TO DEVELOP A TRUCK WEIGHT SAMPLING PROCEDURE FOR USE IN VIRGINIA

B. H. Cottrell, Jr.
Senior Research Scientist

INTRODUCTION

Truck weight data are used for (1) pavement design and monitoring, (2) bridge design and monitoring, (3) size and weight enforcement, (4) legislation and regulation, and (5) administration and planning.[1] Truck weight data are especially important for pavement design and monitoring. Because of the strong relationship between pavement deterioration and traffic loading, the Federal Highway Administration (FHWA) has made improved monitoring of traffic loadings a major element of the pavement management process.[2] The FHWA has also determined that the use of weigh-in-motion (WIM) systems in coordination with a comprehensive automatic classification effort is a beneficial approach to collecting traffic loading or truck weight data for the highway design and planning process.[2] To obtain improved truck weight data, the FHWA has recommended that "all states immediately move from the use of static weights for nonweight enforcement data gathering to the use of WIM data collection using techniques comparable to those outlined in the FHWA *Traffic Monitoring Guide*."[2]

The *Traffic Monitoring Guide* (*TMG*) provides a method for the development of statistically based procedures to monitor traffic characteristics.[1] The *TMG* has two objectives: (1) to relate the intensity of the monitoring effort to the quality of the data gathered and (2) to encourage the perception that traffic counting, vehicle classification, and truck weighing are part of a related set of functions that monitor traffic characteristics.[1] The *TMG*'s statistically based sampling programs estimate (with known levels of reliability) traffic volume, annual vehicle miles of travel, annual average daily traffic, vehicle classification, and truck weights. The *TMG* emphasizes the use of statistical sampling using the Highway Performance Monitoring System (HPMS) sample and the integration of data collection procedures. The three *TMG* subelements of the HPMS sample are interrelated as follows: vehicle classification is a subset of traffic volume, and truck weight is a subset of vehicle classification. These relationships eliminate duplication and directly connect estimates of weight, classification, and volume. Within the HPMS, traffic volume counts are collected on all roads; the vehicle classification sample is a subset of the HPMS (traffic volume) sites; and the truck weight sample is a subset of the vehicle classification sample. (A more detailed account of the background to the *TMG* and Virginia Department of Transportation's (VDOT) truck weight studies can be found in Appendix A.)

The Materials Division of VDOT requested a truck weight data collection program for pavement design. Also, the Office of Policy Analysis, Evaluation & Intergovernmental Relations requested a coordinated WIM program to provide a data base for vehicle cost responsibility studies. VDOT is planning to add WIM systems to its traffic monitoring program. Therefore, there is a need for the development of a truck weight sampling program using WIM systems.

OBJECTIVE

The objective of this research was to develop a plan for VDOT to implement a truck weight sampling procedure using procedures from the *TMG* and using WIM systems. Implementation of such a plan would result in substantially improved truck weight data and, consequently, more accurate traffic loadings for planning, pavement design, and administrative studies. This research project is part of the Virginia Transportation Research Council's emphasis area to determine the applicability of WIM equipment in the collection of data for planning and design in Virginia.

METHODOLOGY

1. Using VDOT's HPMS vehicle-classification sample as the data base, the truck weight sampling procedures of the *TMG* were used to select sites and to develop alternative truck weight data collection plans. Alternative plans were developed based on variations in the distribution of sample measurements. One plan includes a single measurement at each location. To take advantage of permanent, continuously operating WIM at the 12 Strategic Highway Research Program (SHRP) sites, other alternatives include multiple measurements at various locations.

2. The alternative plans developed in task No. 1 were evaluated.

3. Based on task No. 2 and the results from the research project to evaluate WIM systems,[3] a plan for a truck weight sample using *TMG* and recommended WIM systems was developed. The plan includes scheduling and cost estimates.

DEVELOPMENT OF ALTERNATIVE TRUCK WEIGHT SAMPLE PLANS

The development of alternative plans for the truck weight sample was done in two phases. In the first phase, the truck weight sample procedures of the *TMG* (described below) were used to select sites for the first alternative: single measurements at each site during the 3-year cycle. During phase two, other alternatives were developed based on different strategies for multiple measurements at the 12 SHRP sites.

Truck Weight Sample of the *TMG*[1]

The minimum recommended reporting strata are:

- interstate
- all other roads (excluding local roads).

The estimation of sample size for the truck weight sample is based on the characteristic equivalent single axle loads (ESAL). The variability of ESALs is estimated from the HPMS vehicle classification and truck weight case studies. Since 3S2 vehicles (18-wheelers or 5-axle semi-trailers) carry a high proportion of the loads, this vehicle type was selected as the one to guide the sample estimation process. It should be noted that the ESAL variability of 3S2s is significantly less than for most other vehicle types; therefore, the decision also reduced the number of samples needed. About 90 measurements (48 total hours of truck weight data at one location over a 3-year cycle) are needed to estimate ESAL on the interstate system for 3S2 trucks with a precision of ±10 percent with 95 percent confidence. The 3-year cycle acts to further reduce the sample needed annually. Since the variability of the data and the mileage is much greater for all other roads, a sample of 60 measurements (over a 3-year cycle) would be needed to estimate 3S2 truck ESALs with approximately ±10 to ±20 percent precision with 95 percent confidence. The samples would be distributed based on AVMT from the HPMS and selected by a random sampling procedure.

The data are collected in *TMG* format and are processed, analyzed, and compiled using the Traffic Monitoring Data Software.[4]

Alternative 1: Single Measurements at Each Site

The selection and distribution of the sample sections were performed in four steps:

1. The number of measurements for each reporting strata (interstate and all other roads) were stratified by types of area (urban or rural) based on daily vehicle miles of travel (DVMT) percentages (see Table 1).
2. The number of measurements by type of area for each reporting strata were stratified by road functional classification based on DVMT percentages (see Table 2).
3. For each functional classification, the number of measurements were distributed to volume groups based on DVMT percentages (see Table 3).

1483

Table 1

DISTRIBUTION OF SITES BY TYPE OF AREA

Interstate System

Type of Area	Expanded DVMT	DVMT %	Truck Weight Sample
Rural	14.99	52.4	16
Urban	16.48	47.6	14
TOTAL	31.47	100.0	30

All Other Roads

Type of Area	Expanded DVMT	DVMT %	Truck Weight Sample
Rural	51.14	53.6	32
Urban	44.22	46.4	28
TOTAL	95.36	100.00	60

DVMT – daily vehicle miles traveled

The volume groups are defined in Tables B-1 and B-2 in Appendix B.

4. The appropriate number of sites for each volume group was randomly selected. Because truck weight data would be available at SHRP sites, SHRP locations were subtracted from the desired number of samples for a volume group to ensure their inclusion in the sample. Then, the remaining samples were randomly selected as follows:

   - A number was assigned to each candidate site in a volume group. For each site, there was a card with the assigned number.

   - The cards were shuffled, and then a card was selected for each truck weight sample needed in the volume group. For example, if 3 samples were needed from a volume group with 8 sites, 3 cards were selected from the 8 cards.

   This resulted in the selection of 78 sites in addition to the 12 SHRP sites. Thus, 48 continuous hours of truck weight data would be collected at each of these 90 sites during the 3-year cycle.

Table 2

DISTRIBUTION OF SITES BY FUNCTIONAL CLASSIFICATION

Rural

Functional Classification	1988 HPMS Expanded DVMT	DVMT %	Unadjusted Truck Weight Sample
Other Principle Arterials	14.48	28.3	9
Minor Arterial	14.93	29.2	9
Major Collector	20.68	40.4	13
Minor Collector	1.05	2.1	1
	51.14	100.0	32

Urban

Functional Classification	1988 HPMS Expanded DVMT	DVMT %	Unadjusted Truck Weight Sample
Other Expressways	3.45	7.8	2
Other Principal Arterials	20.32	46.0	13
Minor Arterial	16.73	37.8	11
Collector	3.72	8.4	2
	44.22	100.00	28

DVMT – daily vehicle miles traveled

Alternative 2: Multiple Measurements at SHRP Sites Within a Volume Group

This alternative uses the maximum number of multiple measurements at SHRP sites within a volume group. For example, for a volume group that is allocated 6 measurements and has one SHRP site, 3 measurements would be made at the SHRP site (1 each year), and 3 measurements would be made at other sites within the volume group. This results in 1 measurement at 6 SHRP sites, 2 measurements at 3 SHRP sites, and 3 measurements at 3 SHRP sites for a total of 21 measurements at SHRP sites. Therefore, 69 randomly selected sites would be needed to obtain a total of 90 measurements. This is 9 fewer sites than is needed for the first alternative.

1490

Table 3

DISTRIBUTION OF SITES BY VOLUME GROUP

	Class	Volume Group													
Functional Class	(No.)	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Rural Interstate	(1)	0	6	4	2	1	1	0	0	0	0	*	*	*	14
Rural Other	(2)	0	4	3	1	1	0	0	*	*	*	*	*	*	9
Principal Arterial															
Rural Minor Arterial	(6)	2	2	3	2	0	0	*	*	*	*	*	*	*	9
Rural Major Collector	(7)	8	2	2	1	0	0	*	*	*	*	*	*	*	13
Rural Minor Collector	(8)	1	0	0	0	0	0	*	*	*	*	*	*	*	1
Urban Interstate	(11)	0	5	4	2	2	1	2	0	*	*	*	*	*	16
Urban Other Freeway	(12)	1	1	0	0	*	0	*	*	*	*	*	*	*	2
Urban Other	(14)	0	0	1	1	1	3	4	2	1	0	0	*	*	13
Principal Arterial															
Urban Minor Arterial	(16)	0	0	3	2	2	1	2	1	0	0	0	0	*	11
Urban Collector	(17)	0	0	0	1	1	0	0	0	*	*	*	*	*	2
															90

* There are no HPMS samples in these volume groups.

Alternative 3: Multiple Measurements at SHRP Sites Combining Two Volume Groups

In allocating the number of measurements to volume groups, the *TMG* recommends that volume groups be combined to ensure that every vehicle classification sample has a positive selection probability. For this alternative, 2 volume groups are combined to maximize the use of multiple measurements at SHRP sites. Five volume group combinations resulted in 2 measurements at 5 sites and 3 measurements at 7 sites for a total of 31 measurements at the SHRP sites. Therefore, 59 randomly selected sites would be needed to obtain a total of 90 measurements, which is 19 fewer sites than needed for the first alternative.

Alternative 4: Multiple Measurements at SHRP Sites Combining up to Three Volume Groups

The logical step to expand on the use of SHRP sites in alternative 3 is to combine up to 3 volume groups. Three 3-volume group combinations results in 2 measurements at 1 SHRP site and 3 measurements at 11 SHRP sites for 35 measurements at the 12 SHRP sites. Therefore, 55 randomly selected sites would be required to obtain a total of 90 measurements, which is 23 fewer sites than needed for the first alternative. In Table 4, there is a description of the 4 alternatives by types of measurements.

EVALUATION OF ALTERNATIVES

Three measures of performance were identified for evaluation: (1) the percentage of samples obtained from SHRP sites, (2) the estimate of resources needed for data collection, and (3) the statistical confidence. The major difference in the four alternatives is in the number of samples obtained from SHRP sites and the corresponding resources needed for data collection.

Percentage of Samples Obtained From SHRP Sites

Ideally, the 90 measurements should be obtained from 90 sites to represent a completely spatial distribution and random sampling. However, the *TMG* states that judgment must play a part in incorporating both spatial and temporal (multiple measurements at sites) variations into the sample.[1]

The *TMG* states that (1) states with limited system mileage may be best served by multiple measurements at a small number of sites; (2) very large states are best served by single measurements at each site; and (3) a combination of

Table 4

DESCRIPTION OF THE ALTERNATIVES BY TYPES OF MEASUREMENT

Alternative	No. of Single-Measurement SHRP Sites	No. of Two-Measurement SHRP Sites	No. of Three-Measurement SHRP Sites	Total Measurements at SHRP Site	Total Measurements Portable WIM
1	12	0	0	12	78
2	6	3	3	21	69
3	0	5	7	31	59
4	0	1	11	35	55

multiple- and single-measurement sites should be considered for medium-size states.[1] Virginia is ranked as having the 22nd highest nonlocal lane mileage.[5] Therefore, Virginia is in the middle of the two extremes; thus, the consideration of a combination of multiple- and single-measurement sites appears reasonable. The alternatives were evaluated on how well spatial and temporal variations were balanced in them. Table 5 is a list of the percentage of measurements obtained from SHRP sites by functional classification for each alternative.

The balance between multiple and single measurements was examined for each functional class. Four of the 10 functional classes do not include SHRP sites. Therefore, the 27 measurements to be made for these groups (or 30 percent of the samples) would be made at single-measurement sites. If 30 percent of the measurements were to be made at single-measurement sites, then it was judged acceptable for the majority of the measurements in the remaining six classes to be made at multiple-measurement sites. Seventy-five percent was selected as the maximum acceptable percentage of samples obtained from SHRP sites. The selection of 75 percent was based, in part, on the fact that if 75 percent of the remaining 63 measurements (47 measurements) were made at multiple-measurement sites, then 52 percent of the total measurements would be made at these sites. This is close to a 50-50 split between single- and multiple-measurement sites. The urban and other-freeways class with two sample measurements represents a limited mileage class. Therefore, multiple measurements representing 100 percent of the sample were judged acceptable for alternatives 3 and 4. For alternatives 3 and 4, the samples obtained from SHRP sites exceed 75 percent for rural-other-principal arterials. For

Table 5

PERCENTAGE OF MEASUREMENTS OBTAINED FROM SHRP SITES BY FUNCTIONAL CLASS

			Percentage of Measurements Obtained From SHRP Sites			
Functional Class	No. of Measurements	No. of SHRP Sites	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Rural Interstate	14	3	21.4	35.7	57.1	64.3
Rural Other Principal Arterial	9	3	33.3	44.4	77.8	100
Rural, Minor Arterial	9	2	22.2	33.3	55.5	66.7
Rural, Major Collector	13	1	7.7	15.4	23.1	23.1
Rural, Minor Collector	1	0	0	0	0	0
Urban Interstate	16	2	12.5	37.5	37.5	37.5
Urban, Other Freeways	2	1	50.0	50.0	100.0	100.0
Urban, Other Principal Arterial	13	0	0	0	0	0
Urban, Minor Arterial	11	0	0	0	0	0
Urban, Collector	2	0	0	0	0	0
TOTAL	90	12	13.3	23.3	34.4	38.9

alternative 3, the difference of 3.8 percent is assumed small enough to ignore. For alternative 4, all 9 of the measurements are from SHRP sites. It was judged that this large sample of 9 measurements (or 10 percent of all of the measurements) should include some single-measurement sites. Alternative 4 may be revised to have 77.8 percent of the samples obtained from SHRP sites for rural-other-principal arterials. The total number of measurements from SHRP sites would be reduced from 35 to 33. The incremental benefit of combining up to 3 volume groups (alternative 4 revised) over combining 2 volume groups (alternative 3) is substantially lowered with the revision.

Based on the percentage of samples obtained from SHRP sites, the 4 alternatives were ranked as follows:

1. alternative 3 and alternative 4 (revised)
2. alternative 2
3. alternative 1.

Estimate of Resources Needed for Data Collection

The resources needed for data collection are for the operating costs of the portable WIM systems and for salaries for the technicians who operate the WIM systems. Because the SHRP sites will be collecting data continuously, no costs for data collected at SHRP sites are included.

Two portable WIM systems are available for data collection: a capacitance weigh mat system by PAT Equipment Corporation and a portable bridge weighing system by Bridge Weighing Systems, Inc. Both systems are battery operated and are capable of collecting truck weight data in two lanes. The operating costs for a two-lane installation are about $800 for the weigh mat system and $260 for the bridge system.[3] For the weigh mat system, the cost is for traffic control during installation and installation materials, and for the bridge system, the cost is for a calibration truck, a driver, and installation materials.

To determine the number of sites where the bridge WIM system may be used, sites for alternative 1 were randomly selected, and the graphic logs were used to identify most sites on the interstate and principal arterials that were near bridges. Bridges were located near 23 sites. About 20 percent of the bridges are expected to be unsuitable for use because of access problems. Therefore, it is estimated that 20 sites are suitable for the bridge WIM system. Similarly, estimates were made for alternatives 2, 3, and 4 (revised) resulting in 17, 12, and 9 sites for the bridge WIM system, respectively. This trend of a reduction in the number of bridge WIM sites as the number of portable WIM sites is reduced appears reasonable because the number of sites suitable for the bridge WIM system is lowered for the interstate and principal arterials since the sample size is smaller. These are rough estimates only. It is possible to use the bridge WIM system on bridges farther away from the sites if similar traffic is present. Also, a field inspection is necessary to determine with certainty whether a bridge is suitable. The Traffic Engineering Division has expressed a desire to use the Bridge WIM on all non-SHRP interstate sites because of the lower operating cost of this system. This is acceptable if similar traffic is present on the bridge and the HPMS site being sampled. The available traffic data (and some judgment) is required in determining whether the traffic is similar.

For the cost analysis, the capacitance weigh mat system is planned for use at all non-SHRP sites that are not suitable for the bridge system. In Table 6, there are cost estimates and manpower estimates for the four alternatives. The annual cost and manpower differences between alternatives 3 and 4 (revised) ($7.00 and two person days) are small enough to consider the two alternatives equal. When compared to these two alternatives, alternative 2 annually requires $1,767 (11.5 percent) more and 10 person days (14.4 percent) more, and alternative 1 requires $3,627 (21.1 percent) more and 19 person days (32.2 percent) more.

Based on cost and manpower estimates, the four alternatives are ranked as follows:

1. alternatives 3 and alternative 4 (revised)
2. alternative 2
3. alternative 1.

Statistical Confidence

This measure of performance was discussed in the development of alternatives and briefly in other sections of this report.

Table 6

COST AND MANPOWER ESTIMATES FOR THE ALTERNATIVES

Alternative	No. Sites for Portable WIM	3-Year Total Costs ($)	Annual Cost ($)
1	78	51,600	17,200
2	69	46,020	15,340
3	59	40,720	13,573
4 Revised	57	40,740	13,580

Alternative	Total Number of Person Days	Annual Number of Person Days
1	234	78
2	207	69
3	176	59
4 Revised	171	57

To ensure a completely spatial distribution using the *TMG* truck weight sampling format, all sites should be single-measurement sites as in alternative 1. Multiple-measurement sites may be used with judgment; however, the *TMG* provides little guidance for this. The remaining three alternatives represent three levels in the following order of decreasing random sampling: (1) multiple measurements of sites for one volume group, (2) combining two volume groups to use more multiple measurements from SHRP sites, and (3) combining up to three volume groups.

Evaluation Findings

For the three measures of performance, the alternatives are ranked as in Table 7. These three measures are related: the percentage of samples at SHRP sites is directly related to the cost and manpower estimates and inversely related to the degree of random sampling. Alternatives 3 and 4 (revised) are tied for top ranking in two alternatives. The major difference between alternatives 3 and 4 (revised) is in the the statistical confidence. Alternative 4 revised is eliminated from further consideration because of its similarity to alternative 3 on two measures and its lower statistical confidence. Alternative 2 is ranked second for all three measures.

A comparison of alternatives 2 and 3 reveals that annually, alternative 2 has three more portable WIM sites, costs $1,767 (11.5 percent) more, and requires ten (14.4 percent) more person days. No volume groups are combined in alternative 2, whereas for alternative 3, there are five instances where two volume groups are combined. The critical question is: Are the cost and manpower savings worth the potential sacrifice in randomness? The savings in cost are modest, but the potential sacrifice in randomness may be a problem. Throughout the *TMG* truck weight sampling process, several decisions were made to reduce the sample size and the effort required. It was felt that further reductions would reduce the statistical reliability. Therefore, alternative 2 was selected.

Table 7
RANKING OF ALTERNATIVES

Percent of Samples at SHRP Sites	Cost and Manpower Estimates	Degree of Random Sampling
3 and 4 (revised)	3 and 4 (revised)	1
2	2	2
		3
1	1	4 (revised)

A *TMG* TRUCK WEIGHT SAMPLING PLAN FOR VDOT

Truck Weight Sample Sites

The truck weight sample sites are listed in Table 8 in order of volume group. The year of the 3-year cycle in which the data are to be collected is also given. Although there is some flexibility in determining the year, it is suggested that (1) if there are more than 3 sites in a volume group, data should be collected at a site from the volume group each year, and (2) at SHRP sites with multiple measurements, only one measurement should be made for the *TMG* each year. The sites where the bridge WIM system may be applicable are noted. The bridge WIM system may be used at additional sites as appropriate.

Data Collection

Data collection should conform to the following recommendations.

- At SHRP sites (see Table 8), WIM data should be provided for all lanes in one direction for 48 hours.
- Truck weight data should be collected in one direction on roads with four lanes or more. Both portable WIM systems can collect data in two lanes. When using the capacitance weigh mat system for two-lanes, it is recommended that the cables that completely cross the travel lane to reach the field unit be protected to avoid damage to the cables.[3] It is suggested that effective methods of cable protection be identified and used. Without cable protection, it is recommended that only one lane of WIM data be collected.
- WIM data on two-lane roads should be collected in one direction.
- Data should be collected for 48 continuous hours.
- WIM systems should be installed to avoid the possibility of vehicles stopping, accelerating, or decelerating on the sensors. If this problem occurs, especially in urban areas near traffic signals, it will be necessary to determine whether the sensors should be relocated or whether the site should be changed.
- Much care and caution should be exercised while installing the portable WIM systems.

Table 8

TRUCK WEIGHT SAMPLE SITES

SAMPLE ID	YR	RTE	COUNTY/CITY	LOCATION	DIRECTION	DISTRICT	ADT	BRIDGE
F01V2S1	1	64	GOOCHLAND	GOOCHLAND CL** TO GOOCHLAND/LOUISA CL	WB	RICHMOND	12801	
F01V2S2	2	66	FAUQUIER	.77 MI E RT 55 EB TO RT 17 NB	EB	CULPEPER	18605	
F01V2S3	3	77	BLAND	RT 52 UP TO RT 666 UP**	NB	BRISTOL	13615	YES
F01V2S4	1	95	PR. GEORGE *	SUSSEX CL TO 3.32 MI N SUSSEX CL	NB	RICHMOND	17630	
F01V2S5	2	95	PR. GEORGE *	SUSSEX CL TO 3.32 MI N SUSSEX CL	NB	RICHMOND	17630	
F01V2S6	3	95	PR. GEORGE *	SUSSEX CL TO 3.32 MI N SUSSEX CL	SB	RICHMOND	17630	
F01V3S1	3	81	MONTGOMERY	PULASKI CL TO 2.01 MI N RT 232	SB	SALEM	20455	YES
F01V3S2	1	81	BOTETOURT	ROANOKE CL TO RT 220	SB	SALEM	29575	
F01V3S3	2	81	ROCKBRIDGE	RT 699 UP TO EB I-64	NB	STAUNTON	22950	
F01V3S4	3	77	WYTHE	RT 619 TO I-81 RAMP	SB	BRISTOL	21315	
F01V4S1	1	295	HENRICO *	0.90 MI S RTE 64 TO 2.30 MI N RTE 5	SB	RICHMOND	33200	
F01V4S2	2	64	YORK *	JAMES CITY CL TO 1.28 MI W INT RTE 143	EB	SUFFOLK	30940	
F01V5S1	1	95	SPOTSYLVANIA	RT 17 BP TO .46 MI N RT 1 WB	NB	FREDERICKSBURG	42050	YES
F01V6S1	2	66	FAIRFAX	RT 29 OP EAST TO RT 28	WB	NO. VIRGINIA	55455	YES
F02V2S1	2	23	WISE *	1.31 MI N S INT RTE 614 TO 0.05 MI S S INT RTE 614	NB	BRISTOL	6440	
F02V2S2	3	17	FAUQUIER *	0.80 MI S INT RTE 608 TO 0.30 MI N RTE 28	SB	CULPEPER	8790	
F02V2S3	1	19	RUSSELL *	END DIVIDED HIGHWAY TO E INT RTE 80	EB	BRISTOL	7590	
F02V2S4	1	23	WISE *	1.31 MI N S INT RTE 614 TO 0.05 MI S S INT RTE 614	SB	BRISTOL	6440	
F02V3S1	2	220	FRANKLIN	RT 40 OP TO .31 MI S RT 40 OP**	SB	SALEM	10255	
F02V3S2	2	13	ACCOMACK	.45 MI S RT 650 TO NCL ONLEY	SB	SUFFOLK	14955	
F02V3S3	3	29	CAMPBELL	RT 29 BUS UP TO SE OTTER RB**	NB	LYNCHBURG	13270	
F02V4S1	1	29	CAMPBELL	RT 754 TO .33 MS N RT 738	SB	LYNCHBURG	19480	YES
F02V5S1	3	10	CHESTERFIELD	.06 MI S RT 898 TO RT 1 AND 301	SB	RICHMOND	20370	
F06V1S1	2	58	FLOYD	PATRICK CL TO CARROLL CL	EB	SALEM	2105	
F06V1S2	1	14	KING & QUEEN	RT 617 TO .02 MI W E RT 631	EB	FREDERICKSBURG	1765	
F06V2S1	2	156	PRINCE GEORGE	SE JAMES R B TO RT 10	SB	RICHMOND	4590	

continues

Table 8 (continued)

SAMPLE ID	YR	RTE	COUNTY/CITY	LOCATION	DIRECTION	DISTRICT	ADT	BRIDGE
F06V2S2	1	340	WARREN	N RT 613 TO RT 629	NB	STAUNTON	3985	
F06V3S1	2	8	FLOYD*	0.05 MI N INT RTE 730 TO 0.25 MI N INT RTE 705	NB	SALEM	7050	
F06V3S2	3	58	CARROLL*	0.41 MI W INT RTE 759 TO 0.12 MI W E INT RTE 872	EB	SALEM	7560	
F06V3S3	3	8	FLOYD*	0.05 MI N INT RTE 730 TO 0.25 MI N INT RTE 705	SB	SALEM	7050	
F06V4S1	3	258	ISLE OF WIGHT	RT 10 AND 32 TO RT 17	SB	SUFFOLK	17125	
F06V4S2	1	41	PITTSYLVANIA	S RT 1133 TO RT 835	SB	LYNCHBURG	11775	
F07V1S1	2	49	LUNENBURG	NOTTAWAY CL TO RT 723	NB	RICHMOND	1195	
F07V1S2	1	42	SHENANDOAH	.24 MI N RT 688 TO .25 MI N RT 691	SB	STAUNTON	450	
F07V1S3	3	138	MECKLENBURG	SE MEHERR RD TO RT 1	WB	RICHMOND	2025	
F07V1S4	3	31	SUSSEX	SURRY CL** TO ECL WAKEFIELD	EB	SUFFOLK	2205	
F07V1S5	3	250	GOOCHLAND	RT 632 TO RT 522	EB	RICHMOND	2140	
F07V1S6	1	61	BLAND	E RT 52 TO E RT 678	EB	BRISTOL	800	
F07V1S7	3	56	NELSON	RT 626 TO .16 MI E RT 639	WB	LYNCHBURG	1125	
F07V1S8	1	42	GILES	RT 100 TO .76 MI W RT 666	WB	SALEM	1045	
F07V2S1	2	55	WARREN	NCL FRONT ROYAL TO .02 MI W E RT. 614	EB	STAUNTON	3310	
F07V2S2	1	215	FAUQUIER	RT 29 TO PRINCE WILLIAM CL	WB	CULPEPER	4145	
F07V3S1	2	60	HENRICO*	0.46 MI W E INT RTE 156 TO 1.15 MI W INT RTE 295	EB	RICHMOND	6170	
F07V3S2	3	60	HENRICO*	0.46 MI W E INT RTE 156 TO 1.15 MI W INT RTE 295	WB	RICHMOND	6170	
F07V4S1	2	3	STAFFORD	RT 606 TO RT 218	EB	FREDERICKSBURG	16180	
F08V1S1	2	684	POWHATAN	CUMBERLAND CL TO RT 629	WB	RICHMOND	551	
F11V2S1	3	64	CHESAPEAKE*	0.63 MI W RTE 464 TO 0.79 MI E N&W RR	WB	SUFFOLK	46950	
F11V2S2	2	64	CHESAPEAKE*	0.63 MI W RTE 464 TO 0.79 MI E N&W RR	EB	SUFFOLK	46950	
F11V2S3	1	64	CHESAPEAKE*	0.63 MI W RTE 464 TO 0.79 MI E N&W RR	WB	SUFFOLK	46950	
F11V2S4	2	81	ROANOKE	SCL SALEM TO RT 112	NB	SALEM	29110	YES
F11V2S5	1	195	HENRICO	McCLOY ST TO .26 MI N McCLOY ST	SB	RICHMOND	31240	
F11V3S1	1	564	NORFOLK*	1.25 MI N INT RTE 64 TO ENT NORFOLK NAVAL BASE	SB	SUFFOLK	61180	
F11V3S2	2	564	NORFOLK*	1.25 MI N INT RTE 64 TO ENT NORFOLK NAVAL BASE	SB	SUFFOLK	61180	

continues

Table 8 (continued)

SAMPLE ID	YR	RTE	COUNTY/CITY	LOCATION	DIRECTION	DISTRICT	ADT	BRIDGE
F11V3S3	3	564	NORFOLK*	1.25 MI N INT RTE 64 TO ENT NORFOLK NAVAL BASE	NB	SUFFOLK	61180	
F11V3S4	3	95	HENRICO	NCL RICHMOND TO RT 1 UP	SB	RICHMOND	71590	
F11V4S1	1	64	VA BEACH	WCL VA BEACH TO INDIAN RIVER RD	EB	SUFFOLK	93390	YES
F11V4S2	3	64	NORFOLK	EE WILBAY DR TO NBL 4TH AVE	WB	SUFFOLK	79200	YES
F11V5S1	1	264	NORFOLK	EE RT 460 OP TO EE NW RR OP	WB	SUFFOLK	123580	YES
F11V5S2	2	66	FAIRFAX	.02 MI E WCL FAIRFAX TO ECL FAIRFAX	EB	NO. VIRGINIA	110590	YES
F11V6S1	3	95	ALEXANDRIA	WE POTOMAC RIVER TO ECL ALEXANDRIA	SB	NO. VIRGINIA	140000	YES
F11V7S1	3	395	ARLINGTON	ECL ALEXANDRIA TO RT 120	WB	NO. VIRGINIA	166950	YES
F11V7S2	2	95	FAIRFAX	RT 495 TO RT 613	NB	NO. VIRGINIA	169510	YES
F12V1S1	1	150	CHESTERFIELD	RT 1/301 TO .14 MI W RT 1/301	EB	RICHMOND	36855	
F12V2S1	2	265	PITTSYLVANIA*	INT RTE 1156 TO 0.15 MI S INT RTE 86	SB	LYNCHBURG	1960	
F14V3S1	1	501	CAMPBELL	SCL LYNCHBURG TO .22 MI N RT 670	NB	LYNCHBURG	7260	
F14V4S1	1	123	FAIRFAX	N RT 641 TO .04 MI S S RT 641	NB	NO. VIRGINIA	13617	
F14V5S1	1	23	SCOTT	SCL WEBER CITY TO .01 MI S RT 732	SB	BRISTOL	19895	
F14V6S1	3	360	HANOVER	E RT 360 BUS TO W RT 360 BUS	EB	RICHMOND	20285	
F14V6S2	3	29	CAMPBELL	RT 678 TO .09 MI N RT 678	SB	LYNCHBURG	22440	YES
F14V6S3	1	1	HENRICO	.21 MI N NCL TO NCL RICHMOND	NB	RICHMOND	21265	
F14V7S1	1	29	FAIRFAX	RT 655 TO WCL FAIRFAX	EB	NO. VIRGINIA	28870	
F14V7S2	3	419	ROANOKE	RT 904 TO RT 221	WB	SALEM	31105	
F14V7S3	2	123	FAIRFAX	RT 687 TO RT 1813	WB	NO. VIRGINIA	30020	
F14V7S4	2	419	ROANOKE	S RT 685 TO SCL SALEM	SB	SALEM	31225	
F14V8S1	2	17	YORK	.06 MI S RT 650 TO NCL NEWPORT NEWS	NB	SUFFOLK	37900	
F14V8S2	2	17	GLOUCESTER	RT 216 TO .18 MI S RT 216	NB	FREDERICKSBURG	40515	
F14V9S1	3	7	FAIRFAX	SBL RT 244 TO .05 MI W SBL RT 244	NB	NO. VIRGINIA	46990	
F16V3S1	1	416	RICHMOND	9TH ST TO HULL ST	EB	RICHMOND	9794	
F16V3S2	3	337	SUFFOLK	WCL CHESAPEAKE TO .38 MI W WCL	EB	SUFFOLK	6910	
F16V3S3	3	143	NEWPORT NEWS	0.12 MI N RT 17 TO 1.55 MI N RT 17	SB	SUFFOLK	9095	

continues

1499

Table 8 (continued)

SAMPLE ID	YR	RTE	COUNTY/CITY	LOCATION	DIRECTION	DISTRICT	ADT	BRIDGE
F16V4S1	1	58B	SUFFOLK	RT 337 TO RT 614	WB	SUFFOLK	10535	
F16V4S2	1	161	RICHMOND	WESTWOOD AVE TO RT 95 UP	EB	RICHMOND	11075	
F16V5S1	2	165	NORFOLK	RT 337 TO RT 460	SB	SUFFOLK	16481	
F16V5S2	3	460	NORFOLK	N&W RR TO WB RT 264 UP	EB	SUFFOLK	17290	
F16V6S1	1	409	VA BEACH	OLD HOMESTEAD TO WHITEHURST DR	WB	SUFFOLK	20494	
F16V7S1	3	460	NORFOLK	SE ELIZABETH RB TO RT 168	NB	SUFFOLK	31890	
F16V7S2	2	258	HAMPTON	RT 64 WBL TO .17 MI E 64 WBL (MERCURY BLVD/COLISEUM)	EB	SUFFOLK	34615	
F16V8S1	2	33	HENRICO	WBL RT 64 TO DICKENS RD	WB	RICHMOND	35750	
F17V4S1	2	1826	PRINCE WILLIAM	RT 1895 TO RT 1930	EB	NO. VIRGINIA	6037	
F17V5S1	3	631	ALBEMARLE	RT 29 TO .32 MI S RT 29	SB	CULPEPER	13148	

*SHRP sites.

**CL = county or city line; UP = underpass; OP = overpass; RB = river bridge.

Cost and Resources Planning

From the evaluation, it was estimated that for the 3-year cycle, the total cost would be $46,020 for 207 manpower days for data collection at 69 sites. The annual cost and manpower estimates were $15,340 and 69 person days. This assumed that there would be a crew of two technicians and that they would use 35 work days or about 15 percent of their time for this data collection. The cost of WIM equipment repairs or replacement parts and the need to repeat measurements at a site as a result of equipment failure were not included. Although it is acknowledged that such costs are likely, it is difficult to estimate them. It may be reasonable to increase the estimates by 10 or 15 percent to account for such costs. The revised annual cost and manpower estimates at a 15 percent increase would be $17,640 and 79 person days. The cost may be reduced about $2,000 if bridge WIM is used at all non-SHRP interstate sample locations. These estimates do not include costs for replacement of equipment. There is no way to address replacement cost with VDOT's current budget structure. When necessary, large expenditures are made to replace outdated or broken equipment in one budget year. There is a need for some type of accrual account that permits an allocation of an amount in a current account that may be used to provide a fund for equipment replacement.

Eighteen Kip Studies

One advantage of implementing a truck weight sampling plan is that it should reduce the number of 18 Kip ESAL studies for pavement design that are conducted. After the full 3-year data collection cycle is completed, it is hoped that the 18 Kip ESAL data for a particular functional classification will be used instead of 18 Kip studies for specific pavement design projects. The statistical confidence and precision level achieved for the functional classification group could be determined as part of an overall evaluation of the *TMG* truck weight sampling plan after the 3-year cycle is completed. To complicate matters, with 18 Kip studies, traffic loadings by lane are desired, whereas the *TMG*-formatted data does not consider lanes. Summary tables on ESAL values (by vehicle classification by lane) and on vehicle classification by lane should be useful.

During the 3-year cycle of data collection, an effort should be made to conduct the 18 Kip studies as requested. Using the portable WIM equipment, truck weight data should be collected using the guidelines in the previous section on data collection supplemented with vehicle classification counts in all other lanes. Data should be collected for a minimum of 24 hr. Because the data summary tables are based on a calendar day, data collection for a full calendar day is recommended.

Data Management

Data management has two elements: (1) the quality of the WIM data and (2) management of data from several sources.

It is important that the WIM data are accurate and appear reasonable. If the data are suspect, troubleshooting should be performed. After the data are processed, summary tables should be viewed for reasonableness. A process for editing individual truck weight records should be developed to minimize errors in the data base. The Wisconsin DOT uses a two-standard-deviation editing process; that is, trucks with a GVW varying from the mean GVW (by vehicle class from Wisconsin DOT's data base) by more than two standard deviations are eliminated.[6] The FHWA used the two-standard-deviation edit in computing sampling needs for the *TMG*.

Three data bases are in this plan: (1) *TMG* truck weight samples (*TMG* formatted data and summary tables), (2) SHRP WIM data, and (3) 18 Kip studies and other special studies. The Traffic Engineering Division or Information Services Division should develop a data management plan for these three data bases. Although the plan need not be elaborate nor complex, a substantial amount of data is involved, and a way of facilitating data management would be useful.

Plan Review

It is important that the *TMG* truck weight sampling plan satisfies the traffic loadings data needs of VDOT. Several WIM data problems were identified in the VDOT vehicle cost responsibility study. To resolve the data problems, which included a need for a coordinated WIM program, it was proposed that a data task force, consisting of the traffic monitoring data users and collectors in VDOT be developed.[7] Before this *TMG* truck weight sampling plan is implemented, it should be reviewed by the proposed task force to ensure that the traffic loadings data needs are met and that the capabilities and limitations of the plan are understood. The limitations identified in the following section should also be reviewed by the task force.

Limitations of the Proposed *TMG* Truck Weight Sampling Procedure for VDOT

The TMG truck weight sampling procedure begins with a statistically based monitoring system and then incorporates decisions that emphasize practicality. Practicality is achieved by decisions that result in a data collection plan that can be conducted with a modest or reasonable effort and that is flexible enough to be implemented by state DOTs with very diverse sizes of roadway systems and traffic conditions. The tradeoffs between statistical accuracy and practical decisions are described below for four features of the *TMG* truck weight sampling procedure. The fifth feature is more of a practical consideration.

1. Recommended reporting strata of interstate and all other roads (excluding local). One-third of the samples are arbitrarily assigned to the interstate.

Practical—By limiting reporting to two systems, the sample size required is reduced. The arbitrary decision assigning one-third of the samples to the interstate was made to ensure higher precision estimates and to focus on this system, which carries a substantial number of trucks.

Statistical—There are 10 functional classes of highways. For pavement design and other studies, reporting data by functional class would be useful.

2. Use of 3S2 trucks for sample estimation.

Practical—The 3S2 trucks were selected to guide the sample estimation process because these vehicles carry a high proportion of the traffic loadings. Also, because the ESAL variability of 3S2 trucks is significantly lower than other trucks, the number of samples is reduced.

Statistical—By selecting the vehicle class with the least ESAL variability for sample estimation, the statistical accuracy for other vehicle types is likely to be low; therefore, one can only state with any confidence the ESALs for 3S2 trucks.

Discussion—A Wisconsin DOT study states that although computation of exact statistical accuracy for each truck class may be desirable from an academic standpoint, in practice, most interest is centered on the 3S2.[8] In Wisconsin, the 3S2 trucks comprise 50 to 75 percent of the truck traffic at any given time and contribute 75 to 90 percent of the ESALs for all roads.[8] The VDOT 1985 Truck Weight Survey supports this finding by showing that the 3S2 vehicle contributes 85 to 89 percent of the ESALs for all roads.[9] However, for the two urban sites in the VDOT 1985 study (a minor arterial and collector), 3S2 trucks contributed 44.5 percent of the ESALs, and 2-axle-6 tire trucks contributed 30.7 percent.[9] If statistical accuracy were to be attained for each truck class, the sample sizes required would increase substantially to accommodate trucks that contribute only a small percentage of the ESALs. Moreover, it is likely that such a large data collection effort would be less cost-effective, and it may be impractical. On the other hand, it is suspected that on some functional class roads other vehicle classes contribute a significantly large percentage (above 30 percent) of ESALs. Very limited truck weight data are available on these classes. After the first cycle of data collection, the accuracy of ESALs can be determined, and revisions in sampling can be made as needed.

3. Distribution of samples to volume groups of a functional class.

Practical—A random sample of sections does not allow control over selected sections. Because there are more low-volume HPMS sample sections, there is a need to control the selected sections to increase the chance of high-volume sections being included. Therefore, the *TMG* distributes the samples to volume groups.

Statistical—When stratifying, each strata should have at least one sample. In Table 3, there are no samples allocated to a large number of volume groups.

Discussion—According to the *TMG*, the most theoretically correct but complex procedure for the distribution and selection of sample sections would be one that accounts for the probability of the selection of HPMS sections and the vehicle classification sample sections.[1] There may possibly be better ways to distribute the samples.

4. Multiple measurements at one sample section.

Practical—States may be better served by using multiple measurements at HPMS sites based on system mileage rather than single measurements at each site (see the Evaluation of Alternatives section). This also allows states to maximize the use of permanent WIM locations.

Statistical—A completely random sample would necessitate single measurement sites only.

5. Sample measurements exclusive of travel lane and direction.

In the interest of simplicity, the *TMG* excluded direction of travel and travel lane from the sample design. Because travel lane distribution is important in pavement design, there is a need to incorporate this item in the data output. One option is to edit, process, and analyze the data for the right lane only (or if desired, for each lane) and for all lanes in one direction.

RECOMMENDATIONS

1. The Traffic Engineering Division of VDOT should implement the *TMG* truck weight sampling plan with measurements from portable WIM from 69 sites and 21 measurements from 12 SHRP sites (including multiple measurements at 6 sites). Before implementation, the plan should be reviewed by a task force of WIM data users.

2. This plan should be evaluated after the initial 3-year cycle is complete to determine the level of statistical confidence and precision achieved for each functional class and to verify that it meets VDOT's needs. The evaluation should begin after the second year of the 3-year cycle is complete and should be scheduled to minimize delays in starting the second 3-year cycle. Any recommendations resulting from the evaluation should be implemented in the second 3-year cycle. It is suggested that the installation of permanent WIM on functional classes not represented by SHRP sites be considered.

3. The Traffic Engineering Division should implement a vehicle classification count program preferably in accordance with the *TMG*. This program should be developed and ready for implementation before the second 3-year truck weight sample cycle begins.

4. VDOT has several traffic monitoring programs, and traffic monitoring activities, including WIM, are increasing. Although several programs have been reviewed individually, there has been no review of all the traffic monitoring programs of VDOT. Consequently, there is a need to examine the entire VDOT traffic monitoring program for its effectiveness and its efficiency.

5. The Director of Finance should examine the feasibility of setting up a funding mechanism for the replacement of traffic monitoring equipment.

REFERENCES

1. Federal Highway Administration, Office of Highway Planning. 1985. *Traffic Monitoring Guide*. Washington, D.C.

2. Federal Highway Administration. Executive Director. March 2, 1988. Memorandum to Regional Federal Highway Administrators. Subject: Collection of Statistically Based Vehicle Classification and Truck Weight Data for Highway Design and Planning Purposes.

3. Cottrell, B.H., Jr. 1991. Evaluation of Weigh-In-Motion Systems—Final Report. VTRC 91-R. Virginia Transportation Research Council. Charlottesville, Virginia.

4. Garza, I. F., Cunagin, W. D., and T. Scullion. 1989. Traffic Monitoring Data Software (Phase I) Users Manual. Prepared for the Federal Highway Administration. Harlingen, Texas.

5. Field Highway Administration. 1989. *Highway Statistics 1989*. Washington, D.C.

6. Virginia Department of Transportation. 1991. Vehicle Cost Responsibility Study (SJR 121). Richmond, VA.

7. Tischer, M. L. March 29, 1991. Memorandum to R. D. Pethtel. Subject: Follow-up to SJR 121 Data Problems. Richmond, VA.

8. Wisconsin Department of Transportation. Division of Planning and Budget. 1987. Review and Revision of the Wisconsin Department of Transportation Statewide Truck Weight Study Program. Madison, Wisconsin.

9. Virginia Department of Transportation. 1986. 1985 Truck Weight Study. Maintenance Division, Richmond, VA.

ACKNOWLEDGMENTS

The contributions of the following are appreciated: Jan Kennedy for data analysis; Tammie Otto and Linda Barsel for preparing the final report; Roger Howe for report editing; and Gary R. Allen, James B. Robinson, Frank D. Shepard, Ken H. McGee, Cheryl Lynn, and Jack Jernigan for reviewing the final report. Cheryl Lynn's review of the TMG truck weight sample's statistical elements was especially helpful.

This study was supported by HPR funds administered through the FHWA.

APPENDIX A

Background on the *TMG* and VDOT's Monitoring of Truck Weights

BACKGROUND ON THE *TMG*

Highway Performance Monitoring System

The goals of the Highway Performance Monitoring System (HPMS) are (1) to provide a mechanism for assessing the performance of the highway system and the effectiveness of federal highway programs and (2) to provide a system for collecting, inputting, and retrieving information for a nationwide highway data base. The HPMS is also designed to reduce total data reporting, eliminate duplication, and above all, to coordinate data reporting requirements by the states. The objectives of the system are (1) to provide current data necessary for meeting congressional requirements and agency needs in a timely fashion; (2) to provide current statistics on the mileage and extent of the various highway systems; (3) to evaluate highway programs by monitoring changes in highway characteristics and performance based on detailed, section-specific data obtained on a sample basis; (4) to minimize the need for special data requests and special national studies; and (5) to be compatible with other data systems in order to permit meaningful comparisons.[1] Three broad monitoring levels are used in HPMS for each state: universe data, sample section data, and areawide data. The *Traffic Monitoring Guide* (TMG) is focused on the sample section data.

The HPMS universe consists of all public highways or roads within a state with the exception of roads functionally classified as local.[2] The reporting strata for the HPMS include type of area (rural, small urban, and individual or collective urbanized areas) and functional class. In rural areas, these classifications are interstate, other principal arterial, minor arterial, major collector, and minor collector. In urban areas, the classifications are interstate, other freeway or expressway, other principal arterial, minor arterial, and collector. A third level of stratification based on volume (i.e., 13 groups based on volume ranges) was added as a statistical device to reduce the sample size and to ensure the inclusion of higher volume sections in the sample. A complete definition of the stratification levels appears in Appendix F of the *HPMS Field Manual* (January 1984 or later versions).[3]

The HPMS sample design is a stratified random sample. The HPMS sample size estimation process is tied to annual average daily traffic (AADT), although nearly 100 data items are collected. The decision to use AADT was partly based on the fact that AADT is perhaps the most variable data item in the HPMS; consequently, the largest sample is produced. Therefore, the reliability of most other characteristics would be expected to exceed that of AADT.

The spatial sampling element in the HPMS was defined as a section of road. The use of sections acts to reduce sample size, to increase the precision of estimates, and to allow the use of existing state highway inventories. However, the use of road sections introduces additional constraints, which include the assumption that traffic volume and other characteristics or data elements remain constant within the defined section. The fact that some characteristics other than volume may not meet the assumption outright and that other characteristics may change drastically over time within the section requires the subdivision of sample sections.

The HPMS sampling element was defined on the basis of road sections that include both directions of travel and all travel lanes within the section. Direction of travel complicates the definition because characteristics can change drastically depending on the direction of travel. The same problems exist in the case of multilane facilities on which characteristics can change by lane of travel. In the interest of simplicity, direction of travel and travel lane were excluded from the sample design.

TMG

The recommended traffic monitoring sample design is shown in Table A-1. Emphasis is on the HPMS program element and its three sample subelements. All three samples consist of 48-hr measurements over a 3-year cycle. A measurement is defined as the collection of traffic monitoring data for a 48-hr period at one location. Traffic volume measurements are made at all HPMS sites with data collection at one-third of the HPMS sample sections each year. The vehicle classification sample consists of 300 measurements over a 3-year cycle that are distributed to strata based on HPMS annual vehicle miles traveled (AVMT) and randomly selected from the HPMS sample. The recommended truck weight sample consists of 90 measurements over a 3-year cycle distributed to strata based on AVMT and randomly selected from the vehicle classification sample. These guidelines are presented as minimum specifications. They can be expanded and supplemented to any degree as desired by the states.

SHRP Long-Term Pavement Performance

SHRP is a 5-year, $150 million highway research program authorized by Congress under the 1987 Highway Act.[4] It is funded through special state apportioned federal-aid highway funds. SHRP is administered through the National Research Council in cooperation with the Federal Highway Administration and the American Association of State Highway and Transportation Officials. Research is carried out by private sector organizations under contract to the National Research Council. SHRP's long-term pavement performance (LTPP) program seeks to develop better, longer-lasting pavements. By determining the relationships among the factors that influence pavement performance, SHRP is to develop refined pavement performance equations for use in pavement design.

Table A-1

RECOMMENDED TRAFFIC MONITORING SAMPLE DESIGN

Program Element	Sample Subelement	Period	Number	Products	Design (Target) Precision
1. Continuous	—	365 Days	40 to 60 (Average State) Temporal Distribution	Seasonality Growth	Annual Seasonal Factors *95–10*
2. HPMS	HPMS Sample	—	HPMS Sample	System Estimates By Functional Class	Stratum AADT (See HPMS Field Manual)
	Traffic Volume	48 Hours	Annual–1/3 of HPMS Sample 3-Year Cycle Full HPMS Sample	System AVMT By Functional Class AADT At Sample Points	Annual AVMT *(95-5)* (Excluding Local)
	Vehicle Classification	48 Hours	Annual–100 3-Year Cycle–300	Classified AVMT Axle Correction Factor Percentage Distribution of Vehicles	Statewide Percentage of 3S2's *95–10* (3-year)
Truck	48 Hours		Annual-30 Measurements: 10 Interstate 20 Others	Weight + ESAL by Classification Category	Interstate ESAL for 3S2 *95-10* (3-year) Other Roads ESAL for 3S2 *95–20* (3-year)
			3-yr 90 Measurements: 30 Interstate 60 Others		

continues

151c

Table A-1 (continued)

Program Element	Sample Subelement	Period	Number	Products	Design (Target) Precision
3. Special Needs (State Needs and Others)	—	—	At State Discretion	Site Specific Information Project Information I4R Truck Routes Pick-up/Auto Split Local Roads Any Others	—

Source: *Traffic Monitoring Guide.*

The LTPP project will observe pavement performance in the field under actual traffic conditions. More than 1,000 existing pavement sections in the U.S. and in cooperating countries will be monitored. These test sections were selected to reflect a broad variety of materials, designs, climates, sub-bases, loadings, and ages. The condition data will be statistically analyzed to develop pavement performance equations that are applicable to a wide range of site-specific conditions. The first statistical syntheses of the data will be conducted within 5 years.

All 50 states, Puerto Rico, the Canadian provinces, and several other countries have offered test sites. These highway agencies are to provide inventory data on the test sites, to conduct traffic count, classification, and weigh-in-motion studies, and to perform other support functions for SHRP. Traffic studies were to begin in the summer of 1991. Because SHRP LTPP sections require traffic and truck weight data , the FHWA has incorporated SHRP sites into the HPMS to avoid duplication of effort and to take advantage of the data collected for SHRP.

VDOT TRUCK WEIGHT AND *TMG* ACTIVITIES

Truck Weight Study

The Virginia Department of Transportation's primary source of truck weight data was the truck weight study, which is a biennial 8-hr survey using static scales, conducted by the Maintenance Division during the summer at 19 locations (including 12 permanent weigh stations). A 24-hr manual vehicle classification count was also conducted during the truck weight study. It was performed in conjunction with enforcement activities. The truck weight study was part of the statewide highway planning surveys that began over 40 years ago. The purpose of this data collection was to comply with the FHWA truck weight study. Data were sent to FHWA for compilation and processing. These surveys have now been replaced by procedures from the *TMG*. The truck weight survey data were provided to FHWA for the *TMG* data base because FHWA initially included data from static scales in the *TMG* data base. In 1988, use of WIM and procedures from the *TMG* became a priority. By 1990, it was FHWA policy to accept only WIM data.

Eighteen Kip Studies

The Materials Division requests 18 Kip (ESAL) studies for pavement design from the Traffic Engineering Division. Truck weight data are collected at the study site for an 8-hr period using portable static scales by the Maintenance Division. The 8-hr axle volumes are expanded by the Traffic Engineering Division to average daily axle volumes by use of appropriate expansion factors. Average daily traffic loadings data are calculated. Traffic is projected to the end of the pavement service life from the estimated completion date. The design 18 Kip ESAL are developed for the mean year (one-half of the service life). About ten 18 Kip studies are requested annually.

Vehicle Cost Responsibility Study

The General Assembly, through Senate Joint Resolution 121, required VDOT to review the cost responsibility of vehicle classes using the highways, roads, and streets of the Commonwealth and make recommendations to the 1991 General Assembly on the need for modifications to the current mix of revenues from the vehicle classes.[5] Data on truck weights were obtained from the 1989 truck weight study and a special WIM study. It was recommended that the vehicle cost responsibility study be conducted at least every decade.

WIM at SHRP LTPP Sites

There are 12 SHRP LTPP sites in Virginia, and there are plans to install permanent, continuously operating WIM systems in every lane in both directions at each site. Piezoelectric cable WIM systems will be used to collect traffic and truck weight data. Because SHRP sites are HPMS sites, these sites are included in the *TMG* truck weight sample to take advantage of the WIM data that will be collected. The opportunity to make more than one measurement (that is, 48 continuous hr) in the 3-year cycle at a SHRP site is discussed in the section on the development of alternatives.

Data from SHRP sites can provide much useful information not related to the *TMG*. The continuous data collected can provide information on seasonal and directional variations, traffic distribution by travel lane, and monthly and weekly summaries. Data variations on gross vehicle weight and ESAL by vehicle class are particularly useful for identifying trends. Speed, vehicle classification, and count data trends are also useful.

VDOT *TMG* Activities

Until 1989, VDOT's traffic count program consisted of a small number of continuous-count stations, an extensive annual manual-count program on the interstate and primary arterials, an urban-count program, and a secondary-count program. The manual counts were made for 12 hr and factored to obtain 24-hr counts. The manual counts contained up to 6 vehicle classification groups. The 6 groups were expanded to the FHWA Scheme F 13 classifications through factoring using the summer truck weight study vehicle classification data. Data on one-third of the 2,555 HPMS sites (as of Summer 1988) were supplied annually to FHWA from these count programs. Although accepted by FHWA and useful given the limitations of a manual count program, there was much room for improving the quality of traffic monitoring data. In 1989, VDOT began phasing in an automated traffic count program and ceased the manual count program. This program is still being implemented. A classification count program is expected to be added to the automated count program in the future.

Currently, there are 2,700 HPMS sites in Virginia including the 12 SHRP sites and 16 speed-monitoring locations. VDOT has 258 HPMS vehicle classification sites (including 38 on local roads). The 220 HPMS vehicle classification sites not on local roads formed the sample from which the truck weight sample was taken.

REFERENCES FOR APPENDIX A

1. Kittell, H. J. 1984. Effective Utilization of Data From the Highway Performance Monitoring System—Final Report. VTRC 85-R12. Virginia Transportation Research Council. Charlottesville, Virginia.

2. Federal Highway Administration, Office of Highway Planning. 1985. *Traffic Monitoring Guide*. Washington, D.C.

3. Federal Highway Administration. Office of Highway Planning. 1984. *Highway Performance Monitoring System Field Manual*. Washington, D.C.

4. Pavement Management Systems. SHRP North Atlantic Region Coordinator Office Contractor. 1989. Brochure on the Strategic Highway Research Program Long Term Pavement Performance. Amherst, N.Y.

5. Virginia Department of Transportation. 1991. Vehicle Cost Responsibility Study (SJR 121). Richmond, VA.

1522

APPENDIX B

HPMS PRESCRIBED VOLUME GROUPS

Table B-1

PRESCRIBED VOLUME GROUPS AND PRECISION LEVELS: RURAL

VOLUME GROUP	INTERSTATE (90–5)	OTHER PRINCIPAL ARTERIAL (90–5)	MINOR ARTERIAL (90–10)	COLLECTOR MAJOR (90–5)	COLLECTOR MINOR (80–10)
01	0 – 9,999	0 – 4,999	0 – 2,499	0 – 2,499	0 – 999
02	10,000 – 19,999	5,000 – 9,999	2,500 – 4,999	2,500 – 4,999	1,000 – 1,999
03	20,000 – 29,999	10,000 – 14,999	5,000 – 9,999	5,000 – 9,999	2,000 – 2,999
04	30,000 – 39,999	15,000 – 19,999	10,000 – 19,999	10,000 – 19,999	3,000 – 4,999
05	40,000 – 49,999	20,000 – 29,999	20,000 – 29,999	20,000 – 29,999	5,000 – 9,999
06	50,000 – 59,999	30,000 – 39,999	30,000 – 39,999	30,000 – 39,999	10,000 – 19,999
07	60,000 – 69,999	40,000 – 49,999	40,000 – 49,999	40,000 – 49,999	20,000 – 29,999
08	70,000 – 79,999	50,000 – 59,999	50,000 – 59,999	50,000 – 59,999	30,000 – 39,999
09	80,000 – 89,999	60,000 – 69,999	60,000 – 69,999	60,000 – 69,999	40,000 – 49,999
10	90,000 – 104,999	70,000 – 84,999	70,000 – 79,999	70,000 – 79,999	50,000 – 59,999
11	05,000 – 119,999	85,000 – 99,999	80,000 – 89,999	80,000 – 89,999	60,000 – 69,999
12	20,000 – 134,999	100,000 – 114,999	90,000 – 99,999	90,000 – 99,999	70,000 – 79,999
13	> or = 135,000	> or = 115,000	> or = 100,000	> or = 100,000	> or = 80,000

SOURCE: *Highway Performance Monitoring System Field Manual*

TABLE B-2

PRESCRIBED VOLUME GROUPS AND PRECISION LEVELS: URBAN

VOLUME GROUP	INTERSTATE (80–10)[1] (90–5)[2]	AND EXPRESSWAYS (80–10)[1] (90–5)[2]	OTHER FREEWAYS ARTERIAL (80–10)[1] (90–5)[2]	OTHER PRINCIPAL MINOR ARTERIAL[3] (90–10)[2]	COLLECTOR[3] 80–10)[2]
01	0 – 24,999	0 – 24,999	0 – 2,499	0 – 2,499	0 – 999
02	25,000 – 49,999	25,000 – 49,999	2,500 – 4,999	2,500 – 4,999	1,000 – 1,999
03	50,000 – 74,999	50,000 – 74,999	5,000 – 9,999	5,000 – 9,999	2,000 – 4,999
04	75,000 – 99,999	75,000 – 99,999	10,000 – 14,999	10,000 – 14,999	5,000 – 9,999
05	100,000 – 124,999	100,000 – 124,999	15,000 – 19,999	15,000 – 19,999	10,000 – 14,999
06	125,000 – 149,999	125,000 – 149,999	20,000 – 24,999	20,000 – 24,999	15,000 – 24,999
07	150,000 – 174,999	150,000 – 174,999	25,000 – 34,999	25,000 – 34,999	25,000 – 34,999
08	175,000 – 199,999	175,000 – 199,999	35,000 – 44,999	35,000 – 44,999	35,000 – 44,999
09	200,000 – 224,999	200,000 – 224,999	45,000 – 54,999	45,000 – 54,999	45,000 – 54,999
10	225,000 – 249,999	225,000 – 249,999	55,000 – 69,999	55,000 – 69,999	55,000 – 69,999
11	250,000 – 274,999	250,000 – 274,999	70,000 – 84,999	70,000 – 84,999	70,000 – 84,999
12	275,000 – 299,999	275,000 – 299,999	85,000 – 99,999	85,000 – 99,999	85,000 – 99,999
13	> or = 300,000	> or = 300,000	> or = 100,000	> or = 100,000	> or = 100,000

[1]Precision levels for *individual* urbanized areas.
[2]Precision levels for *collective* urbanized areas.
[3]For *individual* urbanized areas, use (70-15) precision level for state with 3 or more individual urbanized areas. Use (80–10) precision level for states with fewer than 3 individual urbanized area.
SOURCE: *Highway Performance Monitoring System Field Manual*