FINAL REPORT

A TRAFFIC DATA PLAN FOR MECHANISTIC-EMPIRICAL PAVEMENT DESIGNS (2002 PAVEMENT DESIGN GUIDE)

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ABSTRACT

The Virginia Department of Transportation (VDOT) is preparing to implement the mechanistic-empirical pavement design methodology being developed under the National Cooperative Research Program's Project 1-37A, commonly referred to as the 2002 Pavement Design Guide(2002 Guide). The developers of the 2002 Guide have stated that transportation agencies in compliance with the Federal Highway Administration's *Traffic Monitoring Guide* will have the traffic data necessary to implement the new pavement design approach. The 2002 Guide is structured in a hierarchical manner with three pavement design levels. For Level 1 designs, all project-specific data will be collected, including axle load spectra information (and axle loadings by vehicle classification) and vehicle classification counts at the project location. For Level 2 designs, regional and project-specific data will be applied. For Level 3 designs, estimated project-specific and statewide average or default data will be used in the analysis.

The purpose of this effort was to develop a plan to position VDOT to collect traffic and truck axle weight data to support Level 2 pavement designs. This report serves as the basis for implementing and maintaining the truck weigh program necessary for the new pavement design approach and provides data for the current pavement design process used in Virginia (i.e., the 1993 pavement design methodology of the American Association of State Highway and Transportation Officials).

To keep program costs at a minimum, the proposed traffic data program for pavement design takes advantage of the flexibility permitted in the *Traffic Monitoring Guide* and the availability of weigh-in-motion data from the Virginia Department of Motor Vehicles. Truck weight Groups 1 and 2, which consist of interstate and arterial roads, where the majority of truck loading occurs, are the first priority for implementation. A traffic data plan and a phased approach to implement the plan were proposed.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) is preparing to implement the mechanistic-empirical pavement design methodology being developed under the National Cooperative Highway Research Program's (NCHRP) Project 1-37A.[1] This project is commonly referred to as the 2002 Pavement Design Guide (2002 Guide). The methodology in the 2002 Guide is more sophisticated in many ways than the current VDOT pavement design methodology, and a major effort by VDOT will be required to implement it fully. However, when implemented, the new design approach should save VDOT millions of dollars in initial construction and premature maintenance costs. One of the key differences between VDOT's current methodology and that specified in the 2002 Guide is the increased emphasis on the actual load per axle used for determining stresses and strains in the pavement. VDOT currently converts axle weight data and combines them into an equivalent single axle load for a vehicle, which cannot be used to reflect the response of the pavement material to loading.

To implement the new pavement design methodology, VDOT established working teams to address the major components of the 2002 Guide. The Traffic Data Implementation Team was charged with evaluating VDOT's current traffic data collection procedures and determining what is required to comply with the Federal Highway Administration's (FHWA) *Traffic Monitoring Guide* (TMG).[2] Transportation agencies in compliance with the TMG will have the traffic data necessary to implement the new pavement design approach in the 2002 Guide.

The 2002 Guide is structured in a hierarchical manner with three pavement design levels. For Level 1 designs, all project-specific data will be collected. For traffic data, this means collecting axle load spectra information (this includes axle loadings by vehicle classification) and vehicle classification counts at the project location. For Level 2 designs, regional and project-specific data will be applied. For traffic data, this means collecting project-specific vehicle classifications with regional axle load spectra data. For Level 3 designs, estimated project-specific and statewide average or default data will be used. Traffic data will include project-specific average annual daily traffic and statewide average axle load spectra data. Weigh-in-motion (WIM), the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of a static vehicle,[3] is used to collect truck weight or axle load data.

The hierarchical levels require different degrees of effort to collect and analyze the data. VDOT's 2002 Pavement Design Steering Committee determined that Level 2 quality traffic data would be sufficient for the vast majority of construction and maintenance projects. Level 2 data would be used for projects on interstate and primary routes and selected secondary routes. Collection of Level 1 data for a limited number of projects would not be the focus of the traffic data team because of excessive costs and unreliable portable WIM technology. Based on the information provided from the developers of the 2002 Guide, if VDOT complies with the provisions of the recommended WIM program detailed in the TMG,[2] Level 2 pavement designs can be supported.

BACKGROUND

Traffic Monitoring Guide

The TMG[2] provides recommendations and best practices for the collection of traffic monitoring data. The new (May 2001) TMG recommends that the number of locations where data are to be gathered correlate with the level of variability in truck weights. This was done in recognition of the major cost and difficulties involved in collecting accurate truck weight data. The objective of the TMG's recommendations is to ensure that each state collects accurate truck weight data to meet agency needs. This is accomplished by:

- defining truck weight roadway groups (so that each road within a group carries truck weights per vehicle type that are similar to those of other roads within the group)
- collecting weight data from at least six sites within each group
- collecting data on the day-of-week and seasonal changes in vehicle weights that occur within each group
- paying specific attention to the calibration of the WIM equipment used for the data collection.[2]

Unlike the volume and classification data programs, which in Virginia consist of 270 continuous count locations supported by approximately 17,000 geographically dispersed short-term coverage counts, the truck weight program recommends collecting data at a relatively small number of locations designed to be representative of much larger groups of roads. The cost of weight data collection and the limitations in available equipment are the main reasons the truck weight program uses a small number of sites. The TMG provides states with flexibility in their program.

Truck Weight Roadway Groups

The TMG[2] recommends that each state divide its roadway system into "truck weight roadway groups" so that each road within a group has truck loading patterns (in terms of vehicle weights per vehicle, not total tonnage using the roadway) similar to those of other roads within the group. Further, it recommends using the characteristics of the freight moved on the roads to help create the roadway groups. This can be accomplished by understanding the type of commodities carried, the vehicles used, and the freight movement function performed by each road. (For example, does the road serve primarily as a through-truck route? Does it serve as a farm-to-market road? Does it provide access to specific types of heavy industry or mining areas? Does it serve conventional urban/suburban development patterns?)

States are encouraged to adopt truck weight groups that can be easily applied within the state and can provide a logical means for discriminating between roads that are likely to have very high load factors and roads that have lower load factors. Vehicle classification counts are helpful in the development of the truck weight groups.

Recommended Number and Location of Counts

The size of any state's weight data collection program will be a function of the variability of the truck weights (the number of weight groups created) and the accuracy and precision desired to monitor and report on those weights. The more count locations measured within a weight group, the better the highway agency will understand the weights present on the group of roads. The truck weight monitoring locations cannot be selected in a random or even semi-random manner because of equipment and site selection considerations.

Vehicle weights within each truck weight group should be measured by a number of WIM sites located within the group. The TMG[2] recommends six sites per truck weight group. This number is based on an analysis of the desired precision levels of the sample size base on the gross vehicle weight of Class 9 (five-axle tractor-trailer) vehicles using sample data from a state.

Truck Weighing and Traffic Monitoring in Virginia

VDOT's Experience with WIM Systems

VDOT's Mobility Management Division (MMD) is responsible for the collection and distribution of traffic data. Division staff had extensive experience with piezoelectric sensor–based WIM systems for a 10-year period beginning in 1990. Piezoelectric sensors were installed in 13 locations for the collection of truck weight data to support the Long-Term Pavement Performance Program (LTPP). Piezoelectric output signals change greatly with temperature changes, pavement wear, roadway bending, site smoothness, vehicle tire type, air pressure, and piezoelectric sensor aging.

Temperature change is the single biggest issue that makes the performance of this device difficult to predict. Most piezoelectric sensor–based systems provide an auto calibration feature to provide for this correction factor. When auto calibration is used, the system dynamically changes its weight gain values based on vendor equipment design rules, site conditions, and weights assumed for the site. Several auto calibration methods have been used in an attempt to resolve the temperature issue, but none was able to produce data results that consistently met the standards of the American Society of Testing and Materials (ASTM).[3]

Weight Data Collection Status

Currently, VDOT does not collect weight data. This function is performed by the Virginia Department of Motor Vehicles (DMV) for weight enforcement purposes only. DMV has static weigh stations supplemented by WIM at some locations for screening trucks for static weighing. Several other WIM systems are either planned, under construction, or non-functional. Although DMV does not store the WIM data generated at the weigh stations, they have provided VDOT access to some WIM data. Therefore, VDOT may be able to use the DMV truck weight data in the short term and perhaps long term, depending on the quality of the data.

From the experiences of VDOT and other transportation agencies, the only method to collect reliable, long-term truck weigh data is through the use of bending plate scales or single load cell WIM. Other technologies such as the piezoelectric sensors mentioned previously have been tried, but none has the required data integrity and longevity (i.e., remain functional for 5 years or more).

Project-specific vehicle classification data will be used to supplement the regional or truck weight group WIM data. VDOT's current traffic monitoring program provides for ample classification data to meet the project-specific vehicle classification needs of the Level 2 design requirement. All 270 continuous count stations are designed to collect vehicle classification data. These stations are located statewide and on all types of road systems with the exception of roads designated as local. In addition, more than 6,100 of the 17,000 short-term counts include the collection of vehicle classification data. The program goal is to have a vehicle classification sample on every roadway functionally classified as collector or above. Should the traffic data collected from these two regular program sources not meet the design needs of the new guide, VDOT has a robust special count program in which a project-specific vehicle classification sample can be requested and normally be available within 6 weeks of the date of the request.

PURPOSE AND SCOPE

The purpose of this effort was to develop a plan to position VDOT to collect traffic and truck axle weight data to support Level 2 pavement designs (as per the 2002 Guide[1]). This report serves as the basis for implementing and maintaining the truck weigh program necessary for the new pavement design approach and provides data for the current pavement design process used in Virginia (i.e., the 1993 pavement design methodology of the American Association of State Highway and Transportation Officials).

METHODS

Five tasks were undertaken to achieve this purpose.

1. Develop truck weight groups. The TMG[2] provides much flexibility in defining truck weight groups. The team started small, used highway functional classifications, and focused on the roads that have most of the truck traffic. Truck volumes on interstate and arterial roads were examined using the 2001 vehicle classification counts. Each direction of a route was analyzed. As suggested in the TMG, FHWA Class 9 (five-axle tractor-trailer units) was used to represent truck traffic. Since VDOT data are grouped by FHWA vehicle Classes 8 through 10 for tractor-trailer units, this group was used to divide high and low truck volumes on interstate and arterial routes. Class 9 trucks are the predominant class among the three combined classes. The tractor-trailer truck volumes were used to identify a point for dividing high and low truck volumes on interstate and arterial routes.

2. Develop the criteria for site selection. ASTM has developed specifications and test methods for WIM systems.[3] The criteria specified in ASTM E 1318-02 were used as the criteria for site selection in this study.

3. Develop the site selection process. From the process to develop truck weight groups in Task 1, a spreadsheet based on 2001 vehicle classification counts by direction assigned road sections to truck weight groups.

4. Estimate the cost to implement the plan.

- Select the technology.
- Calculate the configuration and installation costs.
- Outline and estimate personnel requirements and costs.
- Estimate the annual operating and maintenance costs.

5. Define the benefits of implementing the traffic data plan.

- Estimate the potential savings from improved pavement designs.
- Compare the annual savings with the costs of the implemented program.

RESULTS

Truck Weight Groups

About 40 percent of the interstate and arterial road sites have less than 200 tractor-trailer trucks on average per day. If the other 60 percent are focused on, a possible dividing point to form two truck weight groups is 1,000 tractor-trailer units per day. The proposed truck weight groups are:

1. interstate and arterials with high truck volumes (1,000 or more tractor-trailers per day)

2. interstate and arterials with low truck volume (fewer than 1,000 tractor-trailers per day)

3. minor arterials and major collectors.

The volumes are for one direction only.

Criteria for Site Selection

In essence, ASTM Standard E 1318 requires that a site selected for a WIM device be a straight, level section of roadway. More specifically, six elements of the ASTM standard relate to site selection:

> 6.1.1 *Horizontal Alignment*—The horizontal curvature of the roadway lane for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall have a radius not less than 5700 ft (1.7 km) measured along the centerline of the lane for all types of WIM systems.
>
> 6.1.2 *Longitudinal Alignment (Profile)*—The longitudinal gradient of the road surface for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM system sensors shall not exceed 2% for Type I, Type II, and Type III WIM-system installations, and shall not exceed 1% for Type IV installations. [The WIM Types are defined by their purpose, the types of information collected, and accuracy. In general, Types I and II are used for traffic monitoring and Types III and IV for weight enforcement.]
>
> 6.1.3 *Cross Slope*—The cross-slope (lateral slope) of the road surface for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall not exceed 3% for Type I, Type II, and Type III WIM system installations, and shall not exceed 1% for Type IV installations.
>
> 6.1.4 *Lane Width and Markings*—The width of the paved roadway lane for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall be between 12 and 14 ft (3.6 and 4.3 m), inclusive. For Type III, except those with sensors in the main highway lanes, and Type IV WIM systems, the edges of the lane throughout this distance shall be marked with solid white longitudinal pavement marking lines 4 to 6 in. (100 to 150 mm) wide. At least 3 ft (1 m) of additional clear space for wide loads shall be provided on each side of the WIM-system lane.
>
> 6.1.5 *Surface Smoothness*—To allow reliable WIM-system performance within the tolerances shown in Table 2, the surface of the paved roadway 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall be smooth before sensor installation and maintained in a condition such that a 6-in. (150-mm) diameter circular plate 0.125-in. (3 mm) thick cannot be passed beneath a 20-ft (6-m) long straightedge when the straightedge is positioned and maneuvered in the following manner:
>
> 6.1.5.1 Beginning at the longitudinal center of the WIM system sensors, or sensor array, place the straightedge along each respective lane edge with the end furthest from the sensors at the distances from the longitudinal center of the sensors as indicated below. Then pivot the straightedge about this end, and sweep the end nearest the sensors between the lane edges while checking clearance beneath the straightedge with the circular plate.

> 6.1.6 *Pavement Structure*—The user shall provide and maintain an adequate pavement structure and surface smoothness to accommodate the WIM-system sensors throughout their service life and shall install and maintain the sensors in accordance with the recommendations of the system vendor. Experience has indicated that a Portland cement concrete (also called rigid) pavement structure generally retains its surface smoothness over a longer period of time than a bituminous (also called flexible) pavement structure under heavy traffic at a WIM site. Consideration should be given to providing a 300-ft (90-m) long continuously reinforced concrete pavement (CRCP) or a jointed concrete pavement (JCP), with transverse joints spaced 20 ft (6 m) or less apart, at permanent WIM sites on freeways and principal arterial highways. (See Terminology E 867 for definitions of pavement types.) The surface of every such rigid pavement should be ground smooth after curing and before installing WIM sensors. The user should assure that the skid resistance (See Terminology E 867) of the surface after grinding is at least as good as that of the adjacent surfaces. At a site with flexible pavement, a 50-ft (15-m) long section comprising full-depth-asphalt, or black-base, design should be considered for installation at each end of the Portland cement concrete pavement structure to effect a stiffness transition between the two pavement structural types. Maintenance, replacement, or repair activity at a WIM site under traffic is hazardous and expensive; therefore, the installation should be done right the first time.[3]

Some in the industry consider jointed concrete pavement a best practice. Their experiences reveal that the continuous reinforced concrete pavement has not held over time, and there is no benefit from the extra effort and cost of installing this type of concrete runway. Therefore, jointed concrete pavement is strongly recommended by these individuals. Another recommendation made by some in the industry is the use of a 500-foot section instead of a 300-foot section. Both of these recommendations are provided in the LTPP installation guidelines.[4] VDOT staff believes that the 300-ft long section recommended by ASTM is sufficient and is certainly less costly.

For a WIM data program to be successful, it is important that managers of the data collection program and pavement management personnel work together to ensure that WIM sensors are installed in the best condition possible to provide for longevity and quality of the data collection effort. The program management effort and maintenance requirements should incorporate safety as well as operational issues.

Site Selection Process

DMV has installed several load cell WIM sites on Virginia's interstates and selected primaries. The WIM systems are used to screen trucks for weighing on static scales. Data records are not stored in an electronic system (databases or spreadsheets) where they can be retrieved and used for traffic monitoring purposes. DMV Motor Carrier Services' management supports VDOT's use of its WIM data for traffic monitoring. VDOT staff has begun the process of developing a system where VDOT will collect WIM data from four DMV truck weight screening locations as part of the Traffic Monitoring System Program. The locations for truck weight Group 1 are I-77 (Bland County), I-95 (near Carson), and I-81 (Stephens City). For truck weight Group 2, the U.S. 58 (Suffolk) weigh station is the only site operating. Another DMV truck site in Group 2 on U.S. 522 in Frederick County needs repair but should become operational during the implementation period. Tapping into the existing WIM systems operated by DMV yields some truck weight data relatively quickly and inexpensively. Once the data collection is underway, an analysis will be conducted to verify that the data from the DMV-provided sites are useful for pavement design.

A WIM system is planned for S.R. 288 as part of its pavement warranty; this site will likely be in truck weight Group 2. As part of a national research effort on the LTPP, a bending plate WIM is planned for the specific pavement study site on U.S. 29–Danville Bypass. This site is part of truck weight Group 2. Funding for these two sites is provided externally to this effort. The candidate sites are shown in Table 1.

In essence, to meet the "six site per group" recommendation of the TMG,[2] VDOT will need three additional sites on arterials for truck weight Group 1 and two sites for Group 2. The sites should be distributed geographically across Virginia and by truck volumes. Because of the size of the capital investment, the installation of the WIM system and supporting concrete section should be done in conjunction with pavement rehabilitation programs. Truck weight Groups 1 and 2 are identified in a spreadsheet. From the spreadsheet, tables will be developed to identify the road sections in truck weight Groups 1 and 2 by district. These tables will list candidate sites for installation of a WIM system. VDOT's Materials Division will contact the district materials engineers to determine if any projects in VDOT's Capital Improvement Program match the need and criteria for candidate WIM sites. If yes, then MMD staff will conduct an in-house screening and a field review of the site and report back to the Materials Division. If the site is approved from a technical perspective, funds will be sought for the installation. If particular sites offer multiple benefits where WIM may be needed for other purposes, these sites will also be considered.

Table 1. Initial Candidate Sites for Truck Weight Groups 1 and 2

Truck Weight Group 1	Truck Weight Group 2
I-77 Bland County (DMV)	US 58 Suffolk (DMV)
I-81 Stephens City (DMV)	SR 288
I-95 Carson (DMV)	US 29 Danville Bypass
	US 522 Frederick County (DMV) pending

Cost to Implement the Plan

Selection of Technology

Although the TMG[2] encourages the use of portable WIM, there is no portable WIM system on the market that can provide reliable, quality, WIM data. Therefore, VDOT plans to use permanent WIM systems for continuous operations. When properly installed and maintained, load cells and bending plates are the two WIM sensors or scales that provide data to meet ASTM data collection standards.

As a means of reducing cost, consideration was given to using bending plates instead of load cells as the primary WIM sensor. A bending plate system for one lane costs about $50,000, which is $100,000 less than the cost of the load cell. Bending plates have been associated with safety issues in other states on high-volume roads. The plate has a tendency to move out of its position in the pavement and create a hazard. In a neighboring state, a bending plate came out of the road 1 week after it was field inspected. A bending plate weighs 200 to 400 lb compared to a load cell, which weighs 4,500 lb. Therefore, a loose load cell is not likely to move. VDOT has a major concern regarding public safety in the event a bending plate came loose. Therefore, based on these factors and information from other states' experiences with bending plates, a load cell is the preferred WIM sensor at this time.

The use of piezoelectric sensors to reduce costs was also considered. Based on VDOT's experience (discussed in the background section of this report), the output of the piezoelectric sensor proved to be extremely temperature sensitive, and system performance did not reliably comply with ASTM standards (+/- 30 percent per axle load and +/- 15 percent on gross vehicle weight) in Virginia. Although the cost of piezoelectric sensors is very small compared to the costs of the bending plate and single load cell, the performance of these sensors has been unacceptable. Given these facts, the piezoelectric sensors are not appropriate for WIM at this time.

The load cell, more expensive and more durable, is suggested for use in higher traffic and truck volume locations and/or where data collection is needed over a longer duration. The bending plate is more economical for shorter-term data collection needs (5 years or less).

Configuration and Installation Costs

For truck weight Groups 1 and 2, load cells are recommended. These two groups are deemed priorities since the majority of truck loadings will occur on these roadways. A typical WIM site will include one lane (outside or right lane) with a WIM and vehicle classification sensors and the remaining lanes in the same direction serviced with vehicle classification sensors.

Installation costs estimates are as follows:

Load cell and vehicle classification for one lane	$150,000
Concrete section for two lanes	230,000
Vehicle classification, only, for second lane	10,000
Total for one direction (two lanes) of a four-lane divided roadway	$390,000

The cost of the concrete section for two lanes was based on a 300-ft section of jointed concrete.

The total cost estimate to install load cell WIM and vehicle classification at five sites for truck weight Groups 1 and 2 is $1.95 million. It is expected that the installations would be spread over 5 years, for an annual cost of $390,000.

For the minor arterials and major collectors, truck weight Group 3, six sites would be required. Although these sites are needed to satisfy Level 2 designs and the TMG,[2] they are not the first priority. Therefore, these sites are envisioned as being constructed as part of future phases, such as a Phase III WIM installation. Moreover, it is hoped that a reliable portable WIM system may be available within 5 years to aid in satisfying data requirements for these sites. Otherwise, bending plates may be recommended for use, with caution, depending on the location.

Personnel Requirements and Cost

The proposed WIM program will be a new function for the MMD and its Traffic Monitoring System Section. The MMD will support the WIM effort by maintaining the sites; collecting, processing, analyzing, and storing the data; and providing the data to customers.

Additional personnel are required to implement and manage a program of this size. The anticipated maximum employment level requirements were submitted for the section via the 2003 Workload Planning System Review. Total full-time equivalents (FTEs) required for the WIM mission were submitted as 10. Of this number, approximately 7 would be contract employees who would perform the installation, maintenance. and calibration functions. (Based on changes in the traffic data plan since the FTE submittal, 0.4 contract employee is currently needed.) To ensure proper program management, state forces are required for 3 of the FTE positions. These 3 personnel would perform not only the contract preparation, management, administration, and inspection functions, but also the data analysis and reporting functions that are critical to the success of the program. The estimated annual cost for these three positions is $150,000.

Annual Operating and Maintenance Costs

A key piece of the annual operating and maintaining costs is whether to purchase WIM systems or to lease the equipment with payment based on data quantity and quality. Leasing equipment lowers the upfront costs but would significantly increase annual operating costs. A full analysis would have to be conducted to determine the recommended approach. The estimates shown here are based on purchasing the WIM system with no annual lease costs. The operating and maintenance costs are estimated based on the average annual costs for operating the WIM and vehicle classification systems for 5 years. The DMV sites have no significant costs other than personnel costs covered elsewhere.

The annual estimated operating and maintenance costs per lane are as follows:

Load cell	$21,000
Vehicle classification	2,000
Total per two-lane site	$23,000
Total per three-lane site	$25,000.

It is estimated that the costs for maintaining the bending plate system planned for S.R. 288 would be about the same as the costs for the load cell system. For year 1, two WIM sites are assumed; for year 2, three; for year 4, five; and for year 5, seven.

Contracts would be used for station installation and maintenance. Proposed costs would be the installation cost estimates provided in the earlier documents plus these annual maintenance costs. The key controlling factor for the total is the number of sites installed per year.

Total Annual Costs

By combining the initial, personnel, and operating and maintenance costs, the total cost to implement the program is estimated in Table 2.

The annual cost increases from $509,000 to $701,000 over the 5-year period are to implement, operate, and maintain traffic monitoring systems at the sites for truck weight Groups 1 and 2. The estimated costs beyond year 5 are increasingly uncertain. If additional WIM installations replace DMV sites, the costs will continue to increase at a similar pace as shown in Table 2. At year 5, the program will be evaluated to determine if these two truck weight groups are sufficient for the interstate and arterial systems.

Table 2. Estimated Total Costs ($) for First Five Years of Program

Costs	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Installation	390,000	390,000	390,000	390,000	390,000	1,950,000
Personnel	50,000	100,000	100,000	150,000	150,000	550,000
Operating and Maintenance	69,000	92,000	115,000	138,000	161,000	575,000
Total	509,000	582,000	605,000	678,000	701,000	3,075,000

Benefits of Implementing the Traffic Data Plan

Many factors must be considered when developing pavement designs for new construction, for reconstruction, and for maintenance projects. Two factors have a large influence on the pavement structure: subgrade soils and traffic. The current and predicted loading on the pavement determines the thickness of the structure. In the last few years, VDOT has made tremendous strides in collecting accurate traffic count data. However, more effort is needed in collecting accurate truck weight data. Truck weight data by axle are necessary in the current pavement design process but are even more important in the 2002 Guide.
Several investigators have shown the benefits of an implemented WIM program. Gardiner et al. stated:

> Highway agencies typically want to maximize the serviceability of the road. Data collected from the WIM system is [*sic*] used to strategically determine the appropriate time when road maintenance and repairs must be done in order to ensure at least the minimum level of serviceability. The data is [*sic*] also used to predict future road planning issues along the highway, such as traffic volume and distribution, as well as to evaluate the occurrence of overweight vehicles and the effectiveness of regulatory efforts.[5]

Bergen et al. also found:

> WIM systems provide economic benefits in many respects. WIM systems provide invaluable traffic data for better planning and management of maintenance and new construction activities. Accurate loading data provides highway officials with the opportunity to adjust their maintenance and rehabilitation schedules based on actual levels of deterioration. For example, rehabilitative maintenance may be performed two years earlier than scheduled or more frequently if the traffic volumes exceed the design volumes. This ensures that rehabilitative maintenance is timed correctly, rather than after the structural integrity of the road has already been breached. Since maintaining a good road is five times less expensive than rehabilitating a poor one, it is important to prevent roads from deteriorating. Furthermore, since rehabilitating a bad road is much less expensive than new construction, it is very important to avoid reconstruction and new construction wherever possible. A recent study done on I-66 in Kentucky estimated new construction costs for conventional interstate highways at between $11 million per mile to $19.3 million per mile. WIM systems also allow transportation officials to plan new construction based on actual pavement loadings. Using WIM data, much of the guesswork involved with estimating traffic conditions is eliminated, allowing for more suitable designs. Thus, pavement designs are not under designed, nor over designed, both of which are costly situations to remedy.[6]

Potential Savings from Improved Pavement Designs

Every year, VDOT spends more than $600 million in materials by paving more than 1,000 miles on construction and maintenance program projects. Although having reliable weigh data from the WIM systems may not reduce the amount of money spent, the data will assist in ensuring the right treatment is applied to the road. Over a period of time, the true benefits of a WIM system will be realized in optimal pavement designs and in timing of treatments.

By having reliable truck axle weigh data, more accurate pavement designs can be calculated. By simply reducing the pavement thickness by ½ in over a 1-mile section of roadway, VDOT would save $15,000 in material costs alone. Conversely, if additional structure is required to carry the traffic volumes but is not constructed because of a lack of accurate weight data, VDOT will be spending money earlier than anticipated because of premature failures. Savings, whether in initial construction, future maintenance, or user costs, can be realized by constructing a section adequate for the imposed conditions. The potential savings is enormous for construction and maintenance projects.

Annual Savings vs. Costs of Implemented Program

It is difficult to estimate the magnitude of potential benefits because data are not available on the frequency of under- and over-designing of pavement. However, the magnitude of the potential savings may be illustrated. If the pavement on 10 percent of the more than 1,000 miles paved annually could be reduced by ½ in (10 percent of 1,000 miles times $15,000 per mile), $1,5 million could be saved per year. With 5 percent, the potential savings would be $750,000 per year. This does not include the benefits of not under-designing a highway. At 5 percent, the potential benefit would exceed the cost of implementing the program for each of the first 5 years. The annual cost range over the first 5 years of the program would be $509,000 to $701,000.

CONCLUSIONS

- *The proposed traffic data program for pavement design takes advantage of the flexibility permitted in the TMG and the availability of WIM data from the DMV to keep program costs to a minimum.*

- *Truck weight Groups 1 and 2, which consist of the interstate and arterial roads, where the majority of truck loading occurs, should be the first priority for implementation. Load cell WIM sensors are more appropriate for new sites in these groups.*

- *The potential benefits of implementing the proposed program exceed the estimated costs on an annual basis.*

RECOMMENDATIONS

1. *The proposed traffic data program should be reviewed and approved by the following entities in VDOT in the following order: the VDOT 2002 Pavement Design Committee, the State Materials Engineer, and the Chief Engineer for Program Development.* The MMD and Asset Management Division should provide support for and assistance in implementing the program. Emphasis should be given to all of the resources needed to implement the program.

2. *The Materials Division (Pavement Design Section) and the MMD (Traffic Monitoring Section) should work closely to implement this program.* These divisions, with assistance from the Virginia Transportation Research Council, should evaluate the effectiveness of the program during critical stages of its implementation. The evaluation should include an assessment of the data obtained from the DMV sites within the first 6 months of implementation. Later assessments should include the effectiveness of the truck weight groups.

IMPLEMENTATION PLAN

Three truck weight groups are proposed to achieve the criteria for Level 2 in the TMG[2]:

1. interstate and arterials with high truck volumes (1,000 or more tractor-trailers per day)

2. interstate and arterials with low truck volumes (less than 1,000 tractor-trailers per day)

3. minor arterials and major collectors.

These volumes are for one direction only.

The traffic data program proposed in this study should be implemented in three phases. Phase I would include the five DMV sites and WIM sites listed in Table 3. The sites that are operational could be included as soon as the program is initiated. Other sites would be added as soon as they become operational. The MMD's Traffic Monitoring Section would develop the tables to identify the road sections in truck weight Groups 1 and 2 by district. These tables would list candidate sites for installation of a WIM system. The effectiveness of the program should be evaluated during critical stages of its implementation. The evaluation should include an assessment of the data obtained from the DMV sites within the first 6 months of implementation.

In Phase II, five additional load cell sites would be selected and systems would be installed. This phase would establish the remaining sites necessary to provide six sites per weight group. VDOT's Materials Division would contact the district materials engineers to determine if any projects on the Capital Improvement Program match the need and criteria for candidate WIM sites. If so, VDOT's MMD staff would conduct an in-house screening and a field review of the site and report back to the Materials Division. If the site was approved from a technical perspective, funds would be sought for the installation. If there were sites that might offer multiple benefits where WIM might be needed for other purposes, such sites would be considered as well. For illustration purposes, one would be implemented each year. The WIM installations would be phased in over time to gain experience at one or two sites, to benefit from lessons learned for future sites, and to spread the costs over time. If funding was available, more than one site might be implemented annually. The effectiveness of the program in meeting VDOT's needs and satisfying the criteria in the TMG[2] should be assessed.

Phase III, the implementation plan for monitoring traffic for minor arterials and major collectors, truck weight Group 3, would be developed near the completion of Phase II. The initial step would be to determine the WIM technologies, especially new ones, that are available and appropriate for these types of roads.

Table 3. Initial Candidate Sites for Truck Weight Groups 1 and 2

Truck Weight Group 1	Truck Weight Group 2
I-77 Bland County (DMV)	U.S. 58 Suffolk (DMV)
I-81 Stephens City (DMV)	S.R. 288
I-95 Carson (DMV)	U.S. 29 Danville Bypass
	U.S. 522 Frederick County (DMV) pending

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REFERENCES

1. National Cooperative Highway Research Program. *Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase II.* Project 1-37A. Washington, D.C., 2002. http://www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+1-37A. Accessed September 2003.

2. Federal Highway Administration. *Traffic Monitoring Guide.* Washington, D.C., 2001. http://www.fhwa.dot.gov//ohim/tmguide/index.htm. Accessed September 2003.

3. American Society of Testing and Materials. *Designation: E 1318-02, Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods.* West Conshohocken, Pa., 2002.

4. Federal Highway Administration. *LTPP Bending Plate Weigh-in-Motion System: Model Specifications for Pavement and Installation.* McLean, Va., 2001.

5. Gardiner, A. S., C. Berthelot, and T. Bergan. Role of Weigh-in-Motion in Performance Based Contracts. March 2002. http://www.irdinc.com/english/pdf/tech_ppr/ICWIM-FINAL-March2002.pdf. Accessed September 2003.

6. Bergen, A.T., N. Lindgren, C. Berthelot, and B. Woytowich. *Preserving Highway Infrastructure Using Weigh-in-Motion (WIM).* November 1998. http://www.irdinc.com/english/pdf/tech_ppr/highway_preservation.pdf. Accessed September 2003.