REPORT OF THE
VIRGINIA DEPARTMENT OF TRANSPORTATION ON

Weight Limits for Trucks Hauling Gravel, Sand or Crushed Stone in Certain Southwest Virginia Counties

TO THE GOVERNOR AND
THE GENERAL ASSEMBLY OF VIRGINIA

HOUSE DOCUMENT NO. 18

COMMONWEALTH OF VIRGINIA
RICHMOND
2001

COMMONWEALTH *of* VIRGINIA

DEPARTMENT OF TRANSPORTATION
1401 EAST BROAD STREET
RICHMOND, 23219-2000

CHARLES D. NOTTINGHAM
COMMISSIONER

November 30, 2000

The Honorable James S. Gilmore, III
Members of the General Assembly

Dear Governor Gilmore and General Assembly Members:

The 1999 General Assembly passed HB 2209, which amended Section 46.2-1143 of the *Code of Virginia,* to allow trucks hauling gravel, sand, or crushed stone in seven counties in Southwest Virginia to operate at higher weight limits until July 2001. The bill also requested the Virginia Department of Transportation (VDOT) to study the impact of the higher weight limits on highways in these seven counties and to recommend whether these limits should continue.

Attached is VDOT's report in which we recommend that these higher weight limits be allowed to expire on July 1, 2001. The report addresses the structural inadequacies of some roads to support these higher weight limits. Also included are cost estimates to upgrade these deficient roads. If you have questions or need additional information, please let me know.

Sincerely,

Charles D. Nottingham

Attachment
Cc: The Honorable Shirley J. Ybarra

PREFACE

The work comprising this study represents the most comprehensive investigation of in-service pavements conducted with modern evaluation technology by the Virginia Department of Transportation. These results will prove to be valuable not only for the purpose of answering questions that relate directly to the impact on pavement performance of House Bill 2209 but also for their contribution to the refinement of our ability to predict future pavement performance. An improved understanding of pavement response to traffic loads under a variety of conditions such as those examined here will enhance the ability of managers to make informed, cost-effective maintenance and rehabilitation planning decisions through the use of performance prediction models.

The authors acknowledge the members of the Coal Severance Tax Study Steering Committee for their significant roles in this effort:

Mr. Charles H. Robson, Jr., State Materials Engineer
Mr. Melvin R. Hall, Geotechnical Engineer
Mr. Clinton H. Simpson, Agency Management Analyst
Mr. Billy Pierce, Weight Program Regional Supervisor
Mr. Daniel H. Marston, Bristol District Administrator
Mr. Michael W. Branham, Bristol District Maintenance Engineer
Mr. Steven M. Mullins, P.E., Bristol District Materials Engineer
Mr. Robert F. White, Policy Analyst Senior.

A number of other individuals deserve particular recognition for their unwavering support, exceptional contributions, and consistently positive attitudes throughout the entire duration of the study:

Mr. L.E. Wood, Jr., Engineering Technician VI
Mr. David H. Thacker, Engineering Technician VI
Mr. Tavis Dotson, Engineering Technician IV
Mr. William J. Hughes, District Pavement Lead
Ms. Linda L. DeGrasse, VTRC Program Support Technician
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Mr. Charles E. Ring, Bristol District Pavement Management Engineer
Mr. Thomas R. Tate, P.E., Hampton Roads Pavement Management Engineer
Ms. Linda D. Evans, VTRC Editor
VDOT Maintenance Division Truck Weigh Section Field Personnel
Dr. Imad L. Al-Qadi, P.E., Professor of Civil Engineering, Virginia Tech.

Perhaps most important, special thanks are extended to the employees of the Bristol District Residencies and Area Headquarters who reliably provided traffic control through safe and secure work zones without incident.

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*Appendices B through G are available upon request from:

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EXECUTIVE SUMMARY

Introduction

HB 2209, enacted in the 1999 Session of the General Assembly, required that the *Code of Virginia* be amended and reenacted to extend the higher weight limits prescribed in subsection B of § 46.2-1143 to vehicles hauling sand, gravel, or crushed stone in the seven coal severance tax counties of Southwest Virginia. The bill required the Virginia Department of Transportation (VDOT) to "monitor the operation of vehicles under this subsection and the effects of such operation on the condition of the affected highways." This document serves to fulfill the requirement to report these results and forms the basis for a recommendation to the Governor and the 2001 Regular Session of the General Assembly as to whether the bill's provisions should be allowed to expire on July 1, 2001, or to continue, either in their present form or some modified form.

Purpose and Scope

The purpose of this study was to determine if vehicles operating under the higher allowable weight limit provisions cause pavements to deteriorate faster and, therefore, intensify maintenance and rehabilitation requirements than pavements bound by weight limits applicable elsewhere in the state. This was to be accomplished by conducting detailed field surveys at 18 in-service pavement sites representing the range of roadway and traffic conditions typically found on primary and secondary highways in Southwest Virginia. Ten of the sites selected were within the severance tax counties, and the remaining 8 sites were located elsewhere in Southwest Virginia. Thus, the 10 sites within the severance tax counties were to function as the experimental group, that is, the sites receiving the higher weight loads, and the remaining 8 sites were to function as the "control group," that is, sites that did not receive the higher weight loads.

Study Limitations

The study had three limitations, which the reader should keep in mind when assessing the findings:

1. Because of varying interpretations of the provisions of HB 2209, it was impossible to locate a large number of representative control sites in Southwest Virginia. VDOT originally interpreted HB 2209 to allow higher-weight trucks to travel 50 miles in any direction from their point of origin, *regardless of county destination.* Because of this, one may assume that the higher-weight trucks traveled in 14 of the 18 sites monitored. Eight months into the study, however, in February 2000, the Attorney General's Office rendered an opinion regarding the 50-mile provision that prompted VDOT to prohibit trucks from hauling at the higher weight limits outside the severance tax counties altogether. This further brought into question the relevance of observations regarding rates of condition change between severance tax and non-severance tax sites. The reader is cautioned, therefore, that observations based on comparisons between severance tax and non-severance tax counties are not valid.

2. *The 13 months available to monitor pavement performance was not enough time to allow the capture of data to determine whether there were significant differences in the rates of change among sites.* Therefore, observations that involved comparisons between severance tax and non-severance tax (control) sites are inconclusive.

3. *The tremendous number of variables that influence pavement performance and the vast resources and time required to answer questions related to truck-induced pavement damage would seem to speak against any extension of this study in an attempt to determine any peculiar effects higher-weight trucks may have in Southwest Virginia that they do not have elsewhere in the nation.* The American Association of State Highway and Transportation Officials (AASHTO) has been leading a collaborative, comprehensive pavement research effort among all 50 states continuously for the past 40 years to determine the effects of higher-weight trucks. This effort has included a study of the many variables (e.g., materials, construction techniques, local geology, roadway geometry, quality control effectiveness, weight limits and weight limit enforcement, axle configuration, tire pressure, climate, traffic volume and composition) that would influence the findings. The outcome of AASHTO's study is clear: the damage caused by heavy vehicles increases exponentially with corresponding incremental increases in weight. This outcome comprises the principle of pavement analysis used by all 50 state highway agencies for pavement design and research and is behind the pavement design procedure outlined in the *AASHTO Guide for the Design of Pavement Structures,* considered the "bible" of pavement engineers.

For these three reasons, the recommendations in this study are not based on conclusions about rates of deterioration observed among sites, but, instead, they are based on cost estimates derived from detailed structural analyses of the 18 sites conducted in accordance with procedures designed by AASHTO and the results of a literature review of other pertinent studies.

Methodology

After the initial structural and functional conditions were documented at all study sites at the time HB 2209 went into effect (July 1999), the sites were monitored through documentation of the same condition indicators every 3 months throughout the 13-month study period. The intent here was (1) to establish initial baseline conditions from which subsequent measurements could be made, and (2) for comparative purposes, to permit the measurement of rates of change in condition within and between sites attributed to higher allowable weight limits over time. Specifically, visible surface distress, ride quality, wheel path rutting, and structural capacity were measured during 3- to 4-week periods in July and October 1999 and January, April, and July 2000. In addition, a detailed geotechnical (subsurface) investigation was conducted at each site in October 1999 to document pavement construction history and subgrade support conditions. Subgrade soil samples were extracted from each site during this phase of the work for moisture content determination, plasticity index computation, and grain size analysis in the laboratory. For the asphalt samples, resilient modulus testing was performed in the laboratory as well.

To develop site-specific information about traffic volume and composition, a survey consisting of vehicle counts, classifications, and approximate measurements of weights using weigh-in-motion technology was performed in April and May 2000. Data generated from the traffic survey augmented count and classification data compiled for each study site from pertinent average annual daily traffic (AADT) data published by VDOT's Traffic Engineering Division.

Results of the geotechnical investigation and traffic study were used in conjunction with pavement deflection test results to perform a detailed structural evaluation of all sites in accordance with the AASHTO pavement design and analysis procedure, which is widely used by U.S. state highway agencies. This analysis included (1) an assessment of the capacities of each site to support traffic at pre- and post-HB 2209 weight limits, (2) the thickness of pavement overlay that would be required to meet structural adequacy requirements under the weight limits in effect before and after HB 2209, (3) estimates of the cost to upgrade deficient pavements, and (4) an estimate of the cost of damage attributed only to the net increase in allowable weight limits over a 12-year period in the seven severance tax counties. The structural analysis also included an assessment of service life reduction associated with increased weight limits on underdesigned pavements.

The study also included a review of the findings of several nationally significant studies conducted over the last 15 years addressing the relationship between increased truck weights and pavement damage. This literature review was based on an Internet search of sites by the Transportation Research Board, AASHTO, the American Society of Civil Engineers, and the National Cooperative Highway Research Program.

Discussion

The damaging effect of heavy trucks on pavements is not a new concept. Results of the most comprehensive study ever conducted on the relationship between heavy vehicles and pavement damage[8] demonstrate that an incremental increase in vehicle weight results in an exponential increase in pavement damage. For example, a single pass of a three-axle single-unit truck with a gross weight of 54,000 pounds (the maximum allowed before HB 2209) causes approximately 8,000 times the damage of an ordinary passenger car. Likewise, one pass of the same three-axle truck with a gross weight of 60,000 pounds (maximum allowed by HB 2209) would cause approximately 50 percent more damage than the 54,000-pound truck. Stated differently, for this truck class, an 11 percent increase in weight results in a 50 percent increase in damage. Consider the effects of raising the allowable weight of a five-axle semi-trailer from 80,000 pounds to 90,000 pounds in accordance with the increase allowed by HB 2209. With an increase in gross weight of only 10,000 pounds, or 12.5 percent, a single pass of the 90,000-pound vehicle causes 58 percent more damage than the 80,000-pound vehicle. These examples apply to pavements that are structurally adequate to support the stated loads. The percentage increase in damage resulting from the additional weight would be drastically higher for structurally deficient pavements.

The exponential increase in relative damage corresponding to an incremental increase in weight is due to the severe reduction in the number of vehicle load repetitions that will cause fatigue failure, which is the result of increased stresses and strains within the pavement structure.

An analogy would be the consequence of repetitively bending a thin piece of metal by hand. The metal could survive an indefinite number of repetitions if the degree of bending were quite small (i.e., lighter loads, lower deflections). However, if the degree of bending were increased only slightly, the metal would fail in fatigue after a finite number of repetitions. When the magnitude of truck volume over many years is considered, the cumulative effect of the net increase in damage resulting from a corresponding increase in weight becomes exorbitant.

Findings and Conclusions

- Although the period of time (13 months) available to monitor pavement performance was sufficient to detect and document condition changes *within* sites, it was not sufficient to allow the capture of data to determine whether there were significant differences in the rates of change *among* sites. Therefore, observations that involved making comparisons between severance tax and non-severance tax (control) sites were inconclusive.

- For each of the 18 sites monitored as part of this study, visible load-induced distress increased, wheel path rutting increased, and ride quality decreased from July 1999 through July 2000.

- There were significant differences in the structural conditions of study sites.

- There was no consistent trend in structural deterioration for any site throughout the study period as determined by the pavement deflection analysis.

- Thirty-nine percent of the pavements investigated in this study were structurally inadequate to support traffic operating at weight limits allowed by HB 2209 for a sustained period of time.

- The cost of damage to primary and secondary roadway pavements within the seven severance tax counties caused by the *net additional weight* allowed by HB 2209 is estimated to be on the order of $28 million over a 12-year period. This estimate does not include costs associated with load-induced damage to bridges; motorist delays through work zones because of increased road and bridge repairs; safety and geometric roadway improvements; or loss of life and property resulting from the increased safety hazards of heavy trucks operating in mountainous terrain.

- The damaging effects on pavement performance of increasing vehicle weights are widely documented. The most comprehensive study of pavement performance under heavy vehicle loads, led by AASHTO, has been continuously underway since the 1950s.[8] When applied to this study, pavement analysis principles derived from AASHTO's 40-year national study demonstrate that the damage caused by heavy vehicles increases exponentially with corresponding incremental increases in weight for all classes of trucks affected by HB 2209.

Recommendations

In light of the structural evaluation and cost analysis performed for the 18 study sites and the literature review of pertinent studies, the provisions of HB 2209 pertaining to the authorization of additional weight limits for trucks hauling sand, gravel, or crushed stone should expire on July 1, 2001.

Further, in the opinions of the principal investigators of this research and the members of the Coal Severance Tax Study Steering Committee, the outcome of continued monitoring of the sites studied herein would serve only to support the findings of the widely accepted AASHTO research effort, which are based on more than 40 years of continuous work conducted collaboratively by and for the 50 state highway agencies. It would seem that an attempt to replicate such a comprehensive and costly effort by continuing to monitor these Southwest Virginia sites would be redundant and is, therefore, not recommended.

INTRODUCTION

Beginning in 1979, severance taxes were levied on coal and gases in particular counties in Virginia to generate revenues for infrastructure improvements in Southwest Virginia. Today, the counties of Buchanan, Wise, Tazewell, Russell, Dickenson, Lee, and Scott impose such a severance tax on the coal industry. Upon request by the owner or operator, the Virginia Department of Transportation (VDOT) will issue a free permit for a vehicle used exclusively for hauling coal from a mine or other place of production in these counties to a preparation plant, loading dock, or railroad that authorizes its operation with gross weights in excess of those limits applicable elsewhere in the Commonwealth. The 1999 session of Virginia's General Assembly enacted House Bill 2209, which required that § 46.2-1143 of the *Code of Virginia* be amended and reenacted to extend the higher weight limits prescribed in subsection B to vehicles hauling sand, gravel, or crushed stone in the seven coal severance tax counties.

The following is a summary of weight limits for different vehicle types and axle configurations authorized by HB 2209. For comparative purposes, weight limits for vehicles hauling sand, gravel, or crushed stone that were in effect prior to the enactment of HB 2209 are provided in brackets.[1]

> Vehicles with three axles may have a maximum gross weight, when loaded, of no more than 60,000 pounds *[54,000 pounds for single units, 60,000 pounds for tractor-semi trailers]*, a single axle weight of no more than 24,000 pounds *[20,000 pounds]* and a tandem axle weight of no more than 45,000 pounds *[34,000 pounds]*. Vehicles with four axles may have a maximum gross weight, when loaded, of no more than 70,000 pounds *[50,000 pounds to 76,000 pounds, depending upon axle spacing]*, a single axle weight of no more than 24,000 pounds *[20,000 pounds]*, and a tri-axle weight of no more than 50,000 pounds *[34,000 to 60,000, depending upon axle spacing]*. Vehicles with five axles, having no less than 35 feet of axle space between extreme axles, may have a maximum gross weight, when loaded, of no more than 90,000 pounds *[70,000 pounds to 80,000 pounds, depending upon axle spacing]*, a single axle weight of no more than 20,000 pounds *[20,000 pounds]*, and a tandem axle weight of no more than 40,000 pounds *[34,000 pounds]*.

The bill, effective July 1, 1999, contains specific requirements and limitations:

- The legislation applies to trucks hauling sand, gravel, or crushed stone no more than 50 miles from origin to destination.
- Vehicles are not required to have a permit to transport the increased weights prescribed.
- Extensions of these weight limits are not authorized on interstate highways.

Appendix A of this report contains the complete amendment to § 46.2-1143 of the *Code of Virginia* set forth by HB 2209.

VDOT is responsible for maintaining 4,307 miles (9,052 lane-miles) of primary and secondary roadways within the seven severance tax counties, all of which are affected by the increased weight limits authorized by HB 2209.[2] Table 1 is a summary of primary and secondary roadway system mileage by each county.

Table 1. Primary and Secondary Roadway Mileage Within the Severance Tax Counties

Severance Tax County	Primary System Mileage	Secondary System Mileage	Total Mileage
Buchanan	73	458	531
Dickenson	82	403	485
Lee	113	563	676
Russell	106	573	679
Scott	117	695	812
Tazewell	134	476	610
Wise	116	398	514
Total mileage	741	3,566	4,307

The bill requires VDOT to monitor the operation of vehicles under these provisions and determine the effects such operation has on the condition of the roads in question. This document serves to fulfill the bill's requirement to report the results of this legislative study and forms the basis for findings and recommendations to the Governor and the 2001 Regular Session of the General Assembly as to whether the provisions herein should be allowed to expire on July 1, 2001, or continue, either in their present form or some modified form.

PURPOSE AND SCOPE

The purpose of this study was to determine if pavements supporting vehicles operating under the provisions of HB 2209 deteriorate faster and, therefore, have increased maintenance, repair, and rehabilitation requirements than pavements that do not support traffic operating under the provisions in question. These findings form the basis for a recommendation regarding the future of the provisions of HB 2209 examined in this report.

The scope of this study included detailed field surveys to document the structural and functional conditions of 18 evaluation sites on in-service pavements in Southwest Virginia at the time HB 2209 went into effect. Ten of the sites selected were within the severance tax counties, and the remaining 8 sites were located elsewhere in Southwest Virginia. Thus, the 10 sites within the severance tax counties were to function as the experimental group, that is, the sites receiving the higher weight loads, and the remaining 8 sites were to function as the "control group," that is, sites that did not receive the higher weight loads.

The conditions of the sites were monitored, as required by the bill, at regular intervals throughout a 13-month evaluation period to track their performance and to document changes in pavement condition that may be attributed to the influence of vehicles operating under the increased weight provisions. Field investigation results were used to analyze the capacities of the sites to support traffic loads operating at (1) pre-HB 2209 weight limits, and (2) the higher weight limits allowed by the bill's provision. Additionally, the findings of nationally significant research studies involving the influence of heavy vehicles on pavement performance were reviewed. Results of this literature review and the condition surveys, field investigations, and structural analyses of the 18 study sites form the basis of the findings reported in this study.

STUDY LIMITATIONS

The study had three limitations, which the reader should keep in mind when assessing the findings:

1. *Because of varying interpretations of the provisions of HB 2209, it was impossible to locate a large number of representative control sites in Southwest Virginia.* VDOT originally interpreted HB 2209 to allow higher-weight trucks to travel 50 miles in any direction from their point of origin, *regardless of county destination.* Because of this, one may assume that the higher-weight trucks traveled in 14 of the 18 sites monitored. Eight months into the study, however, in February 2000, the Attorney General's Office rendered an opinion regarding the 50-mile provision that prompted VDOT to prohibit trucks from hauling at the higher weight limits outside the severance tax counties altogether. This further brought into question the relevance of observations regarding rates of condition change between severance tax and non-severance tax sites. The reader is cautioned, therefore, that observations based on comparisons between severance tax and non-severance tax counties are not valid.

2. *The 13 months available to monitor pavement performance was not enough time to allow the capture of data to determine whether there were significant differences in the rates of change among sites.* Therefore, observations that involved comparisons between severance tax and non-severance tax (control) sites are inconclusive.

3. *The tremendous number of variables that influence pavement performance and the vast resources and time required to answer questions related to truck-induced pavement damage would seem to speak against any extension of this study in an attempt to determine any peculiar effects higher-weight trucks may have in Southwest Virginia that they do not have elsewhere in the nation.* The American Association of State Highway and Transportation Officials (AASHTO) has been leading a collaborative, comprehensive pavement research effort among all 50 states continuously for the past 40 years to determine the effects of higher-weight trucks. This effort has included a study of the many variables (e.g., materials, construction techniques, local geology, roadway geometry, quality control effectiveness, weight limits and weight limit enforcement, axle configuration, tire pressure, climate, traffic volume and composition) that would influence the findings. The outcome of AASHTO's study is clear: the damage caused by heavy vehicles increases exponentially with corresponding incremental increases in weight. This outcome comprises the principle of pavement analysis used by all 50 state highway agencies for pavement design and research and is behind the pavement design procedure outlined in the *AASHTO Guide for the Design of Pavement Structures,* considered the "bible" of pavement engineers.

For these three reasons, the recommendations in this study are not based on conclusions about rates of deterioration observed among sites, but, instead, they are based on cost estimates derived from detailed structural analyses of the 18 sites conducted in accordance with procedures designed by AASHTO and the results of a literature review of other pertinent studies.

METHODOLOGY

This study was executed in four parts:

1. the selection of representative roadway study sites in Southwest Virginia for condition evaluation and monitoring

2. the documentation of existing structural and functional condition of the study sites at the time the increased weight limit provisions went into effect and the detailed monitoring of changes in those conditions throughout a 13-month evaluation period

3. analysis and interpretation of the compiled field data

4. a review of nationally significant studies of the relationship between increased vehicle weight and pavement performance.

Selection of Study Sites

Sites selected for inclusion in the study were representative of the variety of paving materials and construction techniques, traffic conditions, and roadway geometry typically found in Southwest Virginia. The number of sites selected was largely a function of the resources available to conduct the fieldwork given the inherent time constraints of the study. Eighteen was determined to be the maximum number of sites that could be documented and monitored at a level of detail that would maximize the opportunity to detect changes in pavement condition attributable to vehicle loads over the relatively short study period. Ten of the sites were intentionally located within severance tax counties, and the remaining 8 "control" sites were located beyond those counties, with the intent of representing both pavements that were subject to vehicles operating under the higher weight limit provisions those that were not.

Another factor bearing on the selection of sites was the safety of the traveling public and the pavement surveyors, equipment operators, and traffic control personnel charged with performing the frequent and time-consuming condition surveys and monitoring activities. To the extent possible, the selected sites were located beyond dangerous intersections and geometrically hazardous roadway sections. Since it was desirable from an experimental standpoint to maintain site length consistency and to include some sites on relatively low-volume, two-lane facilities, the lengths of the study sites were dictated to some extent by the maximum roadway distance within which traffic could be safely controlled in a one-lane work zone closure. Additionally, care was taken to ensure that sufficient uniformity existed in pavement surface construction, material type, etc., in the selection of the exact bounds of the sites. In light of the noted considerations, a roadway section length of 0.30 mile was determined to be the standard for all 18 sites. Figure 1 is a graphical representation of the distribution of study sites throughout Southwest Virginia. Table 2 provides more detailed location descriptions of the same sites.

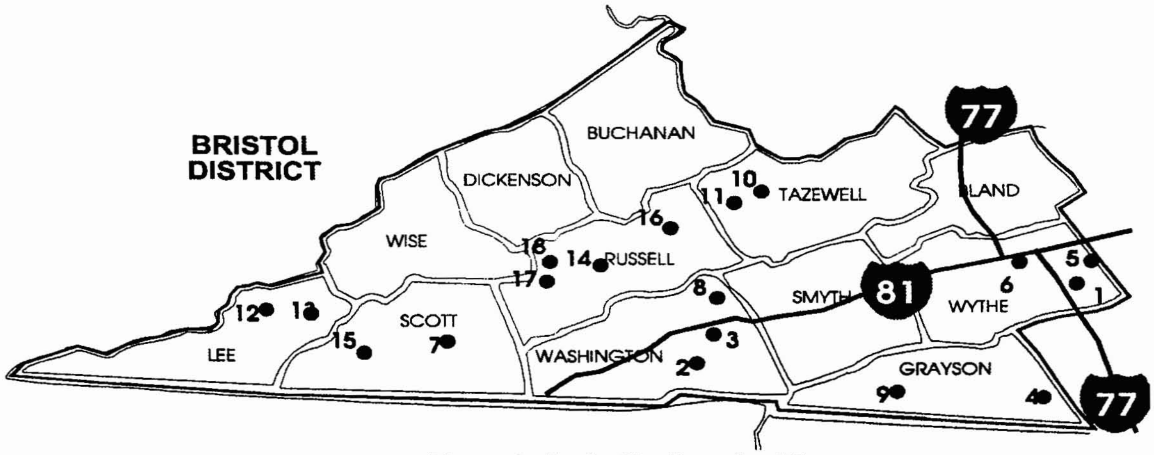

Figure 1. Study Site Location Map

Table 2. Description of Study Sites

Site	County	Route	Direction	Milepost From	Milepost To	Description
1	Wythe	607	West	3.00	3.30	0.70 M S RT 722 TO 0.40 M S RT 772
2	Washington	58	West	32.70	33.00	INT. RT 711 TO 0.30 M W RT. 711
3	Washington	91	North	11.20	11.50	0.07 M N RT 762 TO 0.37 M N RT 762
4	Gray	89	North	2.80	3.10	0.61 M S RT 610(L) TO 0.31 M S RT 610(L)
5	Wythe	100	North	0.80	1.10	0.02 M N RT 637(L) TO 0.32 M N RT 607(L)
6	Wythe	FR-42	South	0.68	0.98	ECHO VALLEY RD TO 0.3 M N ECHO VALLEY RD
7	Scott	72	North	1.30	1.60	0.07M N RT 660 TO 0.37 M N RT 660
8	Washington	91	North	15.80	16.10	0.24 M N INT BUS 91 TO 0.54 M N BUS 91
9	Gray	93	South	0.32	0.62	0.32 M N NC STATE LINE TO 0.5 M S RT 838(L)
10	Tazewell	19N	North	8.30	8.60	0.15 M N QUARRY RD TO 0.5 M N QUARRY RD
11	Tazewell	19S	South	7.16	7.46	0.63 M N RT 1230(L) TO 0.14 M S RT 637(L)
12	Lee	421	East	11.00	11.30	1.03 M N RT 890(R) TO 1368 M N RT 890(R)
13	Lee	58	East	44.60	44.90	1.24 M E RT 421 TO 0.08 M W RT 915(L)
14	Russell	71	North	14.10	14.40	0.07 M N 614(L) TO 0.37 M N 614(L)
15	Scott	23S	South	12.70	13.00	0.08 M N RT 870(L) TO 0.38 M N RT 870(L)
16	Russell	80	South	12.80	13.10	0.50 M S RT 67(R) TO 0.20 M S RT 67(R)
17	Russell	ALT 58E	East	5.00	5.30	0.49 M W RT 604(R) to 0.19 M W RT 604(R)
18	Russell	ALT 58W	West	2.94	3.24	0.34 M E RT 65(L) TO 0.07 M W RT 694

All sites were constructed of asphalt concrete surface, intermediate, and base courses supported by aggregate sub-base layers. To provide replication for experimental purposes, each site was subdivided into 30 uniform 0.01-mile-long (52.8-foot) segments. The beginning and end of each site, as well as the locations of the subdivided segments, were clearly marked on the pavement surface with traffic paint to allow easy reference throughout the study period. To maximize the level of detail of the collected data, each site was composed only of the outer lane in the noted direction.

Documenting Existing Conditions and Monitoring Change Over Time

The structural and functional pavement conditions at each site were documented beginning in July 1999 by detailed field surveys to establish baseline measurements at the time the increased weight limits went into effect. After the baseline conditions were established, measurements of the same condition indicators were performed at regular 3-month intervals through July 2000 to document pavement deterioration. Specifically, the initial and quarterly surveys were conducted during 3- to 4-week periods in July and October 1999 and January, April, and July 2000.

The field monitoring activities performed for each segment included (1) detailed visual surveys to measure surface distress propagation, (2) documentation of surface condition with 35 mm photographs, (3) measurement of transverse surface profile (wheel path rutting), (4) measurement of longitudinal surface profile (ride quality), and (5) assessment of pavement structural capacity by deflection testing. Traffic control at each site was provided by VDOT to enable full access to the entire 0.30-mile length of pavement. Conducting all monitoring activities simultaneously at each site minimized lane closure times. In addition to the regularly scheduled activities, a detailed subsurface investigation consisting of soil test borings, pavement layer thickness measurements, and laboratory testing on recovered pavement material and subgrade soil samples was conducted at each site in October 1999 to document pavement construction history and subsurface support conditions.

To generate information on the volume and composition of traffic, a traffic survey consisting of vehicle counts, classifications, and approximate measurements of weights using weigh-in-motion (WIM) technology was performed once at each site in April and May 2000.

Visual Surveys

Perhaps the most widely accepted method of measuring pavement deterioration is the visual condition survey. This method requires carefully identifying and quantifying the extent and severity of pavement distress. The methodology used in this study was as follows.

Just prior to each scheduled site survey, an identification number for each 0.01-mile-long segment was clearly marked with paint on the pavement surface at the beginning of each segment. The identification number was composed of the site number (consistent with Table 1) and the segment number, which was expressed as a station in terms of the VDOT standard mile point referencing system. For example, segment *15/12+96* refers to the segment that is located at mile point 12.96 at Site 15. This approach allows a pavement segment to be exactly located if long-term future reference is necessary.

The initial documentation of existing surface conditions was conducted during a 3-week period beginning in July 1999. The distress survey was accomplished by a crew of two or three walking along the pavement and manually recording the type, severity and extent of visible distresses (see Photos 1 and 2).

Photo 1. Third Quarter Visual Survey, January 2000

Photo 2. Distress Identification and Documentation During Visual Survey

Specific distresses documented included transverse, longitudinal, and fatigue cracking; patching; and potholes. The same individuals conducted the subsequent surveys in the same manner every 3 months to minimize data variation attributable to human error. The exact locations of distresses within 0.01-mile-long segments were manually sketched on the site's survey sheet, which was essentially a plan view of the study site with station graduations to enable accurate location referencing. A copy of a site's completed distress survey sheet for a given period was then used 3 months later as the base sheet for the site's next survey. Each survey period was coded in a different color of ink so that the propagation of distress would be readily discernible on the sheet from one period to the next. The distresses recorded were identified and classified in general accordance with a pavement distress dictionary developed by the Federal Highway Administration's Strategic Highway Research Program for organizations responsible for maintaining pavement infrastructure.[3]

Photographic Documentation

Permanent records of pavement condition were made during initial and quarterly surveys with 35 mm color photographs. The field crew took at least one photograph of each segment during the visual distress survey. Photos of the segments were taken from the same locations every 3 months with the same camera to maintain consistency over time. Photo 3 is an example of a pavement surface photograph taken for the permanent record.

Photo 3. Photographic Documentation of Site 15. Note the segment's unique identification number and the transverse crack.

Longitudinal Profile Measurements

The change in longitudinal profile over time of a road surface can provide an indication of load-induced deterioration. The study included documenting the longitudinal profile of each site and monitoring changes in those profiles throughout the study period. Longitudinal profile is well correlated with pavement roughness, or ride quality, which is a widely used indicator of a pavement's serviceability. According to the Federal Highway Administration, *pavement roughness* can be defined as "irregularities in the pavement surface that adversely affect ride quality, safety, and vehicle maintenance costs."[4] In terms of profile, *roughness* can be defined as the summation of variations in the surface profile of the pavement from a fixed datum. The profiles of each of these sites were measured quarterly with the Virginia Transportation Research Council's (VTRC) non-contact inertial profiler, which is a vehicle equipped with accelerometers, laser displacement transducers, and a data acquisition computer (see Photos 4 and 5).

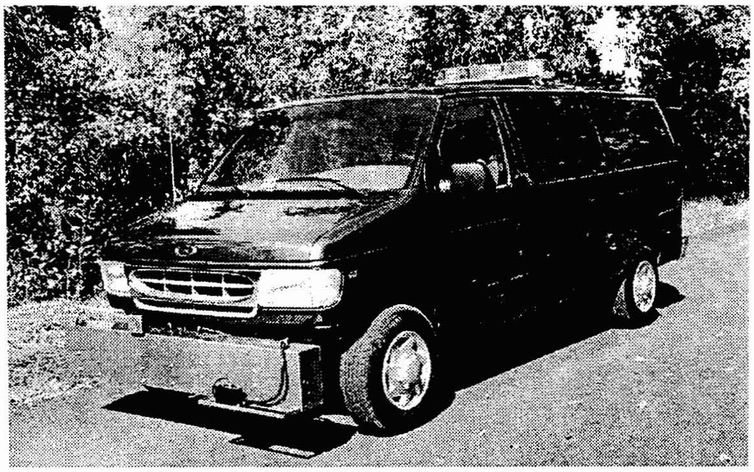

Photo 4. VTRC's Inertial Profiler

Photo 5. Profiler's On-Board Data Acquisition System

Three consecutive tests at each site were made during each quarterly survey, with the profiler in general accordance with VDOT's standard test method for ride quality testing.[5] The lowest International Roughness Index (IRI) of the three consecutive tests was then used to represent the site's ride quality.

Transverse Profile Measurements

Asphaltic concrete pavement structures tend to deform over time because of the channelized nature of repetitive heavy wheel loads. Load-induced compression and/or plastic movement in the asphalt layers or vertical deformation in the subgrade layers result in permanent pavement deformation, otherwise described as a rut within a road's wheel path. Severe rutting can prevent the free drainage of surface water and leads to dangerous hydroplaning. Roadways that support high volumes of heavy truck traffic often require regular rehabilitation as a result of rutting long before other forms of functional or structural deterioration are evident. In this study, rutting was quantified by members of the research team placing a straightedge over the wheel path and measuring the vertical distance to the bottom of the wheel path. Inner and outer wheel path rut depths were measured quarterly at every segment with a 6-foot-long straightedge and recorded. Photo 6 illustrates a typical outer wheel path rut depth measurement.

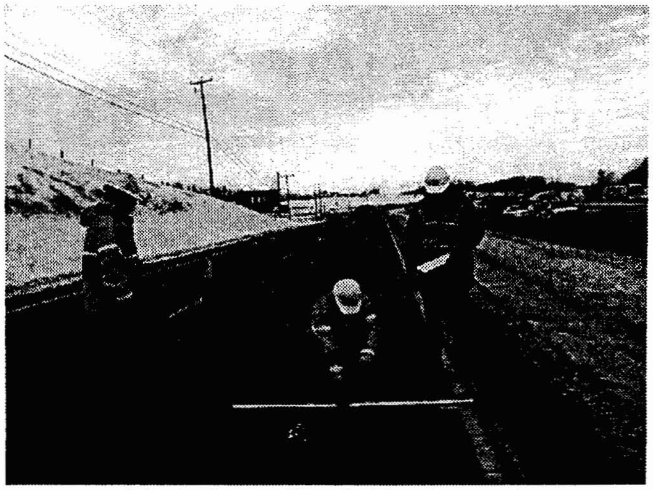

Photo 6. Rut Depth Measurement

Geotechnical Investigation

A comprehensive geotechnical investigation was conducted in October 1999 to develop information about in-place pavement layer material types and thicknesses, to provide pavement cores and subgrade soil samples for laboratory testing, and to provide an indication of engineering properties and load-bearing capacities of the underlying materials. Results of the investigation were used to support the pavement structural evaluation, which is addressed later in this report. The subsurface work was accomplished with a VDOT drill rig (Photo 7) by drilling a series of three to five soil test borings at each site through the pavement to depths of approximately 5 feet. Penetration through the pavement was accomplished by drilling with a 4-inch-diameter, diamond-tipped core barrel (Photo 8). The boring locations were selected by the principal investigator based on preliminary results of the deflection testing effort that was

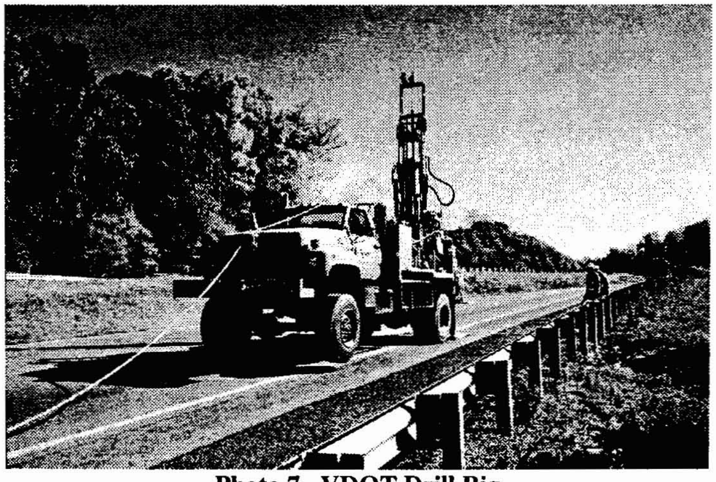

Photo 7. VDOT Drill Rig

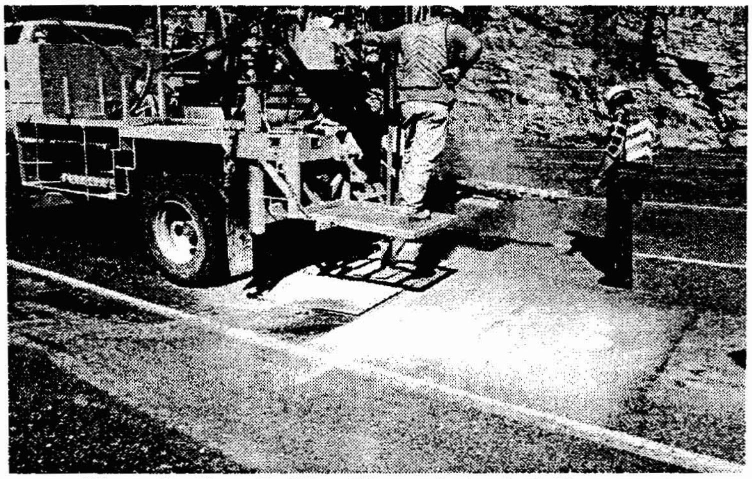

Photo 8. Core Drilling Through Asphalt Pavement

conducted as part of the structural evaluation. The locations of borings reflected the prevailing range of subsurface support conditions at each site as identified by the deflection test results.

The retrieved asphalt cores were labeled by site and station location, measured for layer thickness documentation, and packaged for transport to the VTRC geotechnical laboratory (Photo 9). Aggregate base layer thicknesses were then measured through the core hole and recorded (Photo 10).

The soil test borings were then made by mechanically twisting a continuous flight steel auger into the soil. Soil sampling and penetration testing were performed in general accordance with the procedure outlined in ASTM D 1586. At regular intervals of depth, soil samples were obtained with a standard split-tube sampler (see Photo 11). The sampler was first seated 6 inches to penetrate any loose cuttings and then driven an additional 12 inches with blows of a 140-pound hammer falling 30 inches. The number of blows required to drive the sampler the final 12 inches was recorded and is designated the "penetration resistance." The penetration resistance, when properly evaluated, is an index to the soil's strength and load-bearing capacity.

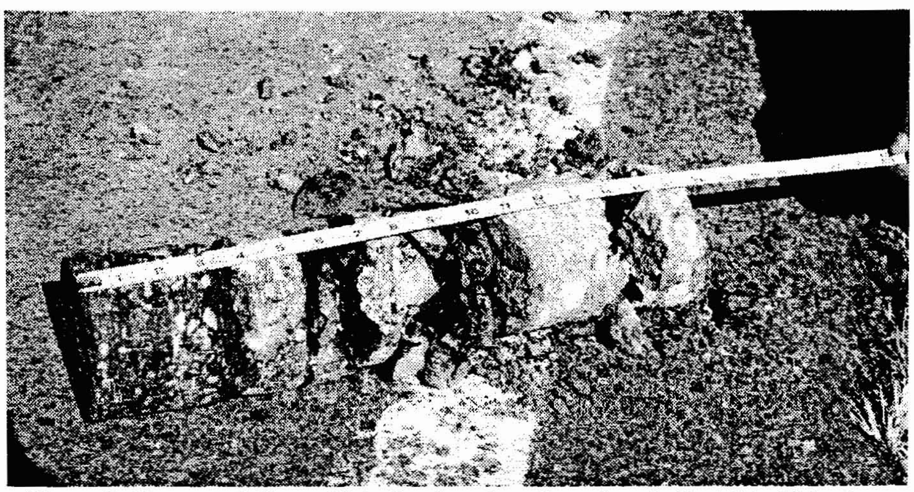

Photo 9. Extracted Core. Note the deterioration of asphalt at 7 to 10 inches.

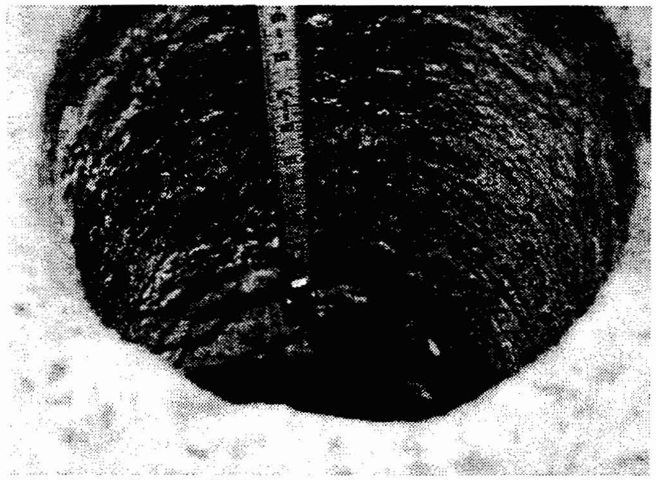

Photo 10. Base Course Thickness Measurement Through Core Hole

Photo 11. Split Tube and Jar Samples of Subgrade Soil

One principal investigator conducted the field classification of the recovered soils. Representative portions of the soil samples were placed in glass jars and transported to the laboratory for a determination of plasticity and moisture content.

Traffic Study

In order to develop information about the volume and composition of traffic using the study sites, traffic data were compiled from two sources. The secondary source of traffic data used in the study came from vehicle count, classification, and WIM surveys, which were conducted specifically for this project at each site in May 2000. This was accomplished with VDOT's traffic counters and portable WIM units. The detected vehicles were categorized by vehicle type according to guidelines by the Federal Highway Administration (i.e., passenger cars; buses; two-, three-, or four-axle single-unit trucks; tractor semi-trailers). Signals from traffic sensors in the roadway were transmitted to on-site data loggers mounted and secured just beyond the roadway shoulder. Data transmitted to the data loggers were downloaded at the end of each day and stored on computer disc for processing. The product of the count/classification effort was a tabular summary of the total number of vehicles, identified by type, traversing the study site during the measured period of time, which was typically from 7 A.M. until 5 P.M. on weekdays. The WIM surveys, which were conducted concurrently with the count/classification activities, generated tabular summaries of weight ranges in 5,000-pound increments by vehicle type. It should be noted that WIM technology is intended to provide only a general indication of the spectrum of weights and types of vehicles using a particular facility. The exact classification and determination of vehicle weight would require measurement by static scales.

The primary source of information used to develop an understanding of the prevailing traffic characteristics at the study sites was *Average Daily Traffic Volumes with Vehicle Classification Data on Interstate, Arterial and Primary Routes.*[6] This publication, compiled by VDOT's Traffic Engineering Division, is based on long-term traffic studies conducted by VDOT. The manual reports average daily traffic volumes, adjusted to account for fluctuations in traffic throughout all days of the week for a period of 1 year, on interstate, primary, and arterial routes. The data are summarized and reported in units of average annual daily traffic (AADT) by route between major intersections. It also reports percentages of the total AADT composed of five classifications of vehicle: buses, two-axle single-unit trucks, three+-axle single-unit trucks, single trailers, and double trailers. Results of the traffic study were used as the basis for quantifying relative load-induced damage and assessing structural adequacies at the study sites.

Pavement Structural Monitoring and Evaluation

As pavements are subjected to traffic over time, they tend to weaken because of structural fatigue, which is a phenomenon resulting from repetitive deflections beneath moving wheel loads, not unlike the concept of bending fatigue in metal structures. It is possible to assess the amount of service life remaining in a pavement system if information about its structural response to predetermined loads is available and if traffic-loading conditions are known. This study included an assessment of the structural conditions of the sites (1) to determine if the in-place pavement structures were adequate to support the prevailing traffic under two different loading conditions, and (2) to form the basis for understanding the extent of the structural deficiency if they were not adequate. In other words, the data generated in this phase of the work were used to determine the minimum thickness of pavement that would be required to bring the road up to a level of structural adequacy. This approach, then, set the stage for equitably satisfying the ultimate objective of quantifying the damage caused by vehicles operating under the higher weight limits *above and beyond* damage caused by vehicles operating otherwise. The structural assessment was accomplished by conducting a comprehensive load-testing program at the sites and analyzing these results, along with results of the subsurface investigation, laboratory tests, and visual surveys, in accordance with an industry standard pavement thickness design and analysis procedure.

Stronger pavements (good quality materials and thick layers) deflect less under a given wheel load than weaker pavements (thin sections). In response to the need for reliable tools to evaluate pavement structures, deflection devices for use in nondestructive testing have been developed whereby tests can be rapidly conducted at any point along a pavement section. VDOT routinely uses the Dynatest Model 8000 Falling Weight Deflectometer (FWD) to evaluate pavement structures for thickness design work and as an analysis tool for failure investigations.

This FWD, which is trailer mounted and towed behind a van with an on-board processing computer, is the most widely used in the United States (see Photos 12 and 13). The impulse force is created by an operator dropping weights (110, 220, 440, or 660 pounds) from different heights (0.8 to 15 inches). By varying the drop heights and drop weights, a peak force range of 1,500 to 24,000 pounds can be developed. The load is transmitted to the pavement through an 11.8-inch-diameter loading plate and measured using a load cell. In keeping with standard procedures for evaluating flexible pavement structures, pavement basin testing was performed at all sites to generate information about the response of subsurface pavement layers to the applied test loads.

Photo 12. VDOT's Dynatest Falling Weight Deflectometer. The operator is measuring the surface temperature with an infrared gage.

Photo 13. Another View of VDOT's Falling Weight Deflectometer. Note the load pad in contact with the pavement surface at the rear.

The sequence of operation used in this study was as follows. The FWD was moved to the beginning of a segment. The loading plate and transducers were then lowered hydraulically to the pavement surface. Then, two tests were conducted at each point by imparting the equivalent of

9,000 pounds followed by 16,000 pounds. The system automatically recorded and stored deflections measured by the nine velocity transducers, which were located at radial distances of 0, 8, 12, 18, 24, 36, 48, 60, and 72 inches from the center of the load plate. In addition to the load and deflection data, pavement surface temperatures were measured automatically with the FWD at each test location. The sequence was then repeated for each segment along a site.

Documentation of the initial structural conditions of the study sites was based, in part, on deflection testing conducted in July 1999. The same sequence of deflection testing activities was repeated every 3 months thereafter as part of the scheduled quarterly surveys in an attempt to collect data to determine the existence of load-induced structural deterioration across survey periods.

Review of Similar National Studies

The findings of several nationally significant studies conducted over the last 15 years have addressed the relationship between increased truck weights and pavement damage. These studies were found by a literature review based on an Internet search of sites by the Transportation Research Board, the American Association of State Highway and Transportation Officials, the American Society of Civil Engineers, and the National Cooperative Highway Research Program.

RESULTS

Visual Surveys

Distress data collected in the field during the visual surveys were used to calculate a rating index for each study segment to enable the objective comparison of pavement condition between sites. The rating index also formed the basis for documenting the propagation of visible surface distress over time. The pavement segments were rated in accordance with VDOT's guide to evaluating pavement distress,[7] which is the standard procedure used to evaluate interstate and primary roadways to prioritize maintenance and rehabilitation (M&R) needs for funding allocation. The procedure was developed for VDOT's Pavement Management Program and involves the input of field survey data into a computer software program that analyzes cumulative distress by severity and extent for a given pavement segment and then calculates the load-related distress index (LDR). The LDR is a numerical index from 0 to 100 that represents the degree to which a pavement is afflicted by distress resulting from vehicle load applications. It is a function of longitudinal and fatigue cracking and patching. A score of 100 represents a pavement that is free of visible structural distress, and a score of 0 represents a pavement plagued with load-induced anomalies.

In this study, after LDRs were computed for all segments comprising a site, the indices were averaged to yield an aggregate rating for that site. The aggregated LDR was calculated at the conclusion of every survey period. For every site, the LDR was plotted over time to provide graphical evidence of a site's deterioration throughout the study period.

The visual survey analysis was expanded for most sites to include an examination of pavement condition over a significantly greater period of time than would have been permitted by the five quarterly field surveys alone. Beginning in 1997, images of all interstate and primary pavements were videotaped annually as part of VDOT's regular evaluation of pavement condition for prioritizing M&R funding needs (see Photo 14). The tapes containing the 1997 and 1998 images of the study sites in question were retrieved and visually examined using the LDR rating procedure with the Pavement Management Program's computer-controlled VCR workstation. The referencing system used to locate the study sites in the field permitted the same sites to be accurately located on tape. Rating sheets identical with the ones used to perform the visual surveys in the field were completed as the tapes were examined. A 1997 and a 1998 LDR were calculated for each site surveyed by video during those years, and the results were plotted on the same LDR-versus-time graphs discussed previously. Note that video recordings were not available for all 18 study sites.

Figure 2 is an example of the change in LDR for Site 14. It reveals that since 1997, the site deteriorated by the equivalent of 56 LDR points. Results for the remaining sites, the graphs of which are included in Appendix B, demonstrate that the rates of deterioration were quite variable. In general, a pavement tends to deteriorate more slowly in the first few years after construction or rehabilitation while its overall condition is still relatively good. The graph illustrates the tendency of a typical pavement deterioration curve to become steeper as the rate of distress formation increases. In most cases, the slope of this curve is a function of a pavement's suitability to support the applied traffic loads: steeper curves tend to reflect pavements that have been loaded beyond design parameters. Although the overall condition index varied from site to site, there were no significant differences in rates of LDR decline among sites.

Photo 14. VCR Work Station for Pavement Video Analysis

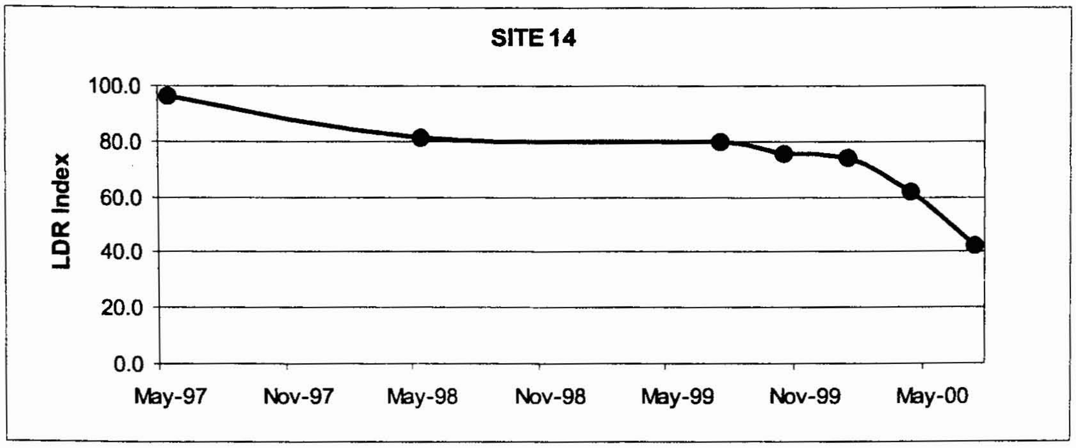

Figure 2. Pavement Deterioration Curve Illustrating Decreasing Condition Index Over Time for Site 14

Ride Quality

The International Roughness Index (IRI) for each site was plotted over the 13-month survey period to permit an analysis of the accumulation of road roughness. To provide a general interpretation of the index, an interstate pavement with an IRI of 60 inches per mile would be quite comfortably smooth to a driver and perhaps even noticeably so. Conversely, the same pavement with an IRI of 250 inches per mile would be noticeably uncomfortable and possibly dangerous to a driver driving at the posted speed limit. Figure 3 illustrates the results of the ride quality analysis for Site 7. Examination of the remaining figures, included in Appendix C, generally indicated that the reduction in ride quality for most sites was not substantial throughout the study period. There was no significant difference in rates of roughness accumulation between severance tax sites and non-severance tax sites. Barring catastrophic pavement failure, the ride quality of a roadway changes very little throughout a period of 1 year.

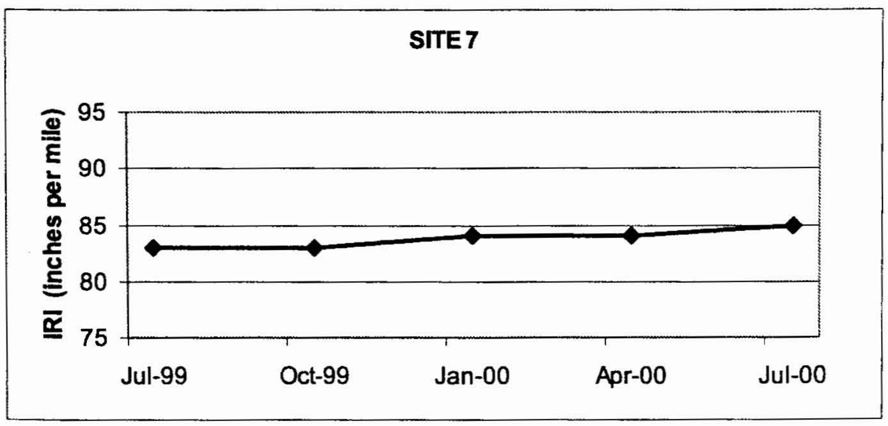

Figure 3. Change in Roughness Over Time for Site 7

Wheel Path Rutting

The rut depth measurements for inner and outer wheel paths were averaged across all 30 segments of the site for each quarterly survey. The results of this analysis were plotted in terms of average rut depth over time to enable an examination of the magnitude of the rutting and a comparison of observations across sites. Figure 4 is an example of this graph for Site 15. An examination of these graphs, the remainder of which are included in Appendix D, revealed that the overall magnitude of the rut depth, which ranged from approximately 0.04 to 0.42 inch, was not significantly different between severance tax and non-severance tax sites. The range of *increase* in rutting from July 1999 to July 2000 was on the order of 0.05 to 0.12 inch, and, likewise, there appeared to be no discernible difference in rate of change in rutting between severance tax and non-severance tax sites.

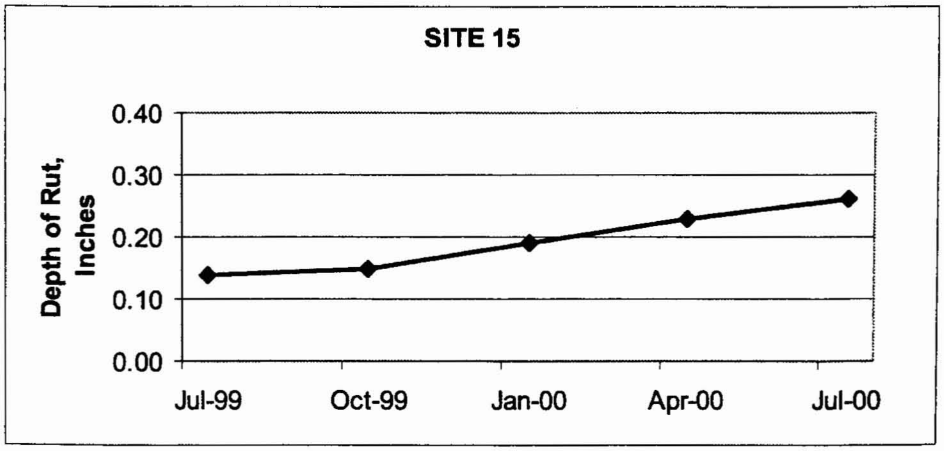

Figure 4. Increase in Rutting Over Time for Site 15

Geotechnical Investigation

The pavement layer thicknesses for each site, based on core length and base course measurements performed in the field during the subsurface investigation, are summarized in Figure 5.

In general, Sites 1 through 6, 8, and 9, which were the non-severance tax sites, had thinner sections than the other sites. In fact, the average asphalt layer thickness of the severance tax sites was 9.2 inches, and the average thickness for the other sites was 7.7 inches. The thicker and more numerous asphalt layers in cores removed from the severance tax sites suggest that these sites were overlaid more aggressively.

The generalized subsurface conditions as found by the soil test borings are presented in the boring log records in Appendix E. The borings typically encountered residual and fill materials consisting of gravels, sands, silts, and clay mixtures beneath asphalt and aggregate base layers. Soil consistencies were quite variable, as indicated by the penetration resistances summarized on the boring logs, which ranged from 5 blows per foot in the softer clay soils to

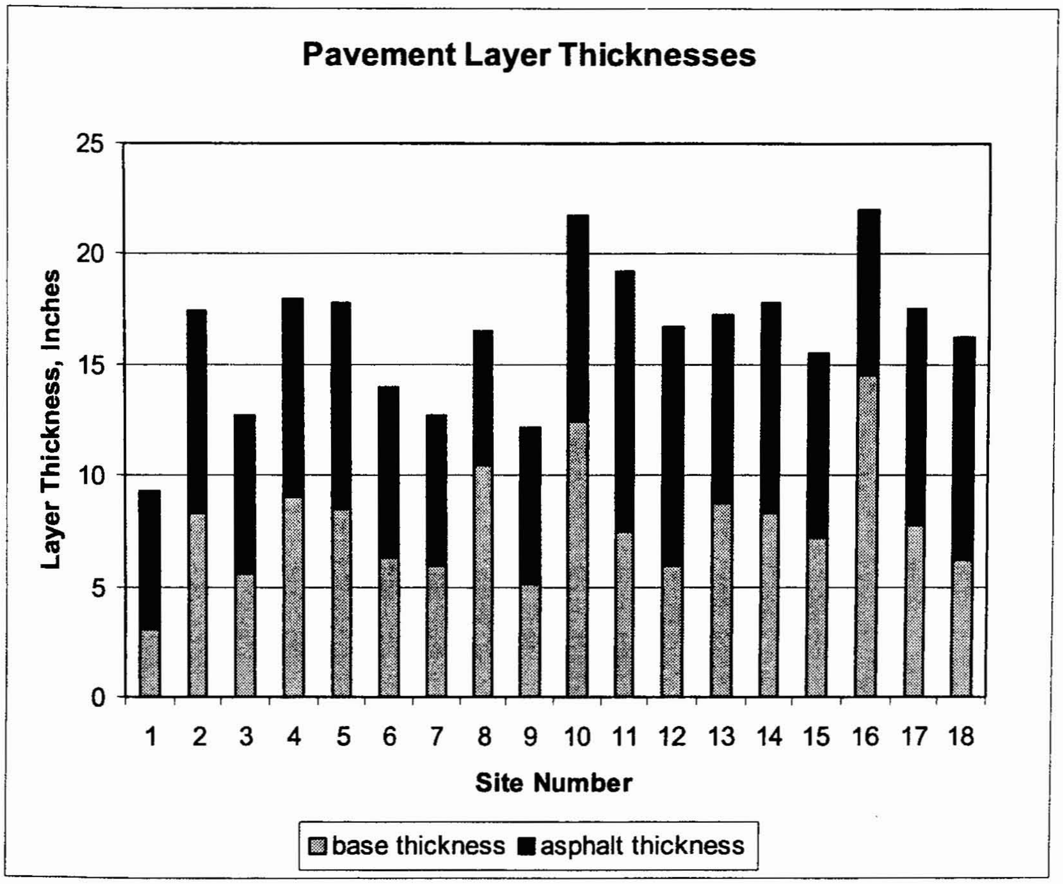

Figure 5. Pavement Layer Thickness

more than 50 blows per foot in the sand-gravel mixtures. Figure 6 is the summary of one soil test boring at Site 1.

Subgrade soil samples were removed from each site during this investigation for additional laboratory testing to further the understanding of the soil's capacity to support loads. This was accomplished by retaining the construction materials laboratory at Virginia Tech to perform resilient modulus tests. The resilient modulus is the definitive, internationally recognized material property used to characterize roadbed soil for pavement design. It is a measure of the elastic property of soil, recognizing certain non-linear characteristics. The results of the resilient modulus work are provided in Appendix F.

Traffic Analysis

The first step in the analysis of traffic data involved compiling specific AADT data by different classes of truck for each study site. The most recent available data for this exercise may be found in VDOT's *Average Daily Traffic Volumes with Vehicle Classification Data.*[6] The manual is based on 1997 data, so for the purposes of this study, the AADT data were extrapolated to 1999 by applying a 2 percent annual traffic growth factor. Table 3 summarizes these traffic data for each site.

BOREHOLE LOG **1-3.08**

Virginia Department of Transportation VDOT

PROJECT #: CSC 1116008
LOCATION: Bristol District (see remarks below for additional info.)

STATION: 1-3.08 OFFSET: WP
EASTING: NORTHING:
SURFACE ELEVATION: ft
BENCHMARK LOCATION: N/A

DATE(S) DRILLED: 10/27/99
DRILLING METHOD(S): 2-1/4 I.D. H.S.A.
SPT METHOD: Automatic
OTHER TEST(S):
DRILLER: DOTSON, T.H.
LOGGER: FREEMAN, T.E.

GROUNDWATER
NOT ENCOUNTERED

FIELD DATA: DEPTH (ft), ELEVATION (ft), SOIL: SPT HAMMER BLOWS, SPT % RECOVERY, SAMPLING, SAMPLE INTERVAL; ROCK: CORE % RECOVERY, RQD, DIP: STRATA, JOINTS; LEGEND

LABORATORY DATA: LIQUID LIMIT (LL), PLASTICITY INDEX (PI), MOISTURE CONTENT (%), PLASTIC LIMIT

DEPTH (ft)	SPT HAMMER BLOWS	SAMPLE INTERVAL	DESCRIPTION OF STRATA	LL	PI	MOISTURE CONTENT (%)	PLASTIC LIMIT
			0.0 / Asphalt Concrete **ASPH**				
			0.4 / Crushed Aggregate Base Course **GW**				
			0.6 / Stone Base **GW**				
		1	0.7 / Tan brown silty sandy GRAVEL **GW-GM**				
	9 5			32	14	8.5	18
			1.5 / Tan brown clayey SILT **MH**				
2		2					
	6 8			54	23	33.3	31
			2.5 / Tan & white SILT **ML** Perched water & residuum encountered @ 2.5 ft				
		3					
	5 9						
4		4					
	9 12			43	11	28.0	32
		5	Borehole terminated @ 5.0 ft				

VDOT1E 8/22/00

REMARKS:
LOCATION: Wythe County, Rte. 607

PROJECT #: CSC 1116008
PAGE 1 OF 1 **SITE 1-3.08**

Figure 6. Record of One Borehole Log at Site 1

Table 3. 1999 Average Annual Daily Traffic and Percentage by Vehicle Class

Site No.	Traffic Volume, AADT	Percentage of AADT by Vehicle Class				
		Buses	2-Axle Trucks	3+-Axle Single Units	Single Trailers	Double Trailers
1	832	0	2	3	1	
2	6,101	1	2	1	3	
3	2,354	1	2	2	2	
4	2,140	1	2	1	3	
5	3,196	1	3	6	7	
6	1,615	0	2	3	1	
7	1,264	0	2	3	1	
8	2,783	1	2	2	2	
9	1,028	1	2	2	2	
10	11,773	0	2	1	7	1
11	11,773	0	2	1	7	1
12	6,956	1	2	1	3	
13	3,960	1	2	1	3	1
14	3,853	1	2	1	3	
15	12,693	0	2	1	4	1
16	8,669	1	2	1	3	
17	9,572	0	2	1	7	
18	9,572	0	2	1	7	

Load Damage Concept

In an effort to reduce the cost of pavement construction, maintenance, and rehabilitation, the nation's state highway and transportation departments and the federal government have sponsored a continuous program of research on pavements. One outcome of that research effort was the *AASHTO Guide for the Design of Pavement Structures.*[8] Perhaps the most widely used pavement design procedure in the nation, the guide is largely based on the findings of the AASHTO Road Test, which was a comprehensive experiment designed and conducted to provide information that could be used to develop pavement design criteria. The results of the road test led to the development of an empirical procedure that is now used by all U.S. transportation agencies to estimate pavement deterioration as a function of vehicle loads. The damage assessment procedure requires that all traffic using the facility in question be converted to a standard equivalent axle load so that the relative damage caused by each class of vehicle may be compared. The results of the AASHTO Road Test have shown that the damaging effects of the passage of an axle of any mass (commonly called load) can be represented by a number of 18,000-pound equivalent single-axle loads (ESALs). In other words, the extent of damage, or reduction in serviceability, caused by a single pass of a vehicle with multiple axles can be equated to and expressed in terms of a particular number of passes of the standard 18,000-pound (18 kip) axle load. For example, one application of a 12,000-pound single-axle load was found to cause damage equal to approximately 0.23 pass of an 18,000-pound single-axle load, and, likewise, four passes of the 12,000-pound single-axle load was required to cause the same damage as one application of an 18,000-pound single-axle load. Almost all U.S. transportation agencies and roadway pavement design procedures have adopted the 18,000-pound ESAL as the standard axle load for design and analysis purposes.

The procedure used to analyze the damaging effects of a mixed traffic stream of different axle loads and axle configurations is complex, and it requires the conversion of actual or expected average daily traffic into an equivalent number of 18,000-pound single-axle loads. The ESALs then must be summed over the performance period. Actual mixed traffic streams are converted to ESALs by multiplying the number of vehicle trips (AADT) in each vehicle class using the facility by the appropriate load equivalence factor. The load equivalence factor, or ESAL factor, defines the damage per pass caused to a specific pavement by the vehicle in question relative to the damage caused by 1 ESAL. For example, one pass of a moderately loaded three-axle dump truck (35,000-pound gross weight) has been determined to cause about the same amount of damage as 0.80 pass of an 18,000-pound single-axle load. Similarly, one pass of a passenger car was determined to cause approximately the same damage as 0.0003 pass of an 18,000-pound single-axle load. Dividing the two load equivalence factors demonstrates that one pass of the dump truck causes more than 2,500 times the damage done by one pass of a car. The relative extent of damage to pavements caused by trucks is so great that most transportation agencies choose not to include the effects of automobile traffic when designing pavement structures for high-truck-volume facilities.

Load Equivalency Factors

To compare the damaging effects of vehicles operating under the HB 2209 higher weight limits and those of vehicles operating otherwise, two sets of ESAL factors were calculated for each of the four truck classes listed in Table 3. These ESAL factors are based on a structural number of 4. The actual ESAL factor for each vehicle is a function of design structural number and terminal serviceability. Although the terminal serviceability for all monitoring sites was constant (2.8), the design structural number is dependent on the traffic characteristics and subgrade strength. The first set of ESAL factors represents gross vehicle weights consistent with weight limits currently in effect outside the severance tax counties. The second set represents those ESAL factors that would apply to vehicles operating under the higher weight limit provisions. Table 4 summarizes the results of the ESAL factor analysis.

Table 4. Load Equivalency (ESAL) Factor Analysis

Vehicle Class	Max Allowable Weight, lb, (Non-severance tax counties)	ESAL Factor (Non-severance tax counties)	Max Allowable Weight, lb, Permitted by HB 2209	ESAL Factor (permitted by HB 2209)
2-axle single units	40,000	2.94	40,000	2.94
3+ axle single units	54,000	2.58	60,000	3.5[a]/4.27[b]
Single trailers	80,000	2.86	90,000	3.96[a]/4.89[b]
Double trailers	80,000	2.15	90,000	3.10

[a]ESAL calculation with 20,000 pounds on front axle.
[b]ESAL calculation with 24,000 pounds on front axle.

Projected ESALs

The actual total number of ESALs for which a facility is designed is obtained by multiplying the ESAL factor by the total number of AADT projected over the design period for each vehicle class. This requires the application of a growth factor to account for anticipated increases in traffic volume over time. In this analysis, an average annual growth rate of 2 percent per year was used for all vehicle classes, which is consistent with growth rates used in pavement designs elsewhere in Southwest Virginia. The total ESAL projection for these 18 sites was used as one direct input into the pavement thickness design process.

Structural Analysis

Overview

The structural analysis formed the basis for determining (1) the pavement structure (i.e., material layer thickness) required to upgrade the existing pavements to support ordinary traffic (i.e., traffic operating in accordance with the weight limit provisions currently in effect outside the severance tax counties), (2) the *net additional* pavement structure (i.e., above and beyond the upgrade) required to support traffic under the higher HB 2209 weight limits, and (3) the range of estimated costs associated with the net additional pavement structure needed to support the heavier traffic. This was accomplished using the traffic and existing pavement and subgrade support conditions established during the preceding efforts as the primary input for pavement thickness design in accordance with the *AASHTO Guide for the Design of Pavement Structures.*[8]

To determine the structural capacity of the existing pavements, results of the deflection testing activities described previously were used in conjunction with subgrade soil classifications to back calculate the subgrade resilient modulus. Since the strength of flexible pavements depends on the temperature of asphalt materials in the structure, deflections were corrected to the equivalent of 68 F in accordance with AASHTO guidelines. The next step involved calculating the effective structural number (SNeff) for each site (or group of structurally similar contiguous segments within a site). The SNeff is a function of subgrade resilient modulus, as well as the condition and total thickness of all pavement layers above the subgrade. The calculations for the effective structural number and subgrade resilient modulus were based on equations found in the AASHTO guide.[8]

The structural analysis results for each monitoring site and test period are provided in Appendix G.

Pavement Overlay Designs

To simplify the process of quantifying structural requirements, all pavement designs and associated cost estimates of the upgrades were based on improvements of the existing sites with asphalt overlays. In Virginia, the procedure for designing asphalt overlays is based on a 12-year overlay service life. To maintain consistency with that approach, the overlays reported on herein were designed for a useful life of 12 years. That is to say, these asphalt overlay thicknesses were designed to last under the projected traffic conditions for 12 years before rehabilitation would be required. Pavement overlays were designed based on the AASHTO guide[8] and VDOT guidelines.[9] Using the calculated design subgrade modulus and effective structural number, overlay thickness designs were developed for three traffic-loading scenarios at each site as follows:

1. The pavement overlay thickness required to upgrade the existing pavements to support ordinary traffic, that is, traffic operating in accordance with the weight limit provisions currently in effect outside the severance tax counties (henceforth referred to as Scenario 1).

2. The pavement overlay thickness required to upgrade the existing pavements to support traffic operating at weight limits allowed by HB 2209 with a load of 20,000 pounds on the front steering axle (henceforth referred to as Scenario 2).

3. The pavement overlay thickness required to upgrade the existing pavements to support traffic operating at weight limits allowed by HB 2209 with a load of 24,000 pounds on the front steering axle (henceforth referred to as Scenario 3).

Table 5 shows the parameters/inputs used in the AASHTO design equation for the overlay design effort. Tables 6 and 7 summarize design inputs for existing subgrade modulus and effective structural number, as well as projected traffic loading conditions, respectively.

The structural analysis revealed that 11 of the 18 study sites in their current condition are structurally adequate to support traffic for a 12-year period, even under the HB 2209 weight limits. However, 7 sites need structural improvement to withstand loads imposed by vehicles

Table 5. Overlay Thickness Design Parameters

Parameter/Input	Pavement Overlay
Initial serviceability	4.2
Terminal serviceability	2.8
Standard deviation	0.49
Reliability	90%
Subgrade modulus	Varies by site (see Table 6)
Effective SN	Varies by site (see Table 6)
Pavement overlay design life	12 years

Table 6. Resilient Modulus and Structural Numbers Used for Overlay Design

Site No.	Design Subgrade Modulus (psi)	Effective Structural Number
1	6,000	1.46
2	7,500	4.15
3	8,700	3.38
4	4,500	3.47
5	12,900	4.41
6	10,500	3.38
7	14,900	3.38
8	6,600	3.33
9	4,200	1.89
10	15,000	5.21
11	15,000	5.16
12	14,000	5.01
13	15,000	5.90
14	6,000	3.21
15	13,600	4.10
16	14,750	4.38
17	15,000	4.89
18	15,000	4.44

Table 7. Projected Equivalent Single-Axle Loads for Overlay Design

Site No.	Existing Legal Limits, Scenario 1[a]	HB 2209 Weight Limits, Scenario 2[b]	HB 2209 Weight Limits, Scenario 3[c]
1	227,290	280,910	380,556
2	2,343,492	2,935,479	3,819,157
3	886,421	1,301,851	1,473,236
4	813,551	1,017,102	1,357,083
5	3,146,881	4,087,779	5,192,174
6	509,852	631,020	847,682
7	391,615	485,544	652,741
8	1,033,718	1,288,564	1,742,061
9	373,145	552,532	619,183
10	7,476,862	9,717,720	12,209,914
11	7,476,862	9,717,720	12,209,914
12	2,672,837	3,300,314	4,442,268
13	1,556,509	1,939,124	2,565,105
14	1,498,879	1,875,470	2,504,822
15	5,369,719	6,895,638	8,933,338
16	3,328,061	4,161,863	5,578,492
17	6,069,204	7,929,658	9,858,562
18	6,640,464	8,530,542	9,858,562

[a]Scenario 1: ESALs based on pre-HB 2209 weight limits.
[b]Scenario 2: ESALS based on HB 2209 weight limits with 20,000 pounds on front axle.
[c]Scenario 3: ESALs based on HB 2209 weight limits with 24,000 pounds on front axle.

operating at the higher weight limits. The *net additional* average asphalt overlay thickness required to support traffic operating at the higher weight limits *above and beyond* the average overlay thickness required to support traffic at the pre-HB 2209 limits ranged from ½ to 1 inch at the deficient sites. Table 8 summarizes the structural overlay design analysis for all sites.

Table 8. Structural Overlay Design Analysis

Site No.	12-Year Asphalt Overlay Thickness, In, Required for:		
	Existing Legal Limits, Scenario 1[a]	HB 2209 Weight Limits, Scenario 2[b]	HB 2209 Weight Limits, Scenario 3[c]
1	3.75	4.02	4.43
2	0.27	0.64	1.07
3	0.05	0.59	0.77
4	2.02	2.39	2.86
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.00	0.00	0.00
8	1.32	1.66	2.14
9	4.64	5.25	5.43
10	0.00	0.00	0.00
11	0.00	0.00	0.00
12	0.00	0.00	0.00
13	0.00	0.00	0.00
14	2.52	2.89	3.36
15	0.00	0.00	0.32
16	0.00	0.00	0.00
17	0.00	0.00	0.00
18	0.00	0.00	0.00
Average[d]	2.0	2.5	3.0

[a]Scenario 1: ESALs based on pre-HB 2209 weight limits.
[b]Scenario 2: ESALS based on HB 2209 weight limits with 20,000 pounds on front axle.
[c]Scenario 3: ESALs based on HB 2209 weight limits with 24,000 pounds on front axle.
[d]For those sites requiring an AC overlay only.

DISCUSSION

Pavement Performance at the Study Sites

As expected, the effort that involved detecting differences in pavement performance between the 18 sites attributable to increased HB 2209 weight limits over the 13-month study period was inconclusive. The task at hand involved quantifying damage to pavements caused by a net increase in the allowable weight limits of particular types of vehicles transporting sand, gravel, or crushed stone. The magnitude of variability that influences the rate and extent of pavement deterioration is enormous. For example, sources and quality of asphalt and aggregate; batching methods; asphalt mix designs; construction equipment and methods; effectiveness of construction quality control; the extent, timing, and suitability of pavement maintenance and rehabilitation activities; traffic stream composition; vehicle weights and weight limit enforcement; tire pressures; axle configurations and weight distribution; adequacy of the pavement structure to support actual loads; subgrade materials and support conditions; local geology; roadway geometry; short- and long-term climatic conditions; influence of the local economy on traffic activity; and the interactive effects of all of these factors have huge impacts on the way a particular pavement performs over time. It is at best extremely difficult and complicated to isolate a single variable and definitively measure the contribution of that variable to a pavement's overall performance. It may be possible, however, to develop an indication of the influence of a variable or set of variables on performance over a period of time sufficient to "wash out" the effects of, for example, an inordinately cold winter or particularly heavy temporary traffic activity attributable to a booming local economy. Clearly, such a period of time would be on the order of years or decades, not months. Therefore, it was unrealistic to expect meaningful conclusions solely from our effort to "monitor the operation of vehicles under this subsection and the effects such operation has on the condition of the affected highways."

Although the results of the visual surveys clearly indicated a decline in surface condition at sites surveyed since 1997, the LDR data did not reflect significant differences in rates of deterioration between sites in severance tax and non-severance tax counties. Likewise, the results of attempts to document differences in rates of pavement roughness and rut depth accumulation were inconclusive. Similarly, changes in load-bearing capacities of the study sites over the study period yielded inconclusive results. In summary, the long-term performance of pavements cannot be accurately modeled with 1 year of performance data. In fact, in the case of the visual LDR data analyzed since 1997, 3 years was not sufficient to detect significant changes in performance between sites.

Structural Rehabilitation Required to Support Heavier Vehicles: Cost Implications

Deflection test results and the structural analysis presented in the previous section permitted an assessment of the adequacy of the sites to support projected future traffic. Based on these findings, the following addresses the cost implications of structural improvements that would be required to upgrade deficient sites. This, then, established the basis for estimating the costs that would apply to upgrading deficient primary and secondary roadway pavements in all counties affected by the bill. The economic analysis is based on the asphalt overlay thickness designs presented in Table 8.

Estimated Cost of Improving Deficient Study Sites

The cost estimates in this analysis are consistent with the cost of prevailing materials in VDOT's Bristol District and are based on an average cost of asphalt per ton, in place, of $40; an average asphalt unit weight, in place, of 140 pounds per cubic foot; and an average lane width of 12 feet.

To clarify and simplify the estimating process, costs associated with guardrail, grade and shoulder improvements, traffic control, pavement markings, etc., were not considered. Only those costs associated with asphalt overlay placement in the mainline pavement were included.

To enable the isolation of costs that would be attributable only to the effects of the net additional weight allowed by the bill, estimates were developed for asphalt overlays required to support projected traffic under the three loading scenarios summarized in Table 9.

Costs attributed to the effects of the *net increase in allowable loads* were arrived at by subtracting improvement costs required to meet Scenario 1 traffic loading conditions (pre-HB 2209 weight limits) from those costs required to meet traffic loading demands under Scenarios 2 and 3 (HB 2209 weight limits). For the sites requiring structural improvement, the average *net cost increase per mile attributed to the additional allowable weights* ranged from approximately $6,000 to $11,000, as shown in Table 10.

Table 9. Cost Estimates of Asphalt Overlays Required for Each Site ($ per lane mile)

Site No.	Scenario 1[a]	Scenario 2[b]	Scenario 3[c]
1	55,440	59,472	65,520
2	4,032	9,408	15,792
3	672	8,736	11,424
4	29,904	35,280	42,336
5	d	d	d
6	d	d	d
7	d	d	d
8	19,488	24,528	31,584
9	68,544	77,616	80,304
10	d	d	d
11	d	d	d
12	d	d	d
13	d	d	d
14	37,296	42,672	49,728
15	d	d	4,704
16	d	d	d
17	d	d	d
18	d	d	d

[a]Scenario 1: ESALs based on pre-HB 2209 weight limits.
[b]Scenario 2: ESALs based on HB 2209 weight limits with 20,000 pounds on front axle.
[c]Scenario 3: ESALs based on HB 2209 weight limits with 24,000 pounds on front axle.
[d]None required.

Table 10. Net Additional Overlay Cost Attributed to Higher Allowable Weight Limits ($ per lane mile)

Site No.	Scenario 2 – Scenario 1	Scenario 3 – Scenario 1	Average
1	$4,032	$10,080	$7,056
2	5,376	11,760	8,568
3	8,064	10,752	9,408
4	5,376	12,432	8,904
5	-	-	-
6	-	-	-
7	-	-	-
8	5,040	12,096	8,568
9	9,072	11,760	10,416
10	-	-	-
11	-	-	-
12	-	-	-
13	-	-	-
14	5,376	12,432	8,904
15	-	4,704	2,352
16	-	-	-
17	-	-	-
18	-	-	-
Average	6,048	10,752	8,022

Estimated Cost of Damage Attributed to Higher Weight Limits

If the proportion of structurally deficient primary and secondary roadways throughout Southwest Virginia is similar to the percentage of deficient sites identified in this study, then 39 percent of the Bristol District network may be presumed to be inadequate even to support traffic operating at pre-HB 2209 weight limits. Using this rationale, of the 9,052 lane miles of roadway affected by the higher weight limit provision, 3,530 miles can be presumed to be deficient. Based on the average net cost increase of $8,022 per lane mile to account for damage by the higher weights, $28,317,660 represents the share of the cost of the total required improvements attributed to the net increase in allowable weights of vehicles operating in the seven affected counties throughout a 12-year period.

Asphalt Overlay Service Life

The result of subjecting roadways to traffic operating at the higher weight limits without all necessary structural improvements being made would be a reduction in service life. In other words, structurally improved roads would be expected to perform under the HB 2209 weights at an acceptable level of service for approximately 12 years. On the other hand, deficient pavements under the heavier loads would require major rehabilitation sooner than 12 years. To quantify this hypothetical reduction in service life, an analysis was conducted to estimate the reduced serviceability of the pavements in the event that funding is not available for the full structural upgrades, that is, improvements above and beyond the previously reported Scenario 1 traffic loading conditions. This was accomplished by examining the ratios of cumulative ESALs projected for the pre-HB 2209 weight limits and ESALs projected for the higher allowable weights.

The results of this analysis indicated that raising the allowable weight limits on pavements that are structurally adequate to support only vehicles operating under the pre-HB 2209 limits would reduce pavement service life from 12 years to approximately 7.3 to 9.4 years. Clearly, in the absence of available funding for the necessary structural improvements, the impact on pavement condition and maintenance costs of more frequent overlay requirements, and the resulting perpetual growth in the backlog of deficient pavements, would be enormous over time.

Relative Load Damage in Perspective

The damaging effect of heavy trucks on pavements is not a new concept. Results of the most comprehensive study ever conducted on the relationship between heavy vehicles and pavement damage, which has been continuously underway since the 1950s,[8] demonstrate that an incremental increase in vehicle weight results in an exponential increase in pavement damage. For example, according to the load damage analysis procedure developed by AASHTO,[8] a single pass of a three-axle single-unit truck with a gross weight of 54,000 pounds (allowable under current law) causes approximately 8,000 times the damage of an ordinary passenger car. Likewise, one pass of the same three-axle truck with a gross weight of 60,000 pounds (allowable under HB 2209 provisions) would cause approximately 50 percent more damage than the 54,000-pound truck. Stated otherwise, for this truck class, an 11 percent increase in weight results in a 50 percent increase in damage. Consider the effects of raising the allowable weight of a five-axle semi-trailer from 80,000 pounds to 90,000 pounds in accordance with HB 2209. With an increase in gross weight of only 10,000 pounds, or 12.5 percent, a single pass of the 90,000-pound vehicle causes 58 percent more damage than the 80,000-pound vehicle. These examples apply to pavements that are structurally adequate to support the stated loads. The percentage increase in damage resulting from the additional weight would be drastically higher for structurally deficient pavements.

The exponential increase in relative damage corresponding to an incremental increase in weight is due to the severe reduction in the number of vehicle load repetitions that will cause fatigue failure, which is the result of increased stresses and strains within the pavement structure. As an analogy, consider the consequence of repetitively bending a thin piece of metal by hand. The metal could survive an indefinite number of repetitions if the degree of bending were quite small (i.e., lighter loads, lower deflections). However, if the degree of bending were increased only slightly, the metal would fail in fatigue after a finite number of repetitions. When the magnitude of the sheer number of trucks using a facility over many years is considered, the cumulative effect of the net increase in damage resulting from a corresponding increase in weight limits becomes exorbitant.

Photos 15 through 18 show the load-induced distress typically observed at the study sites in Southwest Virginia, thus illustrating the damaging effects of heavy truck traffic on pavement.

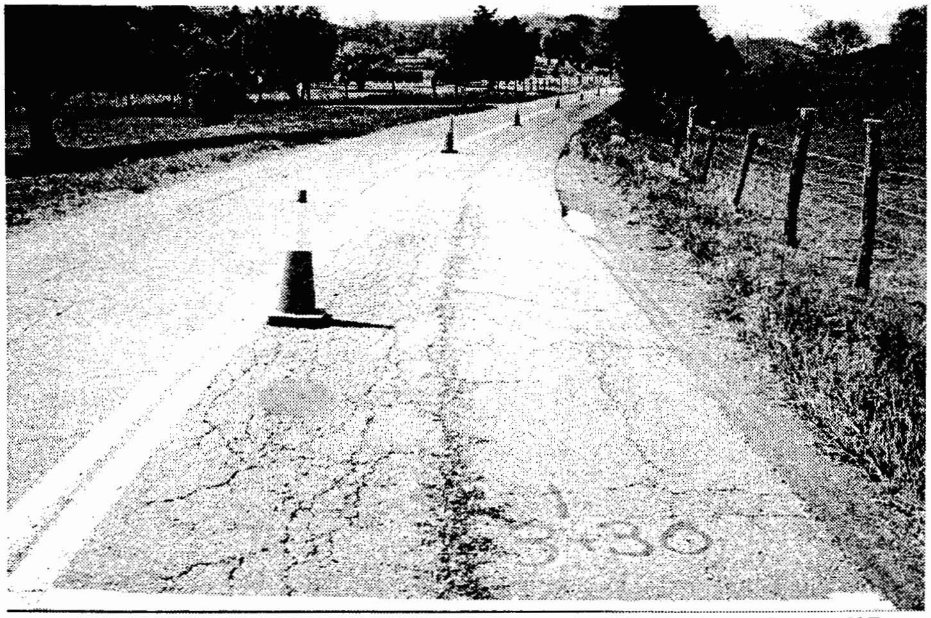

Photo 15. Severe Fatigue Damage with Patched Pothole at Site 1: Route 607, Wythe County, April 2000

Photo 16. Severe Fatigue Damage at Site 9: Route 93, Grayson County, April 2000

Photo 17. Moderate Fatigue Damage at Site 18: Route Alternate 58, Russell County, April 2000

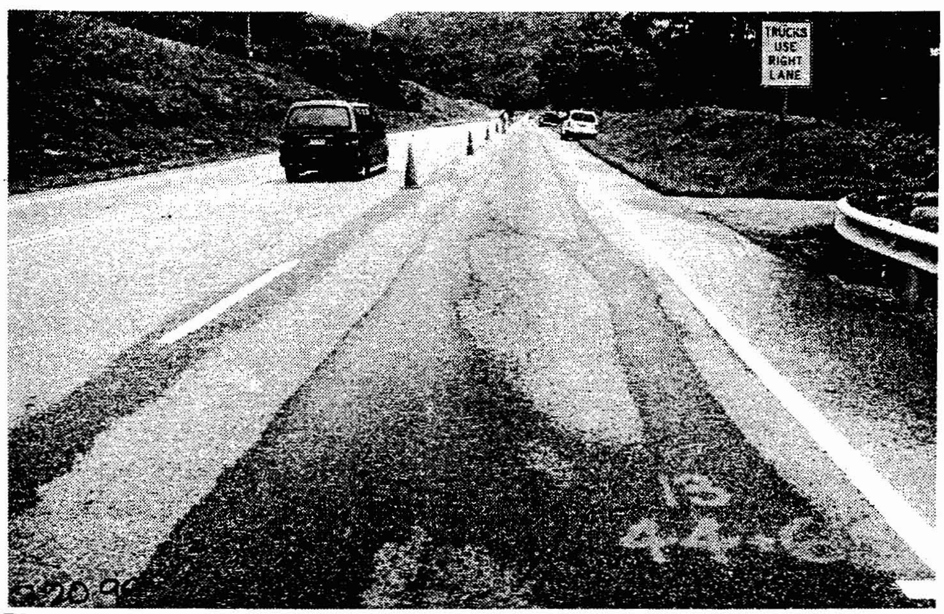

Photo 18. Wheel Path Rutting at Site 13: Route 58, Lee County, July 1999. Note standing water in wheel paths.

Review of Similar National Studies

Other significant studies based on data collected over longer periods of time than the one reported herein have documented the effects of heavy vehicle loads on pavement performance:

- *Assessment of Damage Caused to Pavements by Heavy Trucks in New England,* by Lee and Peckham,[10] presents the results of an investigation of damage to pavements by benchmark (based on federal maximum weight limits) and actual heavy trucks measured by WIM technology. The authors reported consistent observations that heavy trucks caused more damage than benchmark trucks. More damage by heavy trucks was also reported when there was a higher weight limit.

- *Effects of Permit and Illegal Overloads on Pavements,* by Terrell and Bell,[11] was published as a National Cooperative Highway Research Program Synthesis of Highway Practice. It summarizes information on the effects on pavements of loads greater than those used in design. The study found that loads applied to pavements in excess of design loads will significantly shorten pavement life. The report also describes the difficulties in enforcing truck weight laws.

- *Federal Truck Size and Weight Study,* by Stowers et al.,[12] was published by the Transportation Research Board. This study found that "if weight limits are increased without a corresponding increase in highway system expenditures, then the condition of pavements and bridges in the United States would deteriorate, which would, in turn, affect the motor vehicle operating costs, travel speeds, and circuity experienced by highway users."

- *Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance,* by Gillespie et al.,[13] was also published by the Transportation Research Board. In it the authors reported: "The high wheel loads of heavy trucks are a major source of pavement damage by causing fatigue, which leads to cracking, and by permanent deformation, which produces rutting." The study assessed the significance of truck, tire, pavement, and environmental factors as determinants of pavement damage. Maximum axle load and pavement thickness were reported to have the primary influences on fatigue damage. Truck properties, such as number and location of axles, suspension type, and tire type, were also found to be important but less significant.

- *Effect of Load, Tire Pressure, and Tire Type on Flexible Pavement Response,* by Bonaquist, Churilla, and Freund,[14] was also published by the Transportation Research Board. This study used the Federal Highway Administration's Accelerated Loading Facility to measure the effects of load, tire pressure, and tire type on the performance of asphalt pavement by analyzing the responses of surface deflection, surface strain, and strain at the bottom of the asphalt layer. They found that each of these responses was affected more by load than tire pressure. Results indicate that doubling the wheel load from 9,400 to 19,000 pounds increased damage by 1,000 percent whereas doubling the tire pressure from 76 to 140 pounds per square inch increased damage only 20 percent.

CONCLUSIONS

- Although the period of time (13 months) available to monitor pavement performance was sufficient to detect and document condition changes *within* sites, it was not sufficient to allow the capture of data to determine whether there were significant differences in the rates of change *among* sites. Therefore, observations that involved making comparisons between severance tax and non-severance tax (control) sites were inconclusive.

- For each of the 18 sites monitored as part of this study, visible load-induced distress increased, wheel path rutting increased, and ride quality decreased from July 1999 through July 2000.

- There were significant differences in the structural conditions of study sites.

- There was no consistent trend in structural deterioration for any site throughout the study period as determined by the pavement deflection analysis.

- Thirty-nine percent of the pavements investigated in this study were structurally inadequate to support traffic operating at weight limits allowed by HB 2209 for a sustained period of time.

- The cost of damage to primary and secondary roadway pavements within the seven severance tax counties caused by the *net additional weight* allowed by HB 2209 is estimated to be on the order of $28 million over a 12-year period. This estimate does not include costs associated with load-induced damage to bridges; motorist delays through work zones because of increased road and bridge repairs; safety and geometric roadway improvements; or loss of life and property resulting from the increased safety hazards of heavy trucks operating in mountainous terrain.

- The damaging effects on pavement performance of increasing vehicle weights are widely documented. The most comprehensive study of pavement performance under heavy vehicle loads, led by AASHTO, has been continuously underway since the 1950s.[8] When applied to this study, pavement analysis principles derived from AASHTO's 40-year national study demonstrate that the damage caused by heavy vehicles increases exponentially with corresponding incremental increases in weight for all classes of trucks affected by HB 2209.

RECOMMENDATIONS

In light of the structural evaluation and cost analysis performed for the 18 study sites and the literature review of pertinent studies, the provisions of HB 2209 pertaining to the authorization of additional weight limits for trucks hauling sand, gravel, or crushed stone should expire on July 1, 2001.

Further, in the opinions of the principal investigators of this research and the members of the Coal Severance Tax Study Steering Committee, the outcome of continued monitoring of the sites studied herein would serve only to support the findings of the widely accepted AASHTO research effort, which are based on more than 40 years of continuous work conducted collaboratively by and for the 50 state highway agencies. It would seem that an attempt to replicate such a comprehensive and costly effort by continuing to monitor these Southwest Virginia sites would be redundant and is, therefore, not recommended.

REFERENCES

1. Commonwealth of Virginia, in Cooperation with the Department of Transportation, Department of Motor Vehicles, and Department of State Police. July 1999. *Size, Weight, Equipment and Other Requirements for Trucks, Trailers and Towed Vehicles.* Richmond.

2. Virginia Department of Transportation, Traffic Engineering Division. 1999. *Mileage Tables, the State Highway Systems.* Richmond.

3. Strategic Highway Research Program. 1993. *Distress Identification Manual for the Long-Term Pavement Performance Project.* SHRP-P-338. Washington, D.C.: National Research Council.

4. National Highway Institute. 1990. *Highway Pavements, Volume I, Volume II, and Volume III.* Course No. 13114. FHWA-I-II-90-026. Washington, D.C.: U.S. Department of Transportation and Federal Highway Administration.

5. Virginia Department of Transportation. Revised April 2000. *Virginia Test Method for Ride Quality Testing on Ride Specifications Projects Designation: VTM 106.* Richmond.

6. Virginia Department of Transportation, Traffic Engineering Division, in cooperation with the U.S. Department of Transportation, Federal Highway Administration. 1997. *Average Daily Traffic Volumes with Vehicle Classification Data on Interstate, Arterial and Primary Routes.* Richmond.

7. Virginia Department of Transportation, Maintenance Division. March 1998. *A Guide to Evaluating Pavement Distress Through the Use of Video Images.* Richmond.

8. American Association of State Highway and Transportation Officials. 1993. *AASHTO® Guide for Design of Pavement Structures.* Washington, D.C.

9. Virginia Department of Transportation, Materials Division. March 2000. *Guidelines for Project Evaluation and Pavement Design, Version 2.0.* Richmond

10. Lee, K.W., and Peckham, W.L. 1990. *Assessment of Damage Caused to Pavements by Heavy Trucks in New England.* TRR 1286. Washington, D.C.: Transportation Research Board.

11. Terrell, R.L., and Bell, C.A. 1987. *Effects of Permit and Illegal Overloads on Pavements.* NCHRP Synthesis of Highway Practice 131. Washington, D.C.: National Cooperative Highway Research Program.

12. Stowers, J.R.; Cohen, H.S.; Sinnott, J.H.; Weinblatt, H.; Morris, J.R.; and DiRenzo, J. 1983. *Federal Truck Size and Weight Study.* TRR 920. Washington, D.C.: Transportation Research Board.

13. Gillespie, T.D.; Karamihas, S.M.; Sayers, M.W.; Nasim, M.A.; Hansen, W.; Ehsan, N.; and Cebon, D. 1993. *Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance.* Report No. 353. Washington, D.C.: National Cooperative Highway Research Program.

14. Bonaquist, R.F.; Churilla, C.J.; and Fruend, D.M. 1988. *Effect of Load, Tire Pressure, and Tire Type on Flexible Pavement Response.* Report No. TRR 1207. Washington, D.C.: Transportation Research Board.

APPENDIX A
HOUSE BILL 2209

CHAPTER 915

An Act to amend and reenact § 46.2-1143 of the Code of Virginia, relating to weight limits applicable to vehicles hauling coal, gravel, sand, or crushed stone.

[H 2209]

Approved March 29, 1999

Be it enacted by the General Assembly of Virginia:

1. That § 46.2-1143 of the Code of Virginia is amended and reenacted as follows:

§ 46.2-1143. Overweight permits for coal haulers; trucks hauling gravel, sand, or crushed stone in certain counties; penalties.

A. The Commonwealth Transportation Commissioner and local authorities of cities and towns in their respective jurisdictions, upon written application by the owner or operator of vehicles used exclusively for hauling coal from a mine or other place of production to a preparation plant, loading dock, or railroad shall issue, without cost, a permit authorizing those vehicles to operate with gross weights in excess of those established in § 46.2-1126 on the conditions set forth in this section.

B. Vehicles with three axles may have a maximum gross weight, when loaded, of no more than 60,000 pounds, a single axle weight of not more than 24,000 pounds and a tandem axle weight of no more than 45,000 pounds. Vehicles with four axles may have a maximum gross weight, when loaded, of no more than 70,000 pounds, a single axle weight of no more than 24,000 pounds, and a tri-axle weight of no more than 50,000 pounds. Vehicles with five axles having no less than thirty-five feet of axle space between extreme axles may have a maximum gross weight, when loaded, of no more than 90,000 pounds, a single axle weight of no more than 20,000 pounds, and a tandem axle weight of no more than 40,000 pounds.

C. No load of any vehicle operating under a permit issued according to this section shall rise above the top of the bed of such vehicle, not including extensions of the bed. Three-axle vehicles shall not carry loads in excess of the maximum bed size in cubic feet for such vehicle which shall be computed by a formula of 60,000 pounds minus the weight of the empty truck divided by the average weight of coal. For the purposes of this section, the average weight of coal shall be fifty-two pounds per cubic foot. Four-axle vehicles shall not carry loads in excess of the maximum bed size for such vehicle which shall be computed by a formula of 70,000 pounds minus the weight of the truck empty divided by the average weight of coal.

D. For the purposes of this section, the term bed shall mean that part of the vehicle used to haul coal. Bed size shall be measured by its interior dimensions with volume expressed in cubic feet. In order to ensure compliance with this section by visual inspection, if the actual bed size of the vehicle exceeds the maximum as provided above, the owner or operator shall be required to paint a horizontal line two inches wide on the sides of the outside of the bed of the vehicle, clearly visible to indicate the uppermost limit of the maximum bed size applicable to the vehicle as provided in this section. In addition, one hole two inches high and six inches long on each side of the bed shall be cut in the center of the bed and at the top of the painted line. Any vehicle in violation of this section shall subject the vehicle's owner or operator or both to a penalty of $250 for a first offense, $500 for a second offense within a twelve-month period, and $1,000 and revocation of the permit for a third offense within a twelve-month period from the first offense.

E. If the bed of any vehicle is enlarged beyond the maximum bed size for which its permit was granted, or if the line or holes required are altered so that the vehicle exceeds the bed size for which its permit was granted, the owner, operator, or both shall be subject to a penalty of $1,000 for each offense and revocation of the permit. Upon revocation, a permit shall not be reissued for six months. The penalties provided in this section shall be in lieu of those imposed under § 46.2-1135.

F. For any vehicle with a valid permit issued pursuant to the conditions required by this section, when carrying loads which do not rise above the top of the bed or the line indicating the bed's maximum size, if applicable, it shall be, in the absence of proof to the contrary, prima facie evidence that the load is within the applicable weight limits. If any vehicle is stopped by enforcement officials for carrying a load rising above the top of the bed or the line indicating the bed's maximum size, the operator of the vehicle shall be permitted to shift his load within the bed to determine whether the load can be contained in the bed without rising above its top or above the line.

G. No such permit shall be valid for the operation of any such vehicle for a distance of more than thirty-five miles from the preparation plant, loading dock, or railroad.

H. Until July 1, 2001, in counties that impose a severance tax on coal and gases as authorized by § 58.1-3712, the weight limits prescribed in subsection B of this section shall also apply to trucks hauling gravel, sand, or crushed stone no more than fifty miles from origin to destination. Nothing contained in this subsection shall authorize any extension of weight limits provided in § 46.2-1127 for operation on interstate highways. Any weight violation hauling sand, gravel, or crushed stone under this subsection shall be subject to the penalties authorized by § 46.2-1135. The Virginia Department of Transportation shall monitor the operation of vehicles under this subsection and the effects of such operation on the condition of the affected highways and report to the Governor and the 2001 Regular Session of the General Assembly its findings and recommendations as to whether the provisions of this subsection should be allowed to expire on July 1, 2001, or continued, either in its present or some modified form, for some specific or indefinite period. During such monitoring, should the Virginia Department of Transportation determine that the additional weight limits authorized by this subsection are negatively impacting the condition of such highways, the Department is authorized to prohibit the additional weight limits authorized by this subsection.