The benefits may be even greater if the outside rails are removed from the bridges or culverts on horizontal curves. Glennon (4), the Minnesota study (6), AASHTO (1), and TTI (5, p. 25) clearly show the need for additional roadway widths on the outside of horizontal curves.

One of the vexing problems with the removal of rails from existing narrow bridges or culverts is that of liability of the local government unit. Since most of the structures in question were built many years ago under then-prevailing width and roadside barrier standards, it appears that leaving the structures as they exist will not result in liability for the governmental unit.

On the other hand, their removal may increase safety. It seems likely that if rails are removed and an accident occurs there may be some lawsuits in which it is claimed that striking the old rail was safer than the new design (i.e., rail removed). Claims that the old rail was safer and proof of this are probably more difficult to deal with than proof that rail removal is safer.

RESEARCH NEEDED

There is a need for some roadside hazard research aimed specifically at this problem. County or local road engineers need warrants for bridge and culvert rail removal or a set of guidelines for quantifying the hazard of vehicles striking various bridge and culvert rails versus the hazard of vehicles running off the road into the adjacent ditch, stream bed, or drainage area.

It would be most helpful if a set of, say, severity indexes were developed for specific roadside hazards on LVR roads considering typical speeds, roadway cross-sections, alignment, and roadside hazards.

ACKNOWLEDGMENT

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Cost Responsibility for Low-Volume Roads in Virginia

GARY T. HENRY AND JOHN M. BENNETT

Cost responsibility is a research tool for determining the amount highway user groups should contribute to the financing of highways. Several cost-responsibility studies have been conducted at the national and state levels; however, most have omitted from analysis the cost responsibility for low-volume roads. This study presents the method and calculations of cost responsibility for Virginia's 43 000 miles of low-volume roads. Costs were divided for allocation purposes into three categories—occasioned, demand-driven, and common costs. Costs in the categories are divided among four vehicle classes by various methods. Data and methods for three major cost areas are described in detail: site preparation and geometry, pavement construction, and pavement repair and resurfacing. The results of the study show that 75 percent of the costs on low-volume roads is the responsibility of cars and light trucks. The remaining 25 percent is the responsibility of heavy trucks. The study also shows that on low-volume roads the per mile cost responsibility for each vehicle class is more than twice that of high-volume roads.

Cost responsibility has emerged as a central issue in nearly every recent discussion of highway financing. The term cost responsibility has come to mean an analysis of the extent to which highway user groups contribute an equitable share of the costs of financing highways. At the federal level, Congress mandated the completion of a four-year cost-responsibility study by 1982; in the states, at least 20 cost-responsibility studies have been undertaken in the past few years.

Interest in cost responsibility has been spurred by the impact of several recent phenomena on the highway financing system. Highways in the United States are unique among publicly financed facilities in that they have been financed largely by those who use the roads. At the national level, about 70 percent of highway funding has come from user payments (1). The dedication or earmarking of user payments for highway financing has been held to be a major factor in the comparatively high level of development of the highway system (2). In recent years, however, funds from user payments have not met expectations for the continuing development of the system. The Arab oil embargo, mandated increases in fleet fuel efficiency, restrictions on the supply of motor fuel, and general economic malaise have contributed to the revenue shortfall.

The failure of established user tax sources to produce the expected amount of revenues gives impetus for a change in the level or structure of highway taxes. From a political perspective, it is easier to pass tax increases if the burden is distributed fairly. In a social sense, the charges for highway use can suboptimize the resource allocation and consumption patterns for highways. This can be accomplished by establishing an equitable and efficient taxing burden (1,3). An equity based cost-responsibility study may, therefore, provide the basis for a politically feasible and socially rational change in taxing.

Cost-responsibility studies under way at this time have encountered numerous difficulties. The conceptual sticking points of allocating costs of joint-use facilities and long-run versus short-run marginal cost pricing plague the studies. In addition, limited data on highway use and the costs that use generates make the task difficult. Another problem, the cost responsibility for low-volume roads, is the focus of this paper.

LOW-VOLUME ROAD ENIGMA

Although cost-responsibility studies have been touted as important tools for highway financing, low-volume roads have been neglected. In light of the recent activity surrounding cost responsibility and the magnitude of expenditures on low-volume roads, the lack of research in the area is an enigma. Several reasons for not applying cost responsibility to low-volume roads can be identified.

First, cost-responsibility studies are usually sponsored by the federal or a state government. Most low-volume roads are not on the federal system and only four states have direct responsibility for a significant portion of their low-volume roads. Since the study sponsors are most concerned with analyzing the road systems they administer, low-volume roads are not included in the analysis.

Second, states have generally preempted the levy of user taxes by local government. Localities, which typically control low-volume roadways, are therefore unable to use a study to establish a system of equitable user payments. Low-volume roads are generally supported from general fund (nonuser) sources.

Third, data on low-volume roads have not been routinely collected in a manner consistent with the data for higher-volume roads. Usage data and data on the cost of maintenance activities are two examples of data that are necessary but may be lacking. Furthermore, data that are available may be collected differently in each administering jurisdiction. Because the data are expensive to obtain and difficult to manipulate in the same way as data on high-volume roads, the task of determining cost responsibility for low-volume roads can be cumbersome and difficult.

Low-volume roads have not, however, been excluded entirely from cost-related analysis. Two methods of analyzing low-volume road costs were used in the 1961 federal study--relative use and earnings credit. These procedures were designed to split the costs of low-volume roads into user and nonuser portions. The rationale underlying these procedures was that access benefits accrued to nonusers by the provision of the roads. These benefits were, in turn, used as justification for property tax (nonuser) support of low-volume roads.

Although the 1969 federal study clung to the earnings-credit method, little theoretical support exists for the peculiar treatment of access benefit (3,4). Access benefit is accrued as a roadway is used--the greater the use, the greater the benefit. Of course, some types of use derive greater benefits than others, and therein lies the general problem with benefit analysis. The access benefit argument must stand or fall with the decision on whether cost-occasioned or benefit received is to be used as a mechanism for setting the tax burden. If a cost-occasioned approach is executed, no exception should be made for low-volume roads.

Low-volume roads have a range of costs that are incurred to accommodate the use of the roads by vehicles of various types. The revenues produced through the use of those vehicles are not sufficient to recover the expenditures on the roadways. Thus, the charges to recover the costs of low-volume roads must be generated from nonuse or lump sum charges. This does not mean that a nonuser or property tax base is appropriate. Other tax sources, such as registration fees, are available for low-volume road support. The decision to allocate a portion of low-volume road costs to nonusers on the basis of access benefit is therefore arbitrary.

The traditional affiliation between low-volume-road expenditures and nonuser tax support was never established in Virginia. Since 1932, the relatively low-volume secondary road system has existed within the state highway system. Funding for the entire system has been generated primarily through user payments [e.g., motor fuel taxes (59 percent), registration fees (15 percent), and sales tax on motor vehicles (15 percent)]. Thus, a cost-responsibility study of Virginia's highways offered the opportunity to include a cost-occasioned analysis of secondary roads without violating the financing tradition established in the state.

SETTING FOR THE STUDY

When the 1980 session of the Virginia General Assembly mandated a study of the fair apportionment and allocation of highway expenditures among motor vehicles of various sizes and weights, the conditions were ripe for a study of cost responsibility on low-volume roads. As mentioned, the tax base for all highway systems was user-oriented and the state administered the low-volume, secondary road system. Moreover, the importance of the secondary system relative to the other systems was impossible to dismiss.

Secondary roads make up 43 000 miles of Virginia's 67 000-mile system. In addition, 67 percent of the state's secondary roads are paved, in contrast to the national average of 32 percent for the other 49 states. Secondary road expenditures are also a major consideration: approximately 40 percent of the state's maintenance funds and 16 percent of the state's construction funds are expended on secondary roads. These factors made the inclusion of secondary roads a necessity in an analysis of all highway expenditures.

As Table 1 indicates, traffic patterns differ significantly between Virginia's low- and higher-volume roads. As might be expected, traffic on secondary roads shows a higher concentration of passenger cars and pickup trucks. In addition, truck mileage on secondary roads is more skewed toward single-unit trucks than combination vehicles. A difference in expenditure patterns and cost allocations on the systems is expected from the difference in the traffic streams. Therefore, a detailed analysis of the expenditures on secondary roads was needed.

One caveat is necessary here--Virginia's secondary roads do not encompass all low-volume roads in the Commonwealth, and all secondary roads are not exclusively low volume. The state's urban system, which contains at least 7046 miles of low-volume roads, is not included in this presentation, although the state-supported costs of this system were included in the study mandated by the General Assembly (5,6). In addition, some secondary roads in urbanized counties accommodate high-volume traffic. For example, the two highest-volume secondary projects in the study's sample of construction projects had a mean average daily traffic of more than 18 000 cars. Nonetheless, the vast majority of the secondary system is low volume in nature.

Table 1. Travel by each vehicle class on primary and secondary roads.

Vehicle Class	Description	Proportion of Travel (%) Primary Roads	Secondary Roads
1	Passenger cars and light trucks	90.4	93.2
2	Two-axle, six-tire trucks	3.9	4.6
3	Three-axle, single-unit trucks	1.4	1.5
4	Tractor-trailer combination trucks	4.3	0.7

FRAMEWORK FOR COST RESPONSIBILITY

An analysis of cost responsibility determines whether users are contributing an equitable share of the costs of operating the highway system. The cost-occasioned approach defines the costs incurred on behalf of a user to be the costs for which that user is responsible. For example, ferries that transport only automobiles should be supported by the revenues generated by automobiles.

A central problem for cost responsibility arises because the highway system is built to accommodate a variety of vehicles. Different vehicles have a wide range of requirements for pavement width and strength and for the amount of roadway required. The approach followed in this study was to divide highway costs into three categories:

1. Occasioned costs--Costs incurred as a result of some characteristic of the vehicle stream (e.g., weight or size),
2. Demand-driven costs--Costs attributed on the basis of the relative demand exercised by components of the vehicle stream, and
3. Common costs--Costs that are not causally linked to vehicle characteristics or demand and are attributed on the basis of overall highway system use.

IMPLEMENTING THE STUDY

Several key decisions were guided by the mandate provided by the General Assembly. Since the study was to determine the equitable apportionment of user tax burden for Virginia highway users, the state's highway system, construction and maintenance practices, and vehicle use pattern formed the basis for analysis. Therefore, an extensive effort was mounted to develop attribution procedures consistent with the design, construction, and maintenance practices of the Virginia Department of Highways and Transportation (VDHT).

The mandate also provided guidance for the definition of costs to be considered in the study. Cost responsibility can be construed to include all costs generated by the highway system--public, private, and opportunity costs. However, the study mandate asked for a cost-responsibility analysis as a highway financing tool. Hence, costs were defined as the total expenditures on the Virginia highway system.

In defining costs, care had to be exercised to ensure that actual or proposed expenditures fully captured the cost to the public of providing a highway system. If some expenditures, particularly for maintenance, were being deferred, then present costs would have been underestimated and passed to future taxpayers.

Detailed analysis of the possibility of highway deterioration indicated that highway disinvestment was not occurring in significant amounts for the purposes of the study. Relevant maintenance replacement expenditures per lane mile, adjusted for inflation, showed real growth over the past 10 years. Other data regarding the nature of highway construction showed that much current construction consists of major reconstruction, resurfacing, and rehabilitation of existing highway facilities. Moreover, state maintenance engineers consistently judged that no appreciable, premature, structural deterioration was occurring on the state's highways. For these reasons, expenditures were judged to be the relevant measure of highway costs.

Finally, a decision on classifying vehicles had to be made in order to implement the study. The legislative mandate called for a study of cost apportionment among vehicles of various sizes and weights. In theory, a separate cost-responsibility estimate could be calculated for each individual who uses the highway system. Since calculation of millions of individual equations is not possible, cost-responsibility analysis requires a method for classifying users in some meaningful fashion.

Classification was achieved by grouping vehicles into a manageable number of categories based on the following:

1. Characteristics directly associated with how costs are occasioned,
2. The way in which vehicles are defined by law and are taxed, and
3. The way in which traffic and registration data are collected.

Based on these three criteria, four vehicle classes were selected to provide a basis for subsequent analysis.

Class 1--All passenger cars, pickup trucks, panel trucks, and motorcycles;
Class 2--All two-axle, six-tire trucks;
Class 3--All three-axle, single-unit trucks; and
Class 4--Three-, four-, and five-axle tractor-trailer combinations.

COST-ALLOCATION ANALYSIS

Low-volume roads are typically designed by using different procedures than those applied to Interstate and primary highways. In addition, reliable data on expenditures, structural conditions, travel patterns, and vehicle weights may be difficult to acquire. These and other problems generally require that the cost allocation for low-volume roads be addressed separately during cost-responsibility studies.

Site preparation, pavement construction, and pavement maintenance are among the most frequently discussed elements of cost allocation. They represent the highest expenditure elements of most highway systems and include the majority of costs occasioned by particular vehicle characteristics. This section discusses the procedures used to allocate these costs for Virginia's secondary roads. The data and findings apply only to the study's base period, FY 1980.

Roadway Construction Data

Site preparation and pavement construction are the principal costs involved in roadway construction. They include the costs most likely to vary with the size and weight characteristics of the traffic stream. In order to allocate these costs equitably, it was necessary to examine empirically the degree to which vehicle characteristics govern the cost of secondary road construction. A sample of 61 roadway construction projects provided the means for this examination.

Project Sample

In order to ensure that the analysis would not be unduly biased by any single construction project, all projects completed during a fiscal year were selected for the sample. The 61 projects selected ensured that actual costs incurred and materials used would condition the cost allocation.

All projects included in the sample were examined to ensure that they were representative of Virginia's secondary road construction program. The examination showed an appropriate geographical distribution and also showed diversity in project cost, size, and in the nature of construction. As a final check on the representativeness of the sample, the state highway department's construction engineer, in concert with construction division personnel, certified that the project sample represented a typical year.

VDHT maintains an automated file on each construction project that is presented for bid, is under way, or has been completed. These files form the basis of the department's system for estimating project costs. Data kept on the 61 secondary projects included materials costs and quantities for all items included on contract bids. The project files provided the means for determining how pavement and site preparation costs vary with varying traffic.

Because the 61 projects completed during FY 1980 had been initiated over several years, it was necessary to standardize prices for like activities and material quantities. Failure to standardize prices would have caused projects initiated more recently, which showed higher prices caused by inflation, to weigh disproportionately in the overall sample. Item prices were standardized to mid-FY 1980 levels.

State Force Construction

In Virginia, some secondary construction projects are conducted entirely by state highway department personnel. Such projects are statutorily limited to $200 000 and typically involve adjustments to roadway geometry, some resurfacing, or safety improvements. Although these projects represent a small portion of secondary construction, their costs had to be accounted for. However, data on materials quantities and prices are not maintained as accurately as data on contracted projects. It was therefore necessary to compensate for state force construction by adjusting the project sample.

To handle this problem, the 61 secondary construction projects were examined by the state's engineer for secondary construction to see if any projects were directly comparable to the types of projects conducted by state forces. The cost of 12 secondary projects identified as comparable were weighted to represent the cost of state force construction.

Project Clustering

The projects in the sample were grouped to ensure that projects that had similar characteristics would be analyzed together. The grouping of projects also allowed a reduction in the number of projects to be analyzed.

Most cost-responsibility studies reviewed as part of the study literature search simply group projects by administrative or functional classification. However, these classifications often overlap in significant design and traffic features that are used as the basis of cost allocation. In Virginia this is true even for the secondary road system. Although most secondary roads are low volume, there is considerable variation in this regard. Secondary projects included in the sample ranged from the typical two-lane, undivided roadway to a small number of four-lane, divided highways.

Table 2. Clusters of secondary construction projects.

Subgroup Characteristics	No. of Projects	Mean Weighted ADT
2 lanes, less than 12 ft lanes	10	79.3
	24	295.0
	7	708.6
	8	1 982.5
2 lanes, 12 ft lanes	3	623.5
	7	4 263.0
4 lanes, 12 ft lanes	2	18 263.0

The roadway characteristics judged most relevant for cost allocation were the number of lanes, lane width, and traffic. Projects were therefore grouped into clusters based on these characteristics. The process of grouping projects into clusters consisted of two steps.

In step 1 the number of lanes and lane width for each project was used to divide the secondary projects into three subgroups. Projects were divided into subgroups of: 2-lane, less than 12-ft lane projects; 2-lane, 12-ft lane projects; and more than 2-lane, 12-ft lane projects.

In step 2, within each subgroup of projects, clusters were formed by computing the mean and standard deviation of the weighted average daily traffic total, which is used in designing secondary pavement depth. Beginning at the mean, cluster boundaries were formed by moving up (or down) one standard deviation at a time. By this procedure, all secondary projects were enclosed in clusters equal to one standard deviation in length.

Seven clusters of secondary construction projects were identified by this process. Table 2 shows the number of projects, the number of lanes and lane width, and mean weighted average daily traffic (ADT) for each cluster. The clustering procedure allowed a reduction in workload and minimized the effect of aggregation bias, which generally exists if projects are not grouped homogeneously.

The project clusters were used in the allocation of the costs of site preparation and pavement construction.

Site Preparation and Roadway Geometry

Site preparation includes all activities directly related to the construction of a road, except the laying of pavements. In general, the activities are mobilizing the construction crew and equipment, clearing and grubbing, excavating, grading, installing drainage facilities, and providing improvements such as signs, signals, and vegetation. Together these activities amounted to 53.9 percent of secondary construction expenditures in the study year.

Site preparation requirements and costs vary with the size of vehicles that the roadway is designed to carry. For example, wider vehicles require wider lanes and shoulders. The costs of excavation, drainage structures, and other materials are therefore increased. Heavier vehicles require thicker pavements and generate higher excavation costs associated with preparing deeper trenches for pavement.

To determine the proportion of costs occasioned by large, heavy vehicles, an incremental technique was applied. Mixed-traffic design standards currently used by VDHT were examined to identify which aspects of roadway design could be reduced if the roadway were used only by small, light vehicles (class 1). With safety and speed considerations

Figure 1. Example of geometry reduction.

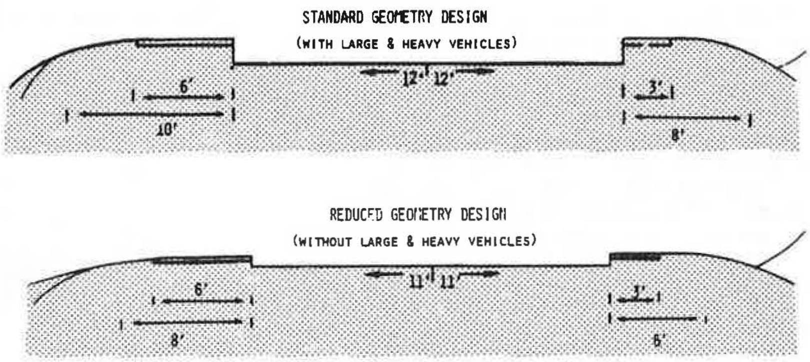


Table 3. Sample cost reduction from project redesign.

Site Preparation	Design Cost ($) Standard	Design Cost ($) Reduced	Cost Difference ($)
Mobilization	351 429	190 889	39 552
Excavation	2 043 665	1 787 778	255 887
Drainage	292 222	288 706	3 516
Traffic and roadside improvements	785 101	782 994	2 107
Total	3 351 429	3 050 367	301 062

held inviolate, three size-related reductions were possible for most clusters:

1. Lane width could be reduced by 1 ft, from 12 to 11 ft;
2. Cut shoulders could be reduced by 2 ft, from 8 to 6 ft; and
3. Fill shoulders could also be reduced 2 ft, from 10 to 8 ft.

As is discussed in the next section, when heavy vehicles were removed from the traffic stream, thinner pavements were also possible. Therefore, the redesigning of site preparation requirements for a thinner pavement allowed a reduction in trench depth. Because the degree of trench depth reduction depended on the depth of the original pavement, the amount of reduction was computed for each cluster. The roadway cross section shown in Figure 1 illustrates the reductions possible for a two-lane, undivided roadway.

Assumptions about cost reductions were tested empirically. VDHT design engineers were asked to redesign actual projects to determine the cost reductions associated with removing large, heavy vehicles from the traffic stream. This procedure ensured that cost reductions were based on actual design practice rather than on theoretical estimates.

A project for each cluster was selected for redesign in order that differences in geometric designs (i.e., 11-ft lanes versus 12-ft lanes) would be accounted for. Preference in selection from a cluster was given to projects that included all major cost elements of site preparation and roadway construction and that helped produce an even geographic distribution of projects across the state.

The difference between the site preparation and roadway geometry costs for the standard design and the reduced design was then used as an estimate of the truck-occasioned increment of site-preparation costs. Table 3 illustrates the results of the reduction for one project, which shows a 9 percent reduction from standard to reduced design.

The degree of reduction possible for each cluster was determined by applying the proportional reduction generated from the project redesign to the site preparation and roadway geometry cost for the entire cluster.

Costs associated with the truck-occasioned increment were assigned to a vehicle class on the basis of their relative use of roadways in the cluster. Costs associated with the reduced design were assumed to be a function of the general demand for the basic roadway facility. The cost of the reduced design was therefore categorized as a demand-driven cost and charged to all vehicles on the basis of relative use. Total cost responsibility for each cluster was first summed and then weighted to equal total FY 1980 expenditures for secondary site preparation and roadway geometry. The table below gives the results of that allocation.

Vehicle Class	Secondary Road Site Preparation and Roadway Geometry Allocation: Cost Responsibility ($)	Percent
1	33 963 446	90.9
2	2 473 315	6.6
3	576 048	1.5
4	362 280	1.0
Total	37 375 089	

Pavement Construction

Pavement construction expenditures accounted for 24.0 percent of roadway construction costs in the study year. Pavement construction included pavements that were laid in construction and reconstruction projects during FY 1980. Other pavement work, such as rehabilitation and replacement, was included in maintenance costs.

Some pavement costs are occasioned by vehicles because they demand wider lanes and thicker pavements. Based on the preceding analysis, it was evident that 1 ft of each 12 ft-lane is required solely for large vehicles. Costs associated with this width increment are truck occasioned.

Pavement depth for the entire lane width is occasioned by factors related to axle weights and the repetitions of axle weights. Pavement cost allocation must therefore be sensitive to both the axle weights and volume of traffic on the roadways.

Pavement Design

Pavement engineering design criteria were used to determine the relation between axle weight and traffic volume on the one hand and pavement depth on the other. The design criteria were originally developed in the American Association of State Highway Officials (AASHO) road tests conducted in Ottawa, Illinois, and were modified in Virginia to serve as the basis for pavement design.

For most roads VDHT uses the 18 000-lb equivalent single axle load (ESAL) measures developed in the AASHO tests to determine required pavement strength. In practice, estimates of daily ESALs for the 10th year (regarded by VDHT as the design year) are used to compute an index of the necessary pavement thickness [referred to as thickness units (T.I.)].

In secondary roads, the design process is somewhat different. Secondary roadway pavements are designed from a nomograph that uses a weighted average daily traffic total. Although ESALs are not directly used in the design, empirically derived assumptions about vehicle weights are included in the nomograph calibration.

The basic objective of pavement cost allocation is to separate a given thickness of pavement into two components: (a) a component that is directly related to the expected weights of vehicles that use the road, and (b) a component that is principally the result of the strength and bonding requirements necessary to preserve the pavement through weathering cycles. The first component is weight-related and allocated to the vehicles that create demand for the pavement because of their weight (Figure 2). The second component is more appropriately considered a demand-driven common cost because it is principally related to weathering (5,6).

Pavement Cost Allocation

The minimum pavement method was used as the primary pavement allocation method for both high- and low-volume roads. It is also being proposed for use in the cost-allocation study being conducted by the Federal Highway Administration and has been endorsed in concept by the American Consulting Engineers Council.

The minimum pavement method begins by determining the amount of pavement to be laid if weight were so low as to be an inconsequential factor in pavement design. VDHT pavement engineers concluded that, in Virginia, the minimum pavement equals 3.6 T.I., the practical equivalent of 6 in of crushed stone base covered by a sealant coat. Pavement thickness required above 3.6 T.I. must be concluded to be related to the axle weights of vehicles in the traffic stream.

Existence of the minimum pavement is best conceived as being related to the demand for the basic roadway facility. Accordingly, costs associated with the minimum pavement can be allocated by a measure of relative roadway use. In this study, the cost of the minimum pavement for each cluster was allocated by each vehicle class's proportion of ADT for the cluster.

Because all pavement above the 3.6 level is weight-related, pavement above the minimum was allocated by the proportion of ESALs contributed by each vehicle class. The handling of the weight-related portion of pavement in this manner distributes equitably the inherent economy of scale in pavement construction.

Application of the minimum pavement method to secondary pavements is more complicated than application of it to Interstate and primary highway pavements. As previously indicated, a nomograph rather than an ESAL-driven equation is used to determine required pavement depth. To avoid a discrepancy between the amount of pavement determined by the ESAL-driven and secondary road procedure, the nomograph was used to compute T.I. ESALs equivalent to the total weighted average traffic for each vehicle type were then used to allocate the pavement. Table 4 shows a sample calculation that uses this procedure.

Figure 2. Pavement cost-allocation illustration.

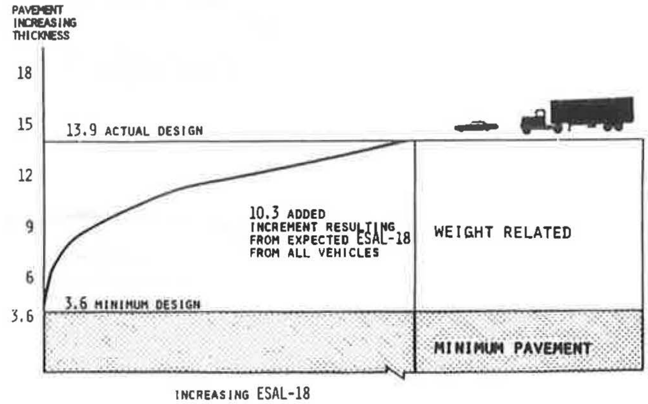


Table 4. Sample allocation of secondary pavement construction costs.

Vehicle Class	ADT (%)	ESALs (%)	Cost ($) Minimum Pavement	Cost ($) Weight-Related Pavement	Cost ($) Total Class Attribution	Percentage of Cost
1	91.9	1.3	512 753	10 960	523 859	37.4
2	5.3	38.7	30 687	326 287	357 972	25.6
3	1.2	20.7	6 695	174 526	179 757	12.8
4	1.4	39.3	7 811	331 346	339 478	24.2
Total			557 947	843 119	1 401 066	

This procedure was used to allocate pavement construction costs for the seven secondary clusters. One cluster contained projects that have pavement thickness indices below the 3.6 minimum. Pavement costs for this cluster were allocated on a proportional traffic basis. All other clusters' pavement costs were allocated by the minimum pavement method. The table below summarizes the results of that allocation.

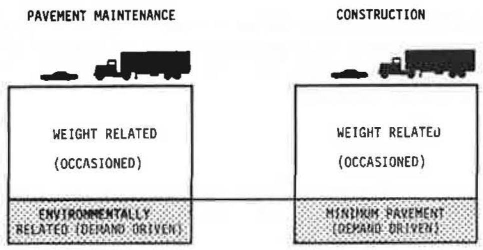
Vehicle Class	Secondary Road Pavement Construction Allocation Cost Responsibility ($)	Percent
1	9 486 473	56.8
2	3 559 709	21.3
3	1 968 351	11.8
4	1 659 588	10.1
Total	16 710 121	

Pavement Repair and Replacement

Pavement maintenance refers to an assortment of activities designed to inhibit or reverse the effects of pavement deterioration. The activities range from seal coating, skin patching, and pothole filling to resurfacing existing roadways. Pavement maintenance had the single highest expenditure of all secondary maintenance activities and accounted for 44.4 percent of total maintenance costs in FY 1980.

A principal concern in allocating pavement maintenance costs is distinguishing the amount of pavement deterioration caused by axle weights, which is occasioned by vehicle classes, from the amount caused by environmental factors, which is unrelated to vehicle use. Although the AASHO road tests establish the direct relationship between the number of ESALs and pavement deterioration, the results are

Figure 3. Pavement maintenance-allocation illustration.



not directly applicable to the problem of pavement maintenance. The tests lasted only two years, an insufficient period to simulate normal weathering cycles. Moreover, because little routine maintenance of the pavement surface was performed during the tests, pavement deterioration was artificially accelerated.

In recognition of the gaps in technical knowledge regarding pavement damage over time, the Federal Highway Administration has contracted with consultants to produce estimates of the proportion of pavement deterioration that results from weight and the proportion that results from environmental conditions. Even when the studies are completed, they are likely to be subject to much additional review. In lieu of empirically confirmed results, estimates regarding weight and environmental deterioration must be developed judgmentally.

This study used an alternative approach. For this study, the problem was characterized as drawing a line through a range of potentially reasonable estimates of weight-related versus environmentally related deterioration (Figure 3). The range of potential estimates is shown as the shaded area and can be labeled the zone of uncertainty. As Figure 3 illustrates, a decision was made to draw the line through the zone of uncertainty on the same basis as the division between weight-related and minimum pavement components in the secondary pavement construction allocation.

Beside providing results that were compatible with those derived from estimates used in other states, the use of an estimate related to construction allowed the study results to be sensitive to highway system differences. For secondary roads, the cluster-based pavement allocation showed that the 3.6 T.I. minimum pavement represented 46.9 percent of pavement costs; 54.1 percent of pavement costs were weight-related. This same proportion was used to split pavement maintenance costs. The environmentally related portion was allocated as a demand-driven common cost, and the weight-related portion was allocated by proportional ESALs on the secondary system. The result of this procedure was to allocate less secondary pavement maintenance expenditures on the basis of weight than were allocated on the Interstate and primary systems (Table 5).

Table 6. Secondary road cost allocation.

Item	Cost Allocation by Vehicle Class ($000 000s) 1	2	3	4
Construction				
Pavement	9.5	3.6	2.0	1.7
Site preparation and geometry	24.8	1.8	0.4	0.3
Engineering and right-of-way	14.3	0.7	0.2	0.1
Bridges	5.4	1.1	0.6	0.4
Total	54.0	7.2	3.2	2.5
Maintenance				
Pavement	19.7	12.1	7.9	5.1
Other	52.3	2.6	0.9	0.4
Total	72.0	14.7	8.8	5.5
Total	126.0	21.9	12.0	8.0

STUDY RESULTS

Thus far, the presentation of results of the cost-responsibility study has been limited to three expenditure areas. Other areas, such as bridge construction and rehabilitation, and other maintenance activities were also considered in the study. A summary of the allocation of all costs associated with secondary roads is given in Table 6. The procedures for arriving at these allocations are discussed in detail elsewhere (5,6).

The data in Table 6 show that more than half of the total cost responsibility of each truck class comes from pavement maintenance. The size of that expenditure item and its high proportion of occasioned costs explains this. Interesting, too, is the proportion of costs borne for bridges--nearly 30 percent of the bridge construction and rehabilitation costs were allocated to trucks. The effect of gross weight on bridge design is evident in this allocation.

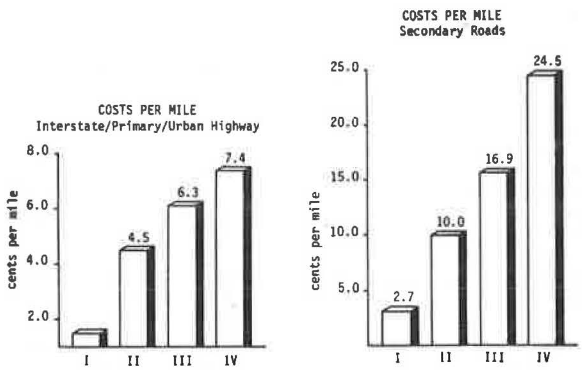
Compared with other cost-responsibility studies, the proportion of costs attributed to the individual truck classes seems incongruous. The proportions are 13.0 percent, 7.2 percent, and 4.8 percent for classes 2-4, respectively. This finding can be explained by the amount of use each of these classes contributes on secondary roads (Table 1). Secondary roads are frequently traveled by delivery trucks, dump trucks, and buses, which are included in classes 2 and 3. Class 4 vehicles travel the secondary roads much less frequently. Therefore, even though the ESALs per pass is greater for class 4 vehicles, the paucity of their presence on secondary roads minimizes their overall cost responsibility.

One further illustration lends comparative perspective on the cost responsibility for low-volume roads. The cost-per-mile responsibility for secondary roads can be compared with the cost-per-mile responsibility for Virginia's Interstate, primary, and urban roads (Figure 4). Both of the responsibilities were calculated following the methods outlined in this paper.

Table 5. Secondary road pavement maintenance allocation.

Vehicle Class	Vehicle Miles Traveled (%)	Cost of Environmental Portion ($)	ESALs (%)	Cost of Weight-Related Portion ($)	Cost Responsibility ($)	Percentage of Cost
1	93.2	19 191 745	2.1	524 572	19 716 317	43.9
2	4.6	945 376	45.9	11 142 296	12 087 672	26.9
3	1.5	313 066	31.4	7 623 292	7 936 359	17.7
4	0.7	146 235	20.6	4 995 576	5 141 811	11.5
Total		20 596 422		24 285 736	44 882 159	

Figure 4. Costs per mile traveled.



The cost-per-mile responsibility is overwhelmingly greater for secondary roads. Even with a consistent methodology, the responsibilities are at least doubled for each class on the secondary roads. Also, the cost-per-mile produces the expected relationship among the truck classes (i.e., combinations have greater responsibility than single-unit trucks). This, of course, stems from removing the impact of the miles traveled on secondary roads.

In sum, determination of the cost responsibility for secondary roads was an important part of the overall study of cost responsibility in Virginia. The findings on secondary roads showed a different distribution of cost responsibility than on the other systems, as had been expected. The combination of secondary road allocations with the other road system allocations led to the conclusion that class 2 and 3 vehicles were underpaying. Inclusion of secondary road expenditures in the state's cost-responsibility analysis was therefore a key factor in influencing study results.

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This paper reflects our positions and opinions and should not be construed to represent the position of the Joint Legislative Audit and Review Commission of the Virginia General Assembly.

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Effect of Unit-Train Grain Shipments on Rural Nebraska Roads

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The unit-train concept has altered the rural pricing structure for grains and consequently encouraged longer-distance truck transportation in larger-sized lots by producers and rural elevators over the 1975-1980 period. Annual data on grain production, livestock consumption, and storage capacity were obtained from Nebraska Agricultural Statistics. Primary data on truck receipts were collected by interview with the managers of 86 unit-train shippers across the state. A computer model was developed to calculate the total ton miles of producer transport of grains within the elevator's trade area for each district as well as ton miles of interelevator transfer. Nebraska producers in 1980 transported 71 percent more ton miles delivering grain to commercial elevators than in 1975. Combined with the growth in interelevator grain transfers by truck, the annual ton miles of rural truck transport of grains in 1980 was nearly double the 1975 level. The investment required to maintain and upgrade the rural road system is not independent of changes in other sectors of the total U.S. transportation system. The increased use of unit-trains has precipitated an increase in the ton miles of grain hauled over low-volume roads as well as an increase in the weight per axle and a subsequent increase in stress on rural roads and ridges.

From 1975 through 1980, Nebraska's annual production of grains and oilseeds averaged more than 22 million metric tons. More than 71 percent of this, or approximately 16.5 million metric tons, moved over rural roads annually via farm vehicles to commercial elevators. The growth in total volume of rural grain traffic in recent years has placed increased demand on the rural road system. Nebraska grain production increased by 7 percent annually between 1975 and 1980, more than twice the growth rate of U.S. production. With no distinguishable trend in Nebraska's feed requirements during the 1975-1980 period, increased production resulted in an average annual increase of nearly 1.5 million metric tons of grain to be marketed commercially.

Historically, bid prices to farmers have differed only marginally between competitive elevators in a