GUIDELINES FOR A STUDY OF HIGHWAY COST ALLOCATION

February 1979

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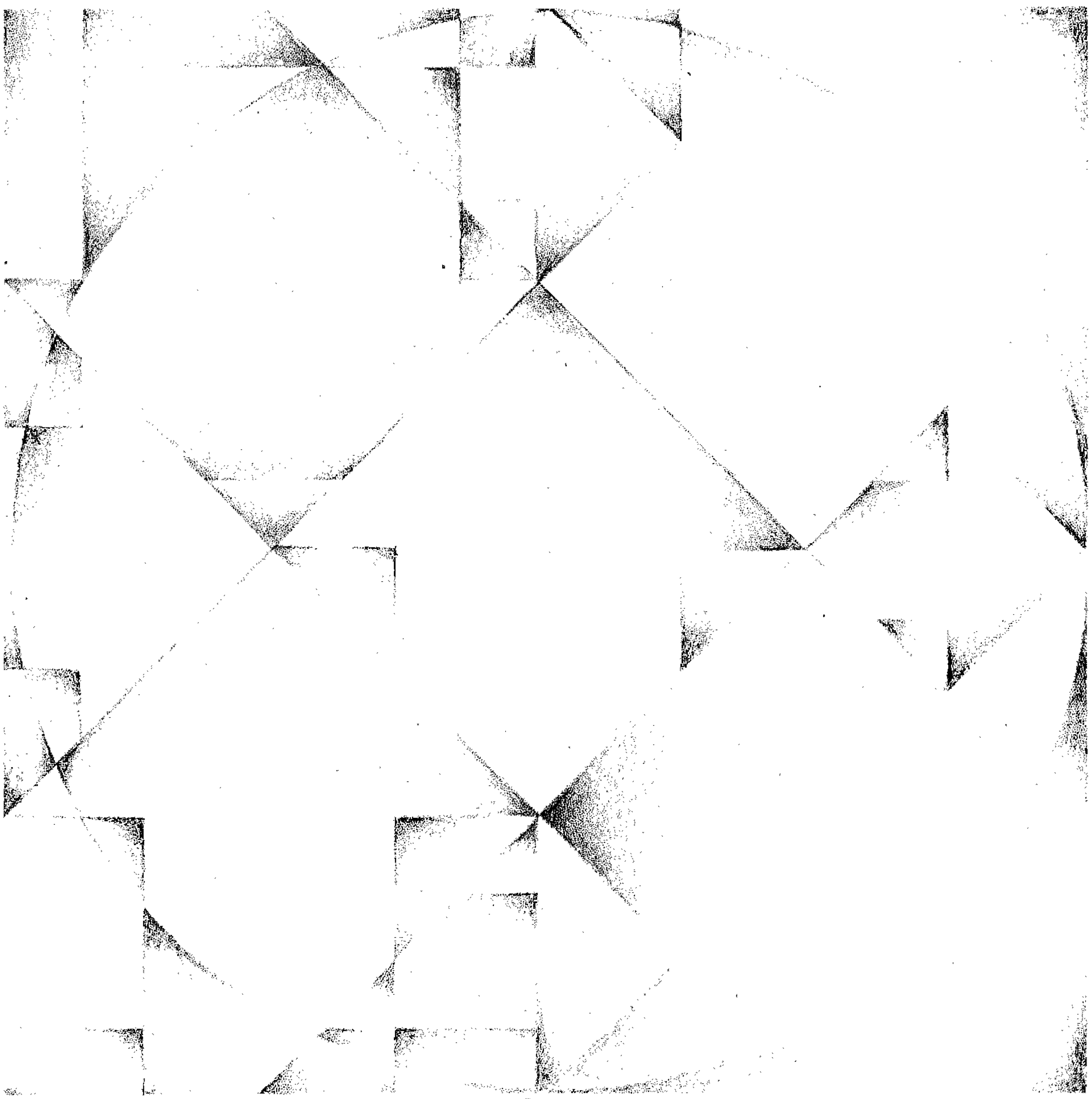

CONGRESS OF THE UNITED STATES

CONGRESSIONAL BUDGET OFFICE

ONGRESSIONAL BUDGET OFFICE
.S. CONGRESS
'ASHINGTON, D.C. 20515

Alice M. Rivlin
Director

February 1, 1979

The President of the Senate
The Speaker of the House of Representatives
The Secretary of Transportation

Dear Mr. President, Mr. Speaker, and Mr. Secretary:

Section 506(b) of the Surface Transportation Assistance Act of 1978 requires that the Congressional Budget Office evaluate procedures and special studies that can be used to allocate the costs of highways. This paper, Guidelines for a Study of Highway Cost Allocation, is CBO's response to that mandate.

This study evaluates techniques for allocating the costs of highways among groups of users of highways, and it describes several studies that would be helpful in applying these techniques and interpreting their results. It presents a set of guidelines for cost allocation in order to assist the Department of Transportation as it conducts the three-year study required by the act.

We appreciate having had the opportunity to assist the Congress and the Department in establishing a framework for cost allocation, and we will be pleased to respond to any questions or to provide any additional assistance.

Respectfully submitted,

Alice M. Rivlin
Director

Enclosure

GUIDELINES FOR A STUDY OF HIGHWAY COST ALLOCATION

The Congress of the United States
Congressional Budget Office

PREFACE

In the Surface Transportation Assistance Act of 1978, the Congress called for a new study of highway cost allocation. This study, which is scheduled for completion by January 15, 1982, will help to guide the Congress as it determines how to impose taxes to finance federal highway programs. The guidelines presented in this report, in response to directions contained in the act, set out procedures for allocating the costs of highways according to the costs occasioned by each type of vehicle. These guidelines are to be used by the U.S. Department of Transportation as it conducts the cost-allocation study.

Because of the large number of technical issues involved in developing these guidelines, the Congressional Budget Office requested that the Transportation Research Board of the National Academy of Sciences assemble a steering group to help evaluate and review the guidelines. This steering group included experts on various aspects of road building, officials from state transportation departments, representatives of interest groups for affected modes, and representatives of the U.S. Department of Transportation and the Federal Highway Administration. The guidelines presented here do not necessarily reflect the opinion of any individual member of that steering group.

The authors of this report are Richard R. Mudge, Damian J. Kulash, and Reid H. Ewing. It was prepared in the Natural Resources and Commerce Division of the Congressional Budget Office under the supervision of Damian J. Kulash. The authors gratefully acknowledge the assistance of David L. Lewis, Patrick J. McCann, Carl R. Neu, and James M. Verdier of the Congressional Budget Office; D. Grant Mickle, who served as chairman of the steering group; Charles N. Brady of the American Automobile Association; William A. Bulley and Roger V. LeClerc of the Washington State Department of Transportation; William N. Carey, Jr., Kenneth E. Cook, and Floyd I. Thiel of the Transportation Research Board; Hugh G. Downs of the Maryland State Highway Department; Thomas M. Downs and William L. Mertz of the Federal Highway Administration; Julian F. Granger of the staff of the Committee on Ways and Means of the U.S. House of Representatives; Lloyd Henion of the Oregon Department of Transportation; W. Ronald Hudson of the University of Texas; Shelton Jackson of the U.S. Department of Transportation; Edward V. Kiley of the American Trucking

Associations, Inc.; Peter G. Koltnow of the Highway Users Federation; A. Scheffer Lang of the Association of American Railroads; Douglass B. Lee, Jr., of the University of Iowa; David C. Sims of the Pennsylvania Department of Transportation; Tom B. Webb, Jr., of the Florida Department of Transportation; and Eldon J. Yoder of Purdue University. The authors also wish to thank many others in the Federal Highway Administration and the U.S. Department of Transportation for providing data and technical assistance.

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Alice M. Rivlin
Director

February 1979

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SUMMARY

In 1956, the Congress established the Highway Trust Fund to finance almost all federal expenditures on roads. Revenues for the fund come from a variety of taxes on users of the highways. A tax on motor fuels is the chief tax, accounting for 70 percent of revenues for the Trust Fund; the other taxes are on tires, trucks, truck parts, lubricating oil, and use of heavy vehicles. In 1956, the Congress also established the policy that highway taxes should be paid equitably by the various classes of highway users. To aid in applying this policy, the Congress has relied on cost-allocation studies to assign the responsibility for highway costs to specific classes of users; the latest study used about 70 classes of vehicles, such as automobiles, two-axle trucks with four wheels, or five-axle combinations. Previous cost allocation studies have been used by the Congress when it has revised and extended the various taxes that support the Highway Trust Fund.

The Congress requested a new highway cost-allocation study in the Surface Transportation Assistance Act of 1978. This new request was prompted by the likelihood of highway tax increases in future years; by changes in the type of highway programs being funded; and by the need for recommendations made on the basis of up-to-date information and appropriate techniques. The legislation emphasized the view that has proved most useful in earlier studies, particularly by:

- Concentrating on expenditures from the Highway Trust Fund rather than all expenditures on roads;

- Allocating these expenditures among vehicle classes on the basis of the costs occasioned by each class rather than the benefits derived by each;

- Examining the costs incurred in the use of roads and ignoring the costs associated with providing access to land; and

- Focusing on the direct costs of roads rather than the social or environmental costs associated with the use of roads.

The Secretary of Transportation has been directed to complete the cost-allocation study and to report the results to the Congress by January 15, 1982. The Congressional Budget Office has been directed to assist in the early stages of this study by evaluating various procedures, information requirements, and the need for special studies. The results of this evaluation, which are reported here, are to be employed as guidelines by the Secretary of Transportation in designing the cost-allocation study.

These guidelines are based on the principle that each class of highway users should pay the costs occasioned by it; this principle is called for in the authorizing legislation. The principle implies, for example, that heavy trucks should pay for the climbing lanes that they require. These guidelines differ from those followed in the past in the extent to which this principle is applied: In response to the legislative directive, every effort has been made to identify costs that are occasioned by specific classes of users. This approach requires that individual components of highway expenditure be examined in somewhat more detail than they were in earlier studies. It results in significant improvements in the allocation of the costs of three components—pavement, right-of-way, and grading—as well as improvements in smaller categories of expenditure.

Pavement

Pavement accounts for more than 20 percent of all federal expenditures, and this percentage is likely to grow in future years as road rehabilitation continues to replace new construction as the principal concern of the highway program.

Previous studies of cost allocation have generated considerable background on how pavement is worn out by vehicles of different types. They have shown that, as a general rule, heavy vehicles cause many times more road wear than do light ones. The guidelines presented here call for the allocation of pavement costs on the basis of this relative wear.

This approach differs from that followed in the past in one important respect: the fact that increases in the thickness of pavement add disproportionately to the strength of the pavement, while adding relatively little to total costs, has been recognized, and this economy of scale has been allocated evenly to all classes of vehicles. With the methodology applied in past studies of cost allocation, all the benefits of economies of scale were generally bestowed on the heaviest classes of vehicles.

Right-of-Way

In previous studies of highway cost allocation, most of the costs of the right-of-way over which a road passes were treated as costs that are common to all vehicles. This approach appears valid for a road of minimum width. The additional capacity of wider roads is required by the level of traffic they are anticipated to have to bear, so increases in the width of right-of-way beyond that of the minimum road should be the responsibility of the vehicles that require them. This statement has two important implications. First, large vehicles require more road space than small vehicles, and this should be reflected in the allocation of costs. Second, the capacity of facilities is designed to meet the needs of traffic at the peak period, and this should be reflected in the allocation of costs.

These two characteristics have been incorporated in the guidelines presented here by allocating some costs of right-of-way to peak-hour traffic, bearing in mind the space required by each type of vehicle.

Grading

In earlier studies of cost allocation, most of the costs of grading were allocated as costs common to all classes of vehicles. As in the case of right-of-way, this practice could be improved by distributing the added costs of grading—above those required for a minimum road—on the basis of peak-period traffic, taking into account the relative consumption of road space by various classes of vehicles.

In addition, roads in rolling or mountainous terrain require some additional grading, partly because of the need to build gentle slopes that are passable by vehicles with limited climbing ability, such as recreational vehicles and heavy trucks. No specific technique for allocating this additional cost is recommended in the guidelines because of the numerous, highly technical issues involved. Nevertheless, some simple methods are discussed and the Department of Transportation is called on to use or improve upon these methods rather than allocate the extra grading costs as common costs.

Bridge Replacement

The bridge-replacement program highlights a special question in cost allocation. Some preliminary data suggest that many expenditures under this program may be made solely for the purpose of removing weight restrictions from bridges now in limited service, but many state officials contend that few expenditures can be so easily categorized. To the extent that bridges are being replaced and repaired to serve the limited group of vehicles now restricted from using them, the costs of the program should be allocated to these vehicles. Nonetheless, the extent to which the bridge-replacement program is driven by load restrictions remains to be seen, and the guidelines call for further examination of this question.

Common Costs

The guidelines presented here should result in more costs being assigned to specific vehicle classes than has been done in the past. Some common costs for which no class of vehicles has any special responsibility will still remain, however. In previous studies, such costs have been allocated in proportion to the miles traveled by vehicles of each class, and this practice is judged to be appropriate for application in the present study.

Supplemental Studies

In order to put into operation the techniques for allocating pavement costs that are called for here, some additional research is needed. For example, research is needed to determine the fraction of pavement costs attributable exclusively to weather and other environmental factors, since such costs should be-allocated without respect to relative wear.

In addition to providing the data and analyses needed to support the procedures summarized above, it is desirable to conduct several supplemental studies in which some of the restrictions inherent in the principal cost-allocation study are relaxed. These supplemental studies will permit the results of the cost allocation to be viewed in a broader context and to be of greater use to state and local governments. Four supplemental studies are called for:

- A guide to how the federal cost-allocation study might be adapted by the states for their own use;

- A summary cost allocation of the total expenditure on roads at all levels of government that will help in developing consistent, and even-handed national transportation policies;

- A study of the indirect costs and benefits of highways (for example, property damage, noise, vibration, accidents, air pollution, or increased property values) that will permit some approximate appraisal of how the allocation of costs might change if these factors were explicitly included; and

- A set of cost allocations revised so as to distribute costs that are common to all vehicles in ways that promote environmental relief, equality of subsidies among modes, transportation sector efficiency, or other social objectives that may be influenced through highway user charges.

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CHAPTER I. INTRODUCTION

In 1956, the Congress established the Highway Trust Fund to finance its principal highway construction programs. This fund is supported by a set of taxes on users of the highways, the most important of which is the four-cents-a-gallon tax on motor fuels. When it established the Trust Fund, the Congress declared that the highway tax burden should be distributed equitably among the various classes of persons using the federal-aid highways. This policy reflected Congressional recognition that different kinds of vehicles affect (or benefit from) highway program costs unequally and thus should be taxed at different rates; for example, vehicles with poor climbing ability should pay the costs of climbing lanes that they require.

To assist the Congress in making highway tax decisions, the 1956 Highway Act also called for a cost-allocation study. In this study, the attempt was made to assign the responsibility for highway costs among the various classes of users. The results of that study and a supplementary report, published by the Bureau of Public Roads in 1961 and 1965 and then updated by the Federal Highway Administration (FHWA) in 1969 and 1975, have been considered by the Congress when it has changed highway-user taxes.

THE NEED FOR A NEW COST-ALLOCATION STUDY

A new cost-allocation study now appears to be needed for several reasons. First, an increase in highway taxes appears likely in the near future as the growth in Highway Trust Fund revenues is outstripped by continued inflation in construction costs. The financial stress on the Highway Trust Fund will intensify as the effects of energy legislation start to dampen the growth in consumption of motor fuels, thereby holding back the growth in associated tax receipts.

Second, a new look at cost allocation becomes timely as the federal highway program shifts emphasis away from new construction and toward repair and rehabilitation. Some of the new programs associated with this shift differ significantly from those now in effect in the ways in which costs can be traced to specific groups of users.

Third, the last comprehensive federal cost-allocation study was published in 1965. Much of the information used in that study is by now out of date and unreliable. Estimates of travel by each class of vehicle, for example, which are essential throughout the process of cost allocation, are based on traffic counts that vary considerably in reliablity.

Finally, the methodology used in previous studies can be improved upon both in a number of technical aspects and in the way it reflects the new mix of federal highway programs.

SOURCE OF TRUST FUND REVENUES

The Highway Trust Fund now receives about 70 percent of its funds from the tax of four cents a gallon on gasoline and diesel fuel. The bulk of the remaining revenues come from excise taxes on tires and on trucks and trailers; smaller amounts come from the heavy-vehicle use tax and from taxes on truck parts and accessories and on lubricating oil. In fiscal year 1978, total net receipts of the Highway Trust Fund were $6.9 billion, excluding interest payments.

Past federal cost-allocation studies have found that automobiles generated about 60 percent of the receipts of the Trust Fund, single-unit trucks somewhat more than 20 percent, and combination trucks somewhat less than 20 percent. While generalizations are difficult to make, it has usually been found that automobiles as a class paid less than their proper share, as did the largest classes of diesel-powered trucks. Other trucks, particularly vehicles in the lightest classes, paid more than their share. 1/

LEGISLATIVE REQUEST FOR STUDY GUIDELINES

In Section 506 of the Surface Transportation Assistance Act of 1978 (STAA), the Congress directs the Secretary of Transportation to conduct a new study of highway cost allocation. The Congressional Budget Office (CBO) is directed to assist by developing guidelines for this study, as follows: 2/

1/ A summary of past federal highway cost-allocation studies can be found in Congressional Budget Office, Who Pays for Highways: Is a New Study of Highway Cost Allocation Needed? Technical Analysis Paper (September 1978).

2/ Subsection (a) referred to in this excerpt is the direction given to the Secretary of Transportation. Section 506 is reproduced in its entirety in Appendix A.

EVALUATION BY CONGRESSIONAL BUDGET OFFICE—To assist the Secretary of Transportation in the conduct of the investigation and study authorized and directed by subsection (a) of this section, the Congressional Budget Office is hereby authorized and directed to make an evaluation of—

(1) the procedures to be employed in determining the equitable allocation of highway costs;

(2) the information to be collected to apply the procedures identified pursuant to paragraph (1);

(3) any special studies essential to the conduct of the investigation which can be identified and completed within the deadlines established by this section; and

(4) the procedures to be employed to ensure a continuing equitable allocation of highway costs after study termination.

The Congressional Budget Office shall report its findings to the Congress and to the Secretary of Transportation within 90 days after the date of the enactment of this section. These findings shall be employed by the Secretary as guidelines in the design of the investigation and study authorized and directed by subsection (a) of this section.

Chapters II and III describe in general terms the limitations that the Congress has placed on the scope of the study and the general approach taken by the Congressional Budget Office, respectively. The last two chapters are more technical in nature. They present the guidelines developed by CBO in response to the STAA. The appendixes describe and evaluate the procedures set forth in the guidelines in greater technical detail.

CHAPTER II. SCOPE OF THE COST-ALLOCATION STUDY

In the Surface Transportation Assistance Act of 1978 (STAA), the Congress set the scope of the new highway cost-allocation study in several ways:

- It requested a study of expenditures from the Highway Trust Fund, not a study of all federal expenditures on roads or of expenditures by all units of government;

- It requested a study of the costs occasioned by various classes of users rather than a study of the benefits they receive;

- It requested a study of the proportionate share of costs attributable to each class of highway users and excluded those attributable to nonusers; and

- It focused attention on the direct costs of highways—design, construction, rehabilitation, and maintenance—distinguishing them from the indirect costs, such as environmental damage, that are occasioned by use of the roadways.

Each of these restrictions on the scope of the cost-allocation study implies judgments about matters that are of concern to the Congress. Such judgments, which are at the base of any study of cost allocation, influence the results of the study significantly. In the following four sections, the issues surrounding each of these judgments is reviewed. 1/

EXPENDITURES FROM THE HIGHWAY TRUST FUND, RATHER THAN ALL EXPENDITURES

An important consideration in defining the scope of a new cost-allocation study is whether the study should be limited to federal expendi-

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1/ More details on some of these concerns can be found in: Congressional Budget Office, Who Pays for Highways: Is a New Study of Highway Cost Allocation Needed? Technical Analysis Paper (September 1978).

tures or whether it should be expanded to include all roads and all related expenditures at every level of government. To analyze only federal expenditures limits the scope of the study, principally to construction and major maintenance activities on the federal-aid highway system. An all-inclusive study would include numerous maintenance activities, such as filling potholes and mowing grass, that are financed entirely by state and local governments.

Past federal cost-allocation studies have been concerned primarily with the federal-aid highway system and generally ignored state and local expenditures. The Highway Trust Fund finances this system, and it is appropriate that a review of federal highway taxes should concentrate on it. Although there is a common national interest in ensuring that user taxes are assessed equitably across all road systems, a broader cost-allocation study is no guarantee that the overall structure of highway taxes will resemble that recommended in the study, since the Congress cannot control charges imposed on users by state and local governments. Nor would a comprehensive federal study of all road systems necessarily provide an improved basis for setting state taxes, because construction practices and traffic patterns vary considerably from one state to another. The conditions in any state are unlikely to be adequately represented by national averages. Furthermore, a given state might wish to emphasize a different set of objectives in its highway financing procedures from those adopted by the federal government, and realization of the state's objectives would require separate cost-allocation studies.

Nevertheless, there are conceptual drawbacks in considering only expenditures from the Highway Trust Fund. The full costs of a road over its useful life include construction, resurfacing and rehabilitation activities, administration, policing, and routine maintenance, and not all these costs are federally financed. A study limited to federal highway expenditures would thus miss an important portion of highway costs.

Although some advantages might theoretically be gained by including all expenditures on highways in a new cost-allocation study, such a study would pose serious practical problems. Lack of uniformity among the states with respect to reporting standards and recording practices would make an all-inclusive study very difficult. Collecting and reconciling the necessary data would take many years.

The STAA sets the scope of the cost-allocation study as "federal-aid highways," and interprets this to include "all programs and projects financed by the Highway Trust Fund." 2/ Such a study, while essential if federal taxes are to be set equitably, has severe limitations as a basis for the setting of state and local highway taxes. To remedy this failing, particular attention should be given to the needs of states and localities in the conduct of the cost-allocation study. When it is possible to do so, the collection of data and the analyses required for the federal cost-allocation study should be broadened to furnish information that will make it easier for lower levels of government to conduct their own cost-allocation efforts. In addition, it is desirable to conduct a subsidiary study in which the allocation of highway costs for all levels of government in combination are examined.

ALLOCATION BASED ON COSTS RATHER THAN BENEFITS

Highway taxes could be based either on costs occasioned by the various classes of users or on their ability and willingness to pay. In legislation enacted before 1978, the Congress did not take an explicit position on this issue except to require that federal costs be offset by highway-related receipts. The appropriate basis for cost allocation was debated during consideration of the 1961 highway legislation, but the highway taxes that were imposed represented a compromise between a cost-based and a benefit-based allocation.

Benefit-Based Taxes. Costs could be allocated so that highway users deriving the greatest benefits from federal highway expenditures would pay proportionately the largest share of federal highway taxes. Under this approach, payments would generally bear a different relation to cost for each class of users. Thus, if all these benefits were to be captured, a highly complex and highly differentiated tax structure would be required. Such a structure could be in conflict with one based upon the costs occasioned by each class of vehicle.

A benefit-based allocation might also be in conflict with other government policies whose aim is to restrict benefit-based pricing. Indeed, the earliest involvement of the federal government in transportation policy was its restriction on private pricing practices, particularly discriminatory tariffs. For example, the Interstate Commerce Commission was established primarily to regulate the railroads and to restrict their ability to charge rates that reflected the value of service to individual users.

2/ Conference Report, Surface Transportation Assistance Act of 1978, H. Rept. 1797, 95 Cong. 2 sess. (October 14, 1978), p. 145.

Taxes based upon benefits derived would require a considerable degree of tax differentiation among users. The fineness of differentiation and the number of tax classes used would be very difficult to establish. For example, auto travelers might be differentiated by income class, by family status, or even by recreational habits. It is likely that nonessential travel, such as sightseeing trips and recreational journeys, which tends to be price-sensitive, would subject the user to very little in taxes, whereas essential travel, such as trips to work or school would be taxed heavily. Such an outcome might conflict with other government objectives.

Benefit-based taxes might also be difficult to administer with respect to freight vehicles. Because of large variations in the value of truckloads and in the value of truck services, benefit-based truck taxes would have to be specified separately for each commodity and for each destination. The complexity of such a scheme is an obvious drawback.

In short, the imposition of charges or taxes on the basis of benefits received by each class of users seems fraught with practical problems and contains a number of conceptual difficulties as well. Because of the problems of estimating benefits received by each class of users, benefits have been excluded from recent federal studies of cost allocation.

Cost-Based Taxes. The imposition of charges or highway taxes on the basis of the costs occasioned by users has several appealing features. Users are encouraged to pattern their use with concern for the associated costs. No class of vehicles is required to pay for the costs of any other class.

Favoring cost-based charges does not, however, solve the problem of identifying the proper level of charges. Two general types of problems can be identified: identifying costs occasioned by each class of users, and assigning common costs. Both are addressed in greater detail in Chapter IV.

Although the cost-based approach to cost allocation raises a number of problems, it seems on balance to be more tractable than any benefit-based approach. It is also more easily understood and probably stands a better chance of being accepted as equitable. The STAA directs that the next cost allocation be based on costs occasioned and does not request any benefit-based analysis.

EXCLUSION OF ACCESS BENEFITS AND COSTS

A special class of costs and benefits is associated with granting access to the persons or activities located along the roads. Although many of the benefits of access to and from a roadway are paid for by their beneficiaries through charges on the use of the road, some may not be. For example, the traffic borne by many local streets is insignificant, but these streets are of critical importance in providing the nearby property owners with access to the overall network of roads. Such benefits of access and their associated costs pose problems in cost allocation because they imply that some highway costs are traceable to nonusers.

The Congress specifically included access of the roadways among the benefits to be investigated when it called for a cost-allocation study in the Highway Revenue Act of 1956. Responsibility for the costs of highway access has been virtually ignored in subsequent federal studies, however, on the assumption that the costs of access are small and that benefits to nonusers are still not quantifiable.

Both assumptions are probably valid. In the 1961 cost-allocation study, costs occasioned by nonusers were estimated to be 2 to 6 percent of all costs of the Interstate and primary highway systems. Nonusers were assigned a much larger responsibility for the costs of the secondary system, but the significance of this assignment was diminished by the recent realignment of the federal-aid highway system, in which the number of miles of secondary roads on the federal system was sharply reduced.

The benefits of improved access may, of course, be much greater than its costs. Highway improvements cause changes in the way land is used, raising productivity and standards of living out of proportion to any reduction in transportation costs for which they are responsible. It is difficult to estimate these added benefits, and it is also difficult to link them to their ultimate beneficiaries.

In any event, access benefits may not be of overriding practical significance in highway cost allocation for a number of reasons. First, resurfacing and rehabilitation of the highways is requiring an increasing share of the expenditures on the federal-aid system, and such activities have a lesser effect on economic development, land use, and land value than does new construction.

Second, access benefits may for the most part accrue to the same individuals and organizations that benefit from the use of highways. Most access benefits are gained only by those who use the highways, though it is true that some of the benefits accrue to others. For example, shopping centers at freeway interchanges reap the benefits of highway access, while their customers pay most of the charges levied on users. Similarly, factories near Interstate highways enjoy access to markets, but the motor carriers that serve them pay the highway charges. Even in these examples, however, the nontraveling beneficiary of highway access may in effect pay the related costs. For example, as taxes paid by truckers are passed along through the rate structure, they are ultimately paid by the shippers.

Finally, it is not clear that any federally imposed tax could actually capture access benefits any better than some mix of user taxes. Taxes designed to capture increases in land value have proved to be unpopular and difficult to administer. Alternatively, using general fund revenues to underwrite those costs of the federal-aid highway system that are occasioned by nonusers might be less equitable than reliance on highway taxes.

The STAA resolves the question of access costs by calling for a study of costs occasioned by the use of vehicles. It does not call for an examination of benefits to nonusers as the Highway Revenue Act of 1956 did.

EXCLUSION OF INDIRECT HIGHWAY COSTS

Although indirect costs, such as traffic noise and air pollution, have not been included in earlier studies of cost allocation, public awareness of these costs has grown, and they could be considered an important component of total highway costs. Motor vehicles have been major contributors to the deterioration of air quality in urban areas. Vehicle emissions damage both health and property. Vehicle-related noise, highway-related urban blight, and transportation-induced relocation of activities have likewise increased during the past two decades as limited-access highways have been constructed in urban areas. Neighborhood opposition to highway construction has become increasingly intense, reflecting these indirect costs.

Congressional concern about these highway-related problems has increased. Legislation aimed at curbing air pollution from motor vehicles was enacted in 1965, and legislation aimed at reducing fuel consumption was enacted 10 years later. Relocation assistance for persons displaced by federal-aid highways was authorized in 1962, and funds for noise abatement measures on existing federal-aid highways were authorized in 1973. Assessment of the social and environmental effects of highways became a requirement under the Federal-Aid Highway Act of 1968, and highway noise standards were introduced in the Federal-Aid Highway Act of 1970.

In sum, Congressional concern over the indirect costs of highways has grown since the first highway cost-allocation study was requested. The increased significance of indirect costs raises the question of whether these costs should be included in determining the cost responsibility of users.

Their inclusion would probably have little effect on the problems of noise, damage to the environment, and disruption of activities, because highway use is affected only slightly by taxes on fuel and other items related to highway use. In the past, the Congress has generally dealt with such problems through regulation rather than through pricing measures.

Nevertheless, the indirect costs of highway use have become apparent and should not be ignored. But it could take much longer to investigate these costs than to investigate direct costs, and they can never be estimated with as much precision. It appears reasonable, therefore, to investigate indirect costs within a supplemental study, which would indicate to the Congress the relative magnitude of indirect costs and the extent to which they are occasioned by different classes of highway users. Inasmuch as some direct federal expenditures are made to reduce indirect costs—for example, the costs of erecting noise barriers next to roads—such expenditures fall within the scope of the principal cost-allocation study.

SUBSIDIARY STUDIES

The restrictions set by the STAA serve to delimit a cost-allocation study that is fair and that will serve the principal needs of the Congress. Other studies, of different scope, are clearly possible, although for the reasons discussed above, it appears that they would be less workable or would have more limited application than the one requested.

In view of the restrictions set out in the STAA on the scope of the cost-allocation study it might be useful to conduct several subsidiary studies to explore areas not included in the cost-allocation study itself. These subsidiary studies might help in applying the results of the cost-allocation study within a broader context. In the foregoing discussion, two areas—the evaluation of indirect costs and the consideration of highway costs beyond those financed by the Highway Trust Fund—in which such subsidiary studies may be warranted have been noted. It is anticipated that during the course of the highway cost-allocation study, other areas for subsidiary studies may be identified.

One function of the guidelines presented in later chapters is to note areas in which it appears that subsidiary studies might be particularly useful; they are not intended to preclude the investigation of still other areas by the Department of Transportation. The results of all subsidiary studies should, however, be clearly subordinate to that of the principal study delimited by the Congress, and the assignment of resources should reflect this priority.

CHAPTER III. INTRODUCTION TO GUIDELINES

Federal expenditures on highways can be seen as having several components, among them the costs of pavement, right of way, bridges, and grading. Table 1 provides a rough estimate of the level of recent federal expenditures in each of these categories. The proportions are likely to change dramatically in the next few years as the federal highway program continues to shift its emphasis from the construction of new highways to the repair and rehabilitation of existing roads.

The pavement cost category is likely to show particularly strong growth as greater emphasis is given to resurfacing and reconstruction. The portion of costs associated with the acquisition and preparation of highway right of way is likely to decline, reflecting the decrease in construction of new highways. It is somewhat more difficult to generalize about bridge expenditures; the overall total, however, is likely to increase as rapidly growing expenditures on replacement and repair of existing bridges more than compensate for decreasing expenditures for the building of new bridges. Grading expenditures are likely to decrease, in line with the drop in new construction. The miscellaneous category may show some growth.

GENERAL APPROACH USED IN PAST STUDIES

In earlier federal cost-allocation studies the principal cost components of highways have been considered individually. For example, pavement costs were allocated according to one set of rules, bridge costs according to another, and grading costs still another. The final cost allocation was the sum of the costs allocated to each class of vehicles for each of the cost components. The precise method used to allocate costs varied according to the dictates of each cost category. Gross vehicle weight was the significant factor in allocating bridge costs, for example, and axle weight was the significant factor in allocating pavement costs. Revenues were allocated across vehicle classes in a similar fashion. Receipts from each tax were allocated individually, and the results were summed across all taxes in order to determine total payments by each class of vehicles.

Although the details varied considerably, most categories of cost in earlier cost-allocation studies were assigned by use of the incremental approach. This approach is based on a theoretical construction called the

TABLE 1. MAJOR COST COMPONENTS OF FEDERAL HIGHWAY PROGRAM

Cost Element	Percent of Federal Highway Costs
Pavement a/	29
Bridges b/	19
Grading c/	16
Right-of-Way d/	14
Miscellaneous e/	22
TOTAL	100

SOURCE: Congressional Budget Office, from several published and unpublished sources. The numbers should be considered as only approximate and likely to change significantly in future years.

a/ Includes through-traffic lanes, resurfacing, shoulders, and widening.

b/ Includes new bridges and bridge replacement.

c/ Includes grading of roadways and grading at interchanges.

d/ Includes acquisition and preparation of right-of-way.

e/ Includes special facilities such as ramps and railroad crossings (7 percent); culverts (4 percent); and other costs, such as engineering, signs and signals, guardrails, and rest areas (11 percent).

basic road—the minimum road required if only automobiles used it. The costs of this basic or minimum road are considered to be common to all classes of vehicles. The costs of additional features not included in the basic road are allocated to the vehicles that require those features. The basic road is hypothetically upgraded in a series of increments or steps that reflect the needs of other, successively heavier, classes of vehicles. For example, the basic road might be designed to have pavement 10 inches deep, that designed to carry light trucks might have pavement 11 inches deep, and that designed to carry heavy trucks might be 12 inches deep; the costs of each of the two one-inch increments would be allocated only to those vehicles that require them, while the costs of the basic road would be shared by all classes of vehicles.

PRINCIPLES UNDERLYING THESE GUIDELINES

As called for in the Surface Transportation Assistance Act of 1978, the guidelines presented here are based on the principle that costs should be assigned to the vehicles that occasion them. Under this approach, each class of vehicles is assigned all the costs for which it alone is responsible, as well as its share of the costs for which more than one class of vehicles are jointly responsible. The incremental cost method used in earlier federal cost-allocation studies is one way of implementing the occasioned-cost approach, although this way can be improved in some instances.

The guidelines reflect an attempt to identify the greatest number of instances in which costs are occasioned by certain classes of vehicles and, correspondingly, to reduce the share of costs that is considered common to all vehicles. This goal reflects the mandate given in the authorizing legislation. It also reflects the fact that while there is a well-accepted way of assigning common costs to classes of vehicles, the theoretical arguments for any particular method of allocation are weaker than those for assigning occasioned costs.

In an effort to make it easier to identify costs occasioned by different vehicle classes, highway costs are discussed in somewhat more detail in the present guidelines than in earlier studies. As costs are grouped into larger and larger categories, it becomes increasingly difficult to discern which particular details of design have been implemented to meet the needs of particular vehicles. Eventually, the conclusion might be reached that all highway costs are common to all vehicles, with no particular class bearing responsibility for specific costs. As part of the effort to identify costs occasioned by different classes of vehicles, an attempt has been made to examine the functions of specific types of road improvements. The reason

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for building a given road may provide a basis for allocating its costs as well as the way in which it was built.

In the guidelines that follow, each of the important components of highway costs is discussed in turn. In most instances, both the discussion and the proposed methodology contain two steps:

- Separation of the common-cost portion from the occasioned-cost portion of total costs; and

- Distribution of the occasioned costs among the responsible classes of vehicles (common costs are pooled and allocated together).

MAJOR DIFFERENCES FROM EARLIER FEDERAL STUDIES

While a number of changes from past methodologies are proposed, the most significant ones involve pavement costs, right-of-way costs, and grading costs.

Pavement costs are to be allocated in proportion to the amount of pavement consumed by different classes of vehicles. Highway engineers have developed mathematical relationships between the wear to which a pavement has been subjected and the weight carried by the axles that pass over it. Direct use of these relationships was not made in earlier studies, and pavement costs were allocated according to incremental construction costs, an approach that appears to favor heavy vehicles. The result was an allocation of pavement costs based largely upon the amount of use made of roads, while the approach set forth here is based upon the amount by which roads have been worn out. Also, the common portions of pavement costs are recognized explicitly in the approach taken here. These common portions are primarily the cost of repairing the damage done to pavement by weather and environmental conditions and to the cost of that part of the pavement which is not worn out but remains usable indefinitely.

In earlier studies, the costs of acquiring rights-of-way were assumed to be common to all vehicles. In the proposed guidelines, it is recognized that, as the volume of traffic expected during peak periods increases, so does the need for a wider right-of-way—not only more lanes but also wider shoulders, medians, and borders, for reasons of safety. The costs of the additional right-of-way—beyond that required for a lightly traveled road—are to be allocated in proportion to the amount of road space consumed by different types of vehicles.

It was also assumed in earlier studies that virtually all grading costs were common to all vehicles. In these guidelines, it is proposed that since some grading, particularly in rolling or mountainous terrain, is done to reduce grades and make it easier for certain vehicles to maintain speed, a portion of the costs of grading should be considered to be occasioned by these vehicles.

CHAPTER IV. PROCEDURES FOR THE COST-ALLOCATION STUDY

The cost-allocation study is scheduled to be a three-year undertaking of the Department of Transportation, with the final report to the Congress due in January 1982. This chapter contains the guidelines, summarized in italics at the beginnings of the sections in which they are discussed, to be used by the Department of Transportation in the preparation of its work plan, which is due within 180 days of enactment of the Surface Transportation Assistance Act of 1980--that is, by May 5, 1979. No formal Congressional action is required at this stage, although the Congress could intervene and redirect the guidelines or the work plan if it so desired.

GENERAL PROCEDURES

The bulk of the three-year study period will probably be devoted to applying procedures such as those outlined later in this chapter. In particular, this involves assembling and analyzing detailed data on highway expenditures and conducting several special studies needed to implement the recommended procedures. While considerable cost detail may be needed at the early stages of the study, when methodological details are still being explored, sampling techniques should be used to minimize the associated effort. After all this, the actual allocation of costs should be straightforward and can probably be performed quickly, near the end of the study period.

In applying the methodology to allocate costs, it is necessary to review actual highway expenditures for a base period of one or two years. The base period may precede or be concurrent with the study itself. Expenditures during this period will be the basis upon which to establish the share of costs that is associated with each type of vehicle using the roads. These shares may be different for each category of highway expenditure and for each functional system of roads, and they must therefore be developed separately for each category of expenditure and each functional system. The time-consuming part of the cost-allocation study will be assembly and analysis of data on actual expenditures that are needed to develop those shares of cost responsibility.

Once the shares of cost responsibliity have been determined, they can be applied to federal highway expenditures by each category of cost and for each functional system of roads and then summed in order to determine the total cost assignable to each class of vehicles. The expenditures to be thus allocated could be actual expenditures for the latest year for which these are available or estimates for the current year or some future year. (Estimates have been used in earlier studies.) Similarly, tax receipts from each class of vehicles should be estimated on the basis of the latest data available.

The final allocation of costs will be expressed as costs occasioned and revenues paid by each of a number of classes of vehicles. Decisions as to the number and types of vehicle classes to be used are critical decisions that reflect tradeoffs between the desire to avoid an excessively cumbersome analysis and the need for detail in determining cost responsibility. In earlier federal cost-allocation studies, between 70 and 200 vehicle classes defined primarily by their visual characteristics—five-axle semitrailer or three-axle single-unit truck, for example—have been used. For each vehicle class, data on the distribution of vehicles by important characteristics, such as gross weight, were collected. This approach is a sensible one, although the number of vehicle classes used should be near the low end of this range.

The remainder of this chapter is devoted to a review of the principal categories of highway expenditures to determine how the costs of each should be distributed among classes of vehicles. Typically, this process involves two steps: first, determining the extent to which costs of each type are occasioned by particular groups of vehicles, and second, determining how these occasioned costs can be allocated among vehicle classes so as to reflect accurately the cost responsibility of each. In compliance with the legislative request, the procedures outlined below impute cost responsibility wherever it is reasonable to do so. Some costs of highways simply cannot be traced to any one class of vehicles, however. The allocation of such common costs is addressed in the final section of this chapter.

UNIQUELY OCCASIONED COSTS

A number of highway elements owe their very existence to a single class of vehicles, and their costs appear to be occasioned by those vehicles alone. Although each such cost represents a small proportion of federal highway costs, these costs can be allocated with maximum confidence, since a single class of vehicles—or, in some instances, a few classes of vehicles—are responsible for them. Some of these uniquely occasioned costs, such as climbing lanes, have been isolated in earlier studies, but others remain to be identified. The following list is intended only as a starting point and should be expanded as other uniquely occasioned costs are identified.

Guardrails appear to be occasioned by lightweight vehicles—primarily automobiles.

Climbing lanes appear to be occasioned by vehicles with low power-to-weight ratios—mostly heavy vehicles.

Scenic overlooks appear to be occasioned by passenger vehicles, including recreational vehicles.

Truck weight stations appear to be occasioned by heavy trucks.

Fringe parking and car-pool facilities appear to be occasioned by automobiles.

Parkways appear to be occasioned by noncommercial vehicles—primarily automobiles.

Some signs—load-limit signs, for example—appear to be occasioned by individual classes of vehicles.

OTHER UNIQUELY OCCASIONED COSTS

In addition to the above elements of cost, there may be some programs whose entire cost should be allocated as uniquely occasioned costs. If a project or program is undertaken for a single class of vehicles, that class should bear all of the program's costs, including those components of cost that can be traced to other vehicle classes.

This principle is, perhaps, best drawn through an illustration: All the costs of a program to repair or replace so-called energy roads—roads primarily used by coal trucks—should be assigned solely to the classes of heavy vehicles that require such special roads, even though some signs, guardrails, or other features that must be included in the design of the road are intended exclusively for the benefit and protection of automobiles.

In sum, if the overriding purpose of a highway facility or improvement is to meet the needs of a particular class of vehicles, all of the resulting costs should be assigned to that class of vehicles. The assignment of these costs would be based on the function of the road improvement—that is, why an improvement is made rather than how it is made. This is a general principle that should take precedence over other approaches wherever it is applicable.

It is not clear how many categories of cost are of this type. One object of the cost-allocation study should be to determine what categories of expenditure, if any, should be borne in their entirety by certain users. Two areas that should be carefully considered for application of this principle are the replacement of structurally deficient bridges and the construction of energy roads.

JOINTLY OCCASIONED COSTS

Most of the costs of highways do not fit into the category of uniquely costs discussed above. Instead, they are the responsibility of all users of the roads, although they may be disproportionately ascribed to some classes of users. In examining these costs, it is necessary to develop a basis for distributing them among classes of vehicles in a way that accurately reflects any disproportionate responsibility. Generally, this involves first isolating any common costs for which no class of vehicles is disproportionately responsible. Next, the remaining costs—those that do reflect disproportionate responsibility among the users that occasion them—are examined to determine the relationship between cost and use by each type of vehicle. Finally, these costs, which are referred to here as jointly occasioned costs, are distributed among classes of vehicles on the basis of this relationship.

Following are cost-allocation guidelines for each of the principal categories of jointly occasioned costs.

Costs of Pavement

General Rule: The cost of paving and resurfacing roads should be allocated among classes of vehicles in proportion to the axle-load equivalent of each class, except as provided below.

Exception to General Rule: The costs of pavement that are exclusively attributable to weather and other environmental factors, as well as the portion of investment in pavement that does not depreciate with increased vehicular usage, should be excluded when the above rule is applied. These costs should be allocated among vehicle classes in the same proportions that the right-of-way required for the pavement is allocated.

Exception to General Rule: The cost of paving shoulders should be allocated in the same proportions that result from application of the two preceding rules.

Exception to General Rule: Additional studies should be conducted to verify the axle-load equivalence factors now in use and to estimate the share of pavement costs subject to each of the first two rules.

Several tests have shown that pavement wear is closely tied to traffic volume and that wear varies significantly with axle load. The relative effects of different types of vehicles upon pavement can, for any specified type of construction, be compared in terms of a measure called axle-load equivalents. Although the precise values of axle-load equivalents should be reconsidered, there is nonetheless a compelling argument for assigning the cost responsibility for pavement according to the axle-load equivalent for each class of vehicles.

Not all pavement is worn out through vehicular use: some deteriorates because of weather and other environmental forces, and some portion may not be worn out at all but rather represents a permanent investment. It would not be appropriate to assign the costs of either of these portions according to axle-load equivalents since neither is consumed differently by one type of vehicle relative to another. Accordingly, these costs should be isolated and assigned differently. Since they are roughly proportional to the surface area of the pavement, they should be allocated in the same proportions as pavement right-of-way, possibly adjusted to reflect any additional pavement depth associated with heavy vehicles.

Pavement deterioration that is attributable to the combined forces of environment and traffic should be subject to the general rule and assigned according to axle-load equivalents, since this wear would not occur in the absence of traffic.

Some additional technical studies are needed to determine the most representative set of axle-load equivalents, to identify the portion of pavement the deterioration of which is caused by weather and environment, and to identify any portion of pavement that remains as a permanent investment. These studies are discussed in Chapter V.

Costs of Right-of-Way

The common cost portion of right-of-way costs should be calculated as the ratio of the minimum right-of-way width to the actual width of the right-of-way. Separate calculations are required for each functional system: for Interstate highways and secondary roads, for urban and rural roads, and for roads in various types of terrain—mountainous, rolling, or flat.

The remaining right-of-way costs should be allocated according to design-hour traffic measured in passenger-car equivalents on the relevant functional system. 1/

Right-of-way costs can most fairly be allocated by distributing the occasioned-cost portion on the basis of the proportion of traffic for which each class of vehicles is responsible. This procedure is a three-step process. First, the minimum width of right-of-way required by each class of highways should be ascertained. The minimum width is that required to provide a given level of service and safety at very low volumes of traffic on the class of highways in question. It varies from system to system, being greater for Interstate highways than for other primary highways and greater for other primary highways than for secondary or urban system roads. It also varies according to type of terrain and urban or rural location.

Second, the ratio of minimum width to actual width of right-of-way should be used to estimate the portion of right-of-way costs that are common to all vehicles using highways. The remaining right-of-way costs should be considered as being occasioned by design-hour traffic. Design-hour traffic occasions such costs through its use of highway capacity, use that directly requires more or wider lanes and that indirectly requires the widening of shoulders, medians, and borders to ensure the safe and efficient functioning of highways.

Third, the occasioned portion of right-of-way costs should be allocated across classes of vehicles on the basis of the contribution of each class to total design-hour volume, expressed in passenger-car equivalents. Design-hour volumes and passenger-car equivalents used in this allocation should be specific to the class of highways in question. They may vary according to system, type of terrain, and urban or rural location. Some of the practical issues that arise in applying this three-step approach are discussed below.

Minimum Width of Right-of-Way. Minimum widths of rights-of-way can be derived, in general, from the geometric design standards of the

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1/ The "design hour "is usually defined as the 30th most heavily traveled hour during the year. It forms a workable definition of peak-hour travel, and it may occur at different times in urban, rural, or recreational areas. "Passenger-car equivalents" are the relative shares of highway capacity required by various vehicles described in terms of passenger cars. These two terms are explained below in the text.

American Association of State Highway and Transportation Officials (AASHTO). 2/ These standards should be cross-checked, however, against available data on actual widths of rights-of-way. Cross-checking is necessary for several reasons:

- o AASHTO standards are not absolutely binding, since there is the possibility of too little or too much design.
- o AASHTO standards may not represent the current state of the art in highway design, since they were last amended more than a decade ago.
- o AASHTO standards leave some room for interpretation, particularly when they are presented as a range of values.
- o AASHTO standards were not developed using the same classification of highways that is most appropriate for allocating costs.

A frequency distribution of actual right-of-way widths by class of highway should be examined, and, if this distribution indicates that the minimum width differs substantially from the corresponding AASHTO standard, the actual minimum width should be used.

Design-Hour Volume. The design-hour volume is most often taken to be the 30th highest hourly traffic volume for some future design year. It is a theoretical construct that is intended to guide engineers in the geometric design of highways.

Design-hour volume can be approximated by current peak-period traffic composition, which can be measured by using the 24-hour vehicle classification counts already conducted by state highway departments. In urban areas, the peak period typically occurs in the late afternoon on weekdays. In rural areas, it typically occurs in the late afternoon on weekends during the summer months. Existing classification counts will generally be adequate for determining peak-hour traffic composition, although it may be necessary to add classification counts on weekends or

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2/ The American Association of State Highway and Transportation Officials (AASHTO) was formerly—prior to 1973--known as the American Association of State Highway Officials (AASHO).

during other seasons in order to make a reliable determination of design-hour traffic composition for each class of highways.

Passenger-Car Equivalents. Passenger-car equivalents describe the relative shares of highway capacity required by vehicles of various sizes and power-to-weight ratios. Passenger-car equivalents have already been established for a few types of vehicles, by type of terrain and by operating speed. Refinements may be needed to reflect current traffic operations, however, and to develop passenger-car equivalents for a larger number of vehicle types. Since passenger-car equivalents will be important in the allocation of most federal highway expenditures, it is imperative that the values used be representative, and additional study may be required to develop them.

Costs of Widening

The costs of widening should be allocated according to design-hour traffic measured in passenger-car equivalents.

Widening of existing roads is considered to be occasioned by traffic since each existing road, whatever its width, clearly represents at least a minimal working road. Accordingly, widening roads beyond the minimum generally represents occasioning by traffic and the costs of widening are best allocated using design-hour volume in passenger-car equivalents.

Costs of Bridges

No specific method of allocation is recommended; the Department of Transportation should assemble a panel of outside experts, including, but not limited to, bridge engineers, to consider alternative methods.

In selecting a method of allocation, consideration should be given to the question of the best way of treating the economies of scale found in bridge construction.

If an incremental approach is chosen, present engineering practice implies that the H15 bridge is the most appropriate one to be selected as the basic bridge.

Vehicle weight is a significant factor in bridge design, and its effect should be isolated in allocating bridge costs. The procedures followed in earlier studies of cost allocation should be improved by refining the manner in which economies of scale are distributed and by updating the concept of the basic or minimal bridge. These refinements are discussed below.

Economies of Scale. The five-step incremental cost method used in allocating bridge costs in earlier studies has one significant drawback: inequitable distribution of economies of scale among classes of vehicles. The unit costs of increasing the capacity of a bridge generally decrease as the load-carrying capacity of the bridge is increased—that is, doubling the capacity of a bridge does not require doubling the cost of the bridge. The additional costs assigned to vehicles that require the increased capacity will, as a general rule, be less than the unit costs of earlier increases in carrying capacity.

Under the incremental method used in earlier cost-allocation studies, the later a particular class of vehicles is considered, the more favorable its assignment of costs—that is, the classes of vehicles considered late in the process receive a disproportionate share of the savings realized from economies of scale. A more equitable method of allocation would be one in which these savings were divided evenly among all classes of vehicles.

This problem can be handled in several ways. Two of these, the two-step incremental method and the dead-load ratio method, are discussed in Appendix G. Under the two-step incremental method, the costs of the first step of the basic bridge are allocated as common costs, while the additional costs of building a complete bridge—the second step—are allocated according to vehicle ton-miles. Under the dead-load ratio method, the ratio of the dead load, or stress produced by the weight of the bridge alone, to the total load, or stress produced by the bridge plus its maximum vehicular load, is used to estimate the common cost portion. The remaining costs, proportional to the stress produced by vehicles, are allocated according to vehicle ton-miles. A major consideration in the allocation of bridge costs should be how to handle economies of scale in an equitable manner.

Basic Bridge. If an incremental approach is selected, the basic bridge should probably be an H15, which is designed for 30,000-pound single-unit trucks and is the typical minimum bridge now being built on the federal-aid highway system. For purposes of cost allocation, the basic bridge should probably be designed according to the load-factor method of design, sometimes called the ultimate stress method, rather than the working-stress method. The load-factor method is growing rapidly in acceptance, and in the near future it is likely to be the method most commonly used in this country. Also, the load-factor method, because it embodies less of the redundancy found in older design methods, more closely approximates the actual design capacity of the bridge. For example, a newly constructed H15 bridge designed under the working-stress approach can usually be expected to carry vehicles close to the Interstate maximum—80,000 pounds gross vehicle weight--safely.

Costs of Grading

> *The cost of compaction in embankments should be allocated as a common cost up to the accepted minimum width of roadway for the system in question, beyond which it should be treated as being occasioned by design-hour traffic in passenger-car equivalents.*
>
> *The cost of compaction in the subgrade directly below pavements and the cost of pavement are interrelated. The cost of this compaction should be reflected in the allocation of pavement costs.*
>
> *A portion of the costs of excavation in level terrain is occasioned by design-hour traffic, expressed in terrain-specific passenger-car equivalents, through increases in the width of roadways beyond the minimum for the highway system in question.*
>
> *A portion of the costs of excavation in rolling and mountainous terrain is occasioned by design-hour traffic, expressed in terrain-specific passenger-car equivalents, through increases in roadway width beyond the accepted minimum for the system in question and/or through flattening of roadway grades beyond what is commonly done on roads in flat terrain.*
>
> *Further study of the relationships between cost of excavation and volume and composition of traffic on various types of roads in various types of terrain is required.*

The two basic grading operations—compaction (compressing earth in the roadbed to achieve greater stability) and excavation (cutting or removing earth from the roadbed and filling or adding earth to the roadbed)—are discussed separately below. Further study in these areas is a particularly significant part of the cost-allocation study since, in most types of terrain, grading adds more to the total cost of new highways than does paving.

Costs of Compaction. Compaction may account for a fifth or more of the total costs of grading and is fundamentally different from excavation in the way costs are occasioned. Costs of compaction in the subgrade are related to the weight and number of wheel-load applications. Since this compaction is done, in effect, to obtain the density of soil that would otherwise occur under traffic loading, it improves the durability of pavement. The costs of subgrade compaction should thus be incorporated into the allocation of pavement costs.

Compaction of embankments is independent of traffic loads and its costs should thus be allocated as common costs, at least up to the amount that would be required for the minimum roadway.

Costs of Excavation. The costs of excavation are related to the peak-traffic volume and to the climbing ability of vehicles, since wider roads and/or gentler grades are required to maintain adequate levels of service as peak traffic increases and as vehicles with limited climbing ability are added to the traffic stream.

The available evidence suggests that the widths of both pavement and shoulders are determined not by the dimensions of vehicles but by the volume of traffic. The decision to build roads in the first place rests on the expectation that the total traffic which they will generate will be sufficient to justify the proposed expenditures. The composition and peaking characteristics of traffic have little effect on such decisions. And if roads are built at all, there must be some minimum width for pavements and shoulders. In flat terrain, the costs of excavation associated with this minimum width of roadway are common costs.

As traffic volumes increase, the widths of both pavement and shoulders come to depend on design-hour volumes, which are expressed in passenger-car equivalents. While width of shoulder is less directly related to design-hour volume than is width of pavement, the two are indeed related.

Rolling and Mountainous Terrain. The cost of grading and drainage per mile of highway is 200 to 300 percent higher in mountainous than in rolling terrain and about 33 percent higher in rolling than in flat terrain. Some of these extra expenditures are made to accommodate vehicles with limited climbing ability.

Separating the occasioned from the common portion of the costs of excavation is particularly difficult in rolling and mountainous terrain. The line between the common and occasioned portions cannot be drawn with much precision because the alignment chosen for a route is itself dependent upon the type of road to be built or the type of traffic anticipated. For example, a road built to carry cars and trucks might follow a different alignment from one built only for cars. Because of the wide range of interacting considerations involved in grading, any method of separating the occasioned portion of the costs of excavation in rolling and mountainous terrain from the common portion is bound to be a matter of judgment.

Although two simple ways of estimating the jointly occasioned portion of the costs of grading are presented in Appendix H, the Department of Transportation should study this problem further. Once the jointly occasioned portion of the costs of excavation have been separated from the common portion, they must be allocated across classes of vehicles. Design-hour volume, expressed in terrain-specific passenger-car equivalents, appears to be the most appropriate basis on which to allocate the occasioned portion of grading costs in rolling and mountainous terrain. This approach reflects recognition of the fact that highways must have sufficient capacity to meet AASHTO standards at design-hour volumes and that additional capacity can be achieved in rolling and mountainous terrain either by widening roads or by flattening slopes. The two can be effectively substituted for one another, since both are undertaken to improve the flow of traffic and reduce safety hazards in passing. Reduced grades result in greater capacity since they also reduce the passenger-car equivalents for vehicles with poor climbing ability.

Costs of Interchanges

Many of the costs of interchanges appear to be occasioned by vehicles of various specifications, and such costs should not be treated as common costs but should be examined to determine the groups of vehicles responsible.

Many features of interchanges are related to the height, length of wheelbase, or acceleration capacity of vehicles. For example, ramp width beyond that required for automobiles appears to be occasioned primarily by vehicles with long wheelbases, which require greater width for turns. Similarly, the cost of acceleration lanes beyond the 500 feet or so required by automobiles appears to be occasioned by vehicles with low power-to-weight ratios.

The costs of overpasses appear to be occasioned in two ways: first, for roads other than Interstate highways, the costs of increasing the height from the 12.5 feet required by maintenance vehicles on parkways to 14 feet appear to be occasioned by high-bodied vehicles; second, to the extent that the width of the structures exceeds the minimum width required for the road system in question, the costs of the added width are occasioned by design-hour traffic, measured in passenger-car equivalents.

Some grading and right-of-way costs are also occasioned by specific types of vehicles. For example, some grading costs around overpasses appear to be occasioned by high-bodied vehicles. Longer and wider ramps and acceleration lanes required by vehicles with low power-to-weight ratios or with need for greater turning area also result in higher grading costs. Some right-of-way costs appear to be occasioned by longer and wider ramps and acceleration lanes.

Costs of Culverts

Long-span culverts under low fill should be subjected to the same cost-allocation procedures as bridges of comparable length and type. The costs of all other culverts should be treated as common costs.

THE ALLOCATION OF COMMON COSTS

Common costs are to be allocated in proportion to vehicle-miles traveled.

Unlike costs that are incurred in meeting the needs of particular users, common costs are incurred in meeting the needs of all users. Thus, the chief principle that guides this study of cost allocation—that road users should pay the costs occasioned by them—does not serve as a guide for the allocation of common costs; any of a wide range of principles could be invoked instead.

The use of vehicle-miles traveled to allocate common costs is logical from a number of points of view; since it is a measure that has been used traditionally, is easily understood and accepted, and presumably will not change the pattern of highway use, it should be used in the cost-allocation study.

Nonetheless, it is recognized that common costs could be allocated in other ways, including some that might help meet certain social objectives such as the reduction of air pollution or the achievement of greater economic efficiency. The Department of Transportation should conduct a subsidiary study to explore the implications of allocating common costs in accordance with other objectives, but the results of this study should be clearly subordinated to the findings of the approach that is based upon vehicle-miles traveled.

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The number and types of classes of vehicles used should be similar to those used in the 1969 federal cost-allocation study.

The process of reconciling diverse estimates of fuel consumption, fuel economy, and vehicle-miles traveled should not be left to any single person or agency, but should consider the views of the relevant state and federal agencies as well as the primary interest groups.

In addition to determining the cost responsibility according to class of vehicles, as discussed in the preceding sections of this chapter, the cost-allocation study must also determine the amounts of the tax payments made by each group. Obtaining accurate estimates of the payments that each group of users makes into the Highway Trust Fund is a critical part of the study because it can influence the apparent fairness of any set of taxes. Two methodological issues of prime importance are the number and types of vehicle classes to be used in the study and the kinds of data that are needed.

In earlier federal cost-allocation studies, classes of vehicles defined by their visual characteristics were used—five-axle semitrailer or three-axle single-unit truck, for example. For each class, vehicle-miles traveled were estimated by various categories of gross weight or of other characteristics, such as axle-weight. This is a reasonable approach, since it combines the important vehicle characteristics that will be needed in allocating costs with comprehensive vehicle types. While the exact number and types of vehicles to be used should be decided by the Department of Transportation, it seems reasonable to begin with the roughly 70 types used in the 1969 and 1975 federal cost-allocation studies. Certain types of vehicles--some gasoline-powered heavy trucks, for example—can probably be dropped, since they make up a declining portion of the fleet, while other types, such as recreational vehicles, should be added. In considering characteristics of vehicles, it is important to include as much detail as is needed for arriving at the extreme values, since these have considerable influence on the way in which costs are occasioned. With respect to gross vehicle weight, the categories used in the 1975 federal cost-allocation study, with one category for vehicles of more than 70,000 pounds gross weight, should be considered as the minimum level of detail desirable.

Vehicle-miles traveled (VMT) is a key variable for allocating revenues, since most receipts of the Highway Trust Fund bear a direct relation to vehicle travel. VMT is not easy to estimate, and information from disparate sources must be reconciled. Two prime sources include vehicle classification counts conducted by most states and the Truck

Inventory and Use Survey prepared by the Bureau of the Census. The results of these surveys must be combined with various estimates of vehicular fuel economy and the results compared with actual fuel consumption. Differences must be reconciled by adjusting either VMT or the estimates of fuel economy. This is a complex, improvisatory process and the involvement of interested parties, including state and federal agencies, is crucial to the development of accurate estimates.

Primary inputs for estimating VMT by vehicle class are vehicle classification counts by road system and by vehicle class and weight. At present, vehicle classification counts are underrepresented on urban roads and on non-primary roads. Present vehicle classification counts, moreover, do not include data on vehicle weight and axle weight. The ease of collection and the accuracy of these data could be improved by using in-motion weighing devices. The burdens of data collection can probably be eased by coordinating this effort with the long-term monitoring of pavement conditions and traffic described in the next chapter.

Data requested from the states should, to the greatest extent possible, be limited to information that is also likely to be useful to the states or that is essential to an accurate cost-allocation study. Much of the burden of data collection placed on states in earlier studies can be avoided by sampling techniques rather than by asking all 50 states to supply every item of information needed for the study. Files of the Federal Highway Administration should be used to the maximum extent possible.

CHAPTER V. SPECIAL INVESTIGATIONS, SUPPLEMENTARY STUDIES, AND CONTINUING TASKS

In addition to the principal study, whose methodology is outlined in the preceding chapter, other studies are associated with the new cost-allocation study. These are of two kinds: special investigations required in order to ensure accurate and technically correct results for the cost-allocation study itself, and supplementary studies that reach beyond the scope of the principal cost-allocation study and help in assessing its findings within a broader context. In general, the special investigations, besides being necessary for the cost-allocation study, are likely to help improve highway design and construction practices. Several of the proposed supplementary studies are likely to be of direct help to states that wish to conduct cost-allocation studies of their own.

SPECIAL INVESTIGATIONS

Additional research is required in several areas in order to complete the cost-allocation procedures presented in Chapter IV. An important goal in each of these studies is to arrive at the best estimates possible within the three years allowed for the cost-allocation study. The time constraint is important, since in a few instances better estimates might be obtained if the studies were carried on over a longer period. In general, however, the value that might be added is likely to be small in comparison with the value of the results that can be obtained within three years, and it does not seem that this further refinement of the results would justify delay of the cost-allocation study.

Much of the information needed to conduct these special studies can be assembled from existing research reports. In a few instances, notably the special studies on pavement, some additional data must be collected and analyzed from a sample of highways. In no instance do the missing data represent information that must be collected from each of the 50 states. Accordingly, it should be possible to conduct the studies by means of intensive research at a few sites. In particular, the practice of sending questionnaires to each of the states--a valuable aid in earlier cost-allocation studies--does not appear to hold much promise for the special investigations outlined below. In all, six special investigations have been identified as essential. The most important of these have to do with pavement.

Long-term monitoring of pavement.

Many of the uncertainties about pavement that make cost allocation difficult can be unequivocally resolved only by carefully monitoring the volume and mix of traffic on selected roads over an extended period and by monitoring changes in the serviceability of the pavement over the same period. Such a pavement-monitoring program should be conducted in order to provide a significantly improved data base for estimating axle-load equivalents and for determining the share of pavement deterioration for which no class of vehicles is responsible. This undertaking would also produce information that could improve practices followed in the construction and maintenance of pavement. The selection of the roads to be monitored should be made in such a way that the study will include a representative set of climatic and environmental conditions. In addition, it is important that a wide range of road types be monitored, including roads on every functional system and both urban and rural roads. To the greatest extent possible, wide variations in the mix of traffic should be sought at otherwise similar monitoring points, so that additional assessment of the relative effects of heavy and light vehicles can be made. Sampling techniques should be used whenever possible. In-motion weighing devices should be used wherever it is practical to use them. The monitoring should be continued for at least six or seven years if accurate long-run results are to be obtained, although preliminary results should be coordinated with the cost-allocation study that is due in 1982. 1/

Short-term review of axle-load equivalents.

Because of the extreme importance of axle-load equivalents in determining the share of pavement cost attributable to each class of vehicles, it is important that the values produced by the 1960 AASHO road test be re-evaluated. Some modification of these equivalents may be needed to reflect changes in construction practice to make them applicable to resurfaced and reconstructed roads and to new construction or to ensure that they are representative of a broad range of climatic and soil conditions. Information from the AASHO road test, subsequent studies conducted by many states, and other pavement studies should provide a reasonable basis for making a preliminary evaluation.

1/ Such a pavement-monitoring study is laid out in Highway Research Board, "An Introduction to Guidelines for Satellite Studies of Pavement Performance," Report No. 2, National Cooperative Highway Research Program (1964); and Highway Research Board, "Guidelines for Satellite Studies of Pavement Performance," Report No. 2a., National Cooperative Highway Research Program (1964).

Determination of the proportion of pavement that is consumed, independent of traffic, by weather and other environmental factors.

In order to determine the share of overall pavement costs attributable to each class of vehicles, it is necessary first of all to determine the portion of pavement deterioration that would occur whether or not any vehicles used a road. Such deterioration cannot be said to be attributable to any particular group of users; rather, since it is independent of use, the deterioration is roughly proportional to the amount of road surface provided. In examining deterioration of this type, it is important to conduct separate analyses of each functional class of highways, under representative sets of traffic conditions, environmental conditions, and types of construction.

Additional research is needed to develop precise relationships between pavement deterioration and weather and other environmental factors. This research, which will probably require several years to complete, should be conducted as part of the long-term monitoring of pavement described above. Meanwhile, considerable information is now available that could be used to provide some preliminary approximations. The use of expert judgment by a panel of pavement engineers is one way of supplementing these data for use in the 1982 report.

Determination of what portion of the pavement is non-depreciable or has salvage value.

Before pavement costs can be allocated on the basis of axle-load equivalents, it is necessary to isolate those components that do not depreciate and to allocate them in some other way.

It is likely that the portion of pavement investment that is nondepreciating cannot be physically isolated but must be inferred from a comparison of the cost of reconstruction with the cost of new roads, or by making professional judgments about the net salvage value, at the point of reconstruction, of aggregate prior expenditures on pavement.

The salvage value of pavement may possibly be estimated by comparing the costs of resurfacing with those of new construction, making adjustments for the expected life of the pavement. For example, if new construction is expected to last 10 years and each resurfacing only 5 years, the salvage value of new construction could be estimated by subtracting the discounted cost of two resurfacings from the original cost of construction.

This approach could be refined by examining the life-cycle costs of roads using any of several analytical models now available, then inferring the salvage value under varying assumptions about maintenance of the pavement.

Passenger-car equivalents should be developed for an extended set of vehicle classes.

At present passenger-car equivalents are available only for automobiles, recreational vehicles, buses, and several types of trucks. Since passenger-car equivalents are to be used to allocate highway costs in many categories, it is important to increase the level of detail in this series of data. In particular, additional research should be conducted to develop, for various types of terrain, passenger-car equivalents for each of several types of trucks--at a minimum, pick-up trucks, two or more sizes of single-unit trucks, and two or more sizes of combination trucks.

Development of cost-allocation procedures for bridges and for grading in rolling and mountainous terrain.

These efforts, while important to cost allocation, are necessarily based on some hypothetical conditions, and further research on the subject would probably have little value in any effort to improve construction practices. Accordingly, only modest resources should be devoted to this special investigation. A reasonable approach would be to rely upon a workable consensus among experts in the field.

While the special investigations described above are considered vital to the cost-allocation study, the Department of Transportation is not constrained from undertaking any other investigations that it may deem important to a sound and timely cost-allocation study.

SUPPLEMENTARY STUDIES

Several studies are suggested in addition to those required for the principal allocation of costs. While these studies should be clearly identified as supplemental, they should be completed within the time limits set by the Congress for the main study. It is anticipated that some of these studies can at best develop rough approximations. Accordingly, only a small part of study resources should be devoted to them.

Guide to use of the federal cost-allocation study by state governments.

More than two-thirds of all highway expenditures are collected and spent by state and local governments. From time to time, many states have conducted highway cost-allocation efforts of their own. It is important that any future efforts by states be technically sound to the greatest extent possible, and it is highly desirable that their methodology be coordinated with that of the federal study. To encourage attainment of these goals, the

Department of Transportation should provide specific suggestions about how the various states could best adapt the federal methodology to allocation of state costs, including suggestions about the data that would be needed and any state-specific research that might be desirable. The federal study could also help by collecting and analyzing data on ways of allocating those components of state highway costs not included in the federal study---normal maintenance, for example.

Allocation of total expenditure on roads.

Although the principal cost-allocation study is concerned only with federal expenditures from the Highway Trust Fund, there are several reasons for also examining the ways in which the total expenditure on roads at all levels of government would be allocated if similar procedures were applied to them. A study of total expenditures would be another benchmark to guide the states in their cost-allocation efforts. In addition, such a study could provide guidance on the implications for cost allocation of possible assumption by the federal government of more of the burden of highway finance. A study of total expenditures would also be useful in determining the extent to which the government subsidizes the various submodes of highway transportation--information that is essential background in developing consistent, even-handed national transportation policies.

Study of indirect costs and benefits of highways.

The use of highways can impose significant costs beyond those associated directly with their construction and maintenance--damage to health and property caused by accidents, noise, vibration, or air pollution, for example. Highways also bring significant benefits--increases in property values because of improved accessibility, for example. These costs and benefits are likely to take much longer to investigate than direct costs of highways, and they can never be estimated with as much precision. Nonetheless, the indirect costs and benefits of roads are significant public concerns that cannot be ignored. Accordingly, the relative magnitude of indirect costs and benefits and the extent to which they are occasioned by various classes of vehicles should be estimated in the supplementary study.

Alternative ways of allocating common costs.

While the guidelines for the principal cost-allocation study state that common costs are to be allocated according to vehicle-miles traveled, there are other measures by which they could be allocated. The implications, both theoretical and practical, of using other measures should be examined in a supplementary study. These other measures might include vehicle registrations, passenger-miles traveled, ton-miles carried, and measures that are based on benefits.

CONTINUING TASKS

While the cost-allocation study is due to be completed in 1982, accurate estimates of cost responsibility by class of vehicles will continue to be needed to provide a basis for future changes in the tax structure as financial conditions change and as the emphases of programs shift. The study should be designed so that new estimates can be made quickly and with reasonable accuracy as conditions change.

Changes that could alter the ways in which highway costs should be allocated are of four basic types:

- Changes in vehicle design that change the amount of taxable product consumed;
- Changes in the mix of federal highway programs;
- Changes in the number and characteristics of vehicles and the nature and amount of travel; and
- Changes in highway design or construction practices that cause changes in the way in which costs are occasioned.

Vehicle Design

The fuel economy of automobiles is expected to continue to improve throughout the next decade, with the result that the tax per mile paid by automobiles will fall in relation to that paid by heavy trucks, whose fuel economy is not expected to improve as much. Similarly, increased use of radial tires and synthetic oil will bring about shifts in the taxes collected on tires and oil. These shifts in the rates of consumption should be anticipated within the computations of the cost-allocation study, and the study should be updated periodically after 1982 to reflect actual shifts in rates of consumption and revised expectations of future changes.

Program Mix

It appears likely that the shift in orientation of the federal highway program toward rehabilitation of existing roads rather than construction of new ones will continue. As new programs are added, the responsibility for their costs should be reviewed to determine how the costs should be allocated. With respect to many new programs, this might be easily accomplished by the use or modification of allocation procedures developed for existing programs. If substantial amounts of federal funds are made available for activities formerly excluded from the federal highway program, it may be necessary to develop new cost-allocation procedures appropriate for them. The attempt should be made in the cost-allocation study to anticipate significant new programs and to prepare cost-allocation procedures for them. Doing so will make it easy to recompute cost responsibilities as the mix of programs shifts.

Number and Characteristics of Vehicles and Travel

For accuracy in cost allocation as well as for a variety of planning purposes it is essential to collect good, current information on vehicle-miles traveled by each class of vehicles. In addition, as there are changes in the vehicle characteristics upon which cost responsibility is based, cost responsibility should be recalculated. For example, increases in size and weight limits for trucks or decreases in the acceleration capacities of automobiles could alter the responsibility of selected vehicles for some highway costs. Cost-allocation procedures should be reviewed periodically to ensure that they adequately reflect such changes.

Design and Construction Practices

Changes in design and construction practices are not likely to be so far-reaching as to require adjustments in the procedures for allocating costs. Nevertheless, when these practices do change, assessing the effect on cost allocation can be difficult and time consuming. This difficulty can be substantially reduced by attempts to gather information on cost responsibility while new practices are in the research stage.

APPENDIXES

APPENDIX A. LEGISLATIVE REQUEST

In Section 506 of the Surface Transportation Assistance Act of 1978, the Congress directed that the Secretary of Transportation undertake a thoroughgoing study of the allocation of highway costs and that the Congressional Budget Office develop guidelines for that study. Section 506 is reproduced here in its entirety.

REQUIREMENTS FOR A COST ALLOCATION STUDY.

(a) STUDY DIRECTED.—The Secretary of Transportation is hereby authorized and directed, in cooperation with the State highway departments, to undertake a full and complete investigation and study of—

> (1) the costs occasioned in design, construction, rehabilitation, and maintenance of Federal-aid highways by the use of vehicles of different dimensions, weights, and other specifications, and by the frequency of such vehicles in the traffic stream;
>
> (2) the proportionate share of such design, construction, rehabilitation, and maintenance costs attributable to each class of persons and vehicles using such highways; and
>
> (3) the need for long-term or continuous monitoring of roadway deterioration to determine the relative damage attributable to traffic and environmental factors.

(b) EVALUATION BY CONGRESSIONAL BUDGET OFFICE.--To assist the Secretary of Transportation in the conduct of the investigation and study authorized and directed by subsection (a) of this section, the Congressional Budget Office is hereby authorized and directed to make an evaluation of—

> (1) the procedures to be employed in determining the equitable allocation of highway costs;
>
> (2) the information to be collected to apply the procedures identified pursuant to paragraph (1);

(3) any special studies essential to the conduct of the investigation which can be identified and completed within the deadlines established by this section; and

(4) the procedures to be employed to ensure a continuing equitable allocation of highway costs after study termination.

The Congressional Budget Office shall report its findings to the Congress and to the Secretary of Transportation within 90 days after the date of the enactment of this section. These findings shall be employed by the Secretary as guidelines in the design of the investigation and study authorized and directed by subsection (a) of this section.

(c) REPORTS.--

(1) Within 180 days after the date of the enactment of this section, the Secretary of Transportation shall report to the Congress on a plan for the investigation and study. Such plan shall include, but not be limited to, the data to be gathered; the sources of such data; the method to be used to allocate costs; the method to be used to attribute revenues; the criteria to be employed in arriving at an equitable distribution of the tax burden; the agency or agencies responsible for performance and review of the study; a projected schedule for study performance; and the estimated costs of the study.

(2) On or before January 15, 1980, and January 15, 1981, the Secretary of Transportation shall report to the Congress the progress which has been made in carrying out the study and investigation required by this section. Such progress reports shall include, but not be limited to, a discussion of any changes from the study plan as submitted under provisions of this section and of preliminary findings of the investigation.

(3) The Secretary shall report to the Congress the findings and recommendations of the study no later than January 15, 1982. Such recommendations shall include any alternative tax structures which the Secretary believes would more nearly achieve an equitable distribution of the tax burden among classes of persons and vehicles using Federal-aid highways, and the projected impact of such structures on affected industries and other users.

APPENDIX B. ALLOCATION OF COMMON COSTS

Common costs are the costs that are incurred for the benefit of all classes of highway users. Common costs cannot be traced to any one class of vehicle any more directly than they can be traced to some other class of vehicle. Thus, the chief principle that guides this study of cost allocation--that road users should pay the costs occasioned by them--does not guide the allocation of common costs, which are not occasioned by any segment of users. Instead, any of a wide range of other principles could be invoked in allocating common costs.

Any procedure that allocates common costs without regard for the amount of road use appears to conflict with the user-pays principle. For example, allocating common costs equally to all vehicles would place as much tax on a vehicle used one day a year as on one used every day. Although such an allocation would be an equal treatment in one sense, it appears to conflict with the principle that users should pay for the highways they use.

In addition, vehicle-miles traveled (VMT) has become the most widely used measure of output for the national road system and the most widely used basis for allocating common costs in federal and state highway cost-allocation studies.

It could be argued that common costs should be allocated in a way that serves some social objective related to transportation. For example, common costs might be allocated in some way that would minimize the environmental damage done by highway vehicles, increase the efficiency of highway use, increase the efficiency of the transportation sector as a whole, or reduce the disparity in transportation subsidies across commercial modes of transportation. The consequences of distributing common costs in accordance with broad objectives such as these should be explored in the cost-allocation study, but the results of those studies should be clearly subordinated to the findings of a method of cost allocation that is based upon VMT.

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APPENDIX C. BROADER INTERPRETATION OF UNIQUELY OCCASIONED COSTS

In most earlier highway cost-allocation studies, including those prepared by the Federal Highway Administration (FHWA), equity has been interpreted to mean that each class of vehicles should pay for those highway costs for which it is responsible. 1/ That is, each class of vehicles is assigned the costs that it occasions. Since there are several ways in which the principle of occasioned costs can be interpreted, many questions remain about the best way of applying it.

How Does This Concept Differ from Past Practice

In past studies the interpretation of uniquely occasioned costs has been narrow—based largely on structural or engineering principles. A somewhat broader interpretation is proposed here. In particular, it may be more appropriate to allocate some costs on the basis of the function of the new road or improvement--that is, the reason for building the road rather than the way in which it is built. If the primary function of a new road or improvement is to meet the needs of a particular class of vehicles, the resulting costs should be assigned to vehicles of that class. For example, the cost of a program to repair or replace coal roads should probably be assigned solely to the classes of heavy trucks that require those roads.

There is nothing inherently wrong with determining occasioned costs by analyzing engineering details and assigning their costs to the vehicle classes responsible for them. In some instances, however, such an approach is unduly restrictive, since it focuses only on the way road improvements are made and ignores the reasons for making them. In instances in which programs or projects are undertaken for a distinct subset of road users, those users should be taxed. That is, if some class of vehicles is responsible for a project, that class should be assigned all the project's costs, even if

1/ The 1965 FHWA cost-allocation study results were also presented on the basis of several other methodologies, but in subsequent reports only the occasioned-costs approach has been used.

some of these costs are for components that are associated with other classes of vehicles. Such instances probably represent only a small fraction of highway expenditures.

This principle has been selectively applied in earlier studies of cost allocation. In particular, all costs of climbing lanes were charged to the trucks whose limited climbing ability made the lanes necessary, even though some of the costs, such as the cost of pavement occasioned by automobiles, would not otherwise have been assigned to trucks.

Example: Structurally Deficient Bridges

Earlier FHWA cost-allocation studies of bridges were based on the differences in the costs of bridges built to carry vehicles of particular weights. For example, if a bridge designed to accommodate cars could be extended to carry trucks by the spending of an additional 50 percent on construction costs, in earlier studies one-third (50/150) of the costs would have been assigned exclusively to trucks while two-thirds (100/150) would have been assigned to both trucks and cars. If, however, the bridge in question is one that is being replaced, it may be appropriate to go a step further and ask why it is being replaced. For example, if a bridge could still accommodate cars and carry them indefinitely but its use by heavier vehicles such as trucks is restricted and it is rebuilt to remove this restriction, then trucks should be assigned the full cost of rebuilding the bridge, since there would be no need to replace the bridge if there were no truck traffic.

The bridge-replacement program will be consuming a growing portion of federal highway expenditures, so it should be scrutinized to determine the extent to which the broader interpretation of uniquely occasioned costs presented here may be applicable. In the present bridge-replacement program, federal aid is restricted to bridges that are termed structurally deficient--those with serious structural problems that make them potentially unsafe for at least certain types of traffic. Given the number of such bridges, they are likely to remain the focus of federal bridge-replacement efforts. The extent to which such replacement is uniquely occasioned thus has important consequences for cost allocation.

In 1977, 5,500 bridges on the federal-aid system were identified as structurally deficient. Of these, 31 percent had inventory ratings of less than 10,000 pounds, 23 percent between 10,000 and 20,000 pounds, 22 percent between 20,000 and 30,000 pounds, 11 percent between 30,000 and 40,000 pounds, and 13 percent more than 40,000 pounds. 2/ If all these bridges were replaced, lightweight vehicles (less than 10,000 pounds) should clearly be assigned a portion of the costs of the 31 percent of bridges that need to be improved on their account. The costs of the remaining 69 percent of bridges, which survey results indicate can be used "indefinitely" by automobiles, may contain some that are uniquely occasioned. The bridge-replacement program should be reviewed carefully in the cost-allocation study to determine what share of the costs should be considered as being uniquely occasioned under this broader definition.

Conclusion

When it is applicable, the principle of uniquely occasioned costs as defined in this Appendix should be given precedence over views of occasioned costs that are based on construction or engineering. One advantage of this approach is that it reduces the portion of highway costs that must be allocated as common costs. To the extent that costs can be identified as uniquely occasioned or jointly occasioned by particular classes of vehicles, the reliability of any future cost-allocation study is likely to be improved.

The example presented above represents a rather clear instance of costs that are occasioned because of the function of the improvement. While a serious attempt should be made to apply the principle to other highway expenditures, the bulk of occasioned costs are likely to continue to be estimated by using engineering cost-estimating techniques.

2/ The inventory rating is also called the lower stress level or "load which can safely utilize an existing structure for an indefinite period." American Association of State Highway and Transportation Officials, Manual for Maintenance Inspection of Bridges (1974), p. 14. The ratings are from unpublished data in the FHWA National Bridge Inventory, 1977. Bridges over highways and bridges less than 20 feet long are excluded.

APPENDIX D. ALLOCATING THE COSTS OF PAVEMENT: AN AXLE-LOAD-EQUIVALENT APPROACH

The costs of pavement are usually the first thing that comes to mind when the subject of cost allocation is raised. The widespread publicity on the deterioration of the nation's roads tends to increase the visibility of vehicle-induced wear. Pavement wear has also been the subject of extensive research. The road test conducted in 1958-1960 by the American Association of State Highway Officials (AASHO), at a cost of more than $20 million, remains one of the largest analytical efforts ever conducted for the guidance of transportation policy.

Nevertheless, pavement costs represent about one-quarter of the costs of federal roadways at present, the remainder being used for right-of-way, grading, construction of bridges, and the like. Accordingly, even a dramatic shift in the allocation of the costs of pavement could have only modest effects on the allocation of present highway costs. The costs of pavement will, however, become more significant as the highway program shifts its emphasis from new construction to maintenance.

The allocation of pavement costs raises a unique set of conceptual issues in the cost-allocation process. Unlike right-of-way or grading, which for all practical purposes last indefinitely, pavement deteriorates through use. The varieties of deterioration are diverse: rutting, cracking, becoming slippery, and so on. Some forms of damage, such as frost damage or salt corrosion, may be independent of use. Even so, wear by vehicles is responsible for much of the deterioration of roads, and this is one of the few instances in which the process whereby the use of a vehicle contributes to cost can actually be observed. With respect to most other elements of cost, the special features required by any particular type of vehicle are considered once--at the design stage--before construction begins. Such special features of the design are sunk costs once the road has been constructed, and their life does not depend on the traffic actually using the road. With the exception of pavement costs, the costs of building most roads to accommodate various types of vehicles must be inferred from estimates of what would have been done under hypothetical conditions.

Incremental Allocation

In spite of their tangible nature, pavement costs promise to be one of the most controversial aspects of highway cost allocation. There are two contrasting viewpoints as to the way in which they should be allocated. The first, which has been used in earlier studies by the Federal Highway Administration (FHWA), contends that the costs of pavement should be allocated on the basis of the incremental costs of construction needed to build a road capable of accommodating a particular category of traffic. The second, which is suggested by CBO as well as others, contends that the costs of pavement should be allocated to classes of vehicles on the basis of the wear they cause.

According to the first contention, the cost of the extra depth of pavement required by roads designed to carry heavy trucks would be charged to heavy trucks, while trucks and cars would share the costs of the basic depth of pavement--the pavement that would be needed to carry only cars. In earlier FHWA studies, the costs of the basic pavement have been shared on the basis of axle-miles. In effect, this approach reflects the assumption that the only extra costs of pavement that are imposed by trucks are the extra depth of pavement, and that trucks alone should pay for it. The costs of the basic pavement are common to all vehicles, and the basis upon which they are shared is essentially arbitrary, although axle-miles appear to be as reasonable a basis as any. 1/

Wear-Based Allocation

The extensive AASHO road test, conducted in the late 1950s, was undertaken to assist the study of highway cost allocation that was requested in the Federal Highway Act of 1956. This test was designed to determine the relative degrees to which pavement was worn by cars and by trucks. This test provided information on the extra thickness of pavement needed to accommodate heavy trucks, and on the relative amounts of wear for which various types of vehicles were responsible. In particular, it was found that heavy trucks are responsible for wear equivalent to that caused by an enormous number of automobiles—one heavy truck causing the same amount of wear as thousands of cars. Earlier studies of cost allocation, in which the

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1/ Other possible bases are vehicle-miles, numbers of vehicles, ton-miles, or any of a wide range of similar measures.

cost of the basic road has been allocated among various classes of vehicles without regard for the relative amount of wear for which each was responsible, hardly seem to reflect adequately the way in which vehicles actually wear out the pavement on the basic road.

The relationships of the relative amounts of wear caused by various classes of vehicles that were found in that early road test may not be applicable to current practice, however, because it exposed pavement to controlled traffic loads until the pavement failed, with little interim maintenance. Accordingly, the resulting data on relative responsibility for wear may not be truly indicative of the wear caused by vehicles of varying weights under more realistic conditions of maintenance.

The allocation of pavement costs based on axle-load equivalents is an attempt to allocate the costs of pavement in proportion to the way in which it is actually worn out through vehicular use. There is evidence that some of the wear on roads, especially on thin pavements is also attributable to weather, environment, or age. That is, some wear would occur whether or not there was any traffic on the road. Such wear cannot be attributed to any particular class of vehicles and should thus be considered a common cost. In addition, there is also a portion of the investment in pavement that does not appear to depreciate with use: this also appears primarily to represent a common cost. Accordingly, both the nondepreciating portion of the costs of pavement and the costs attributable to weather and other environmental factors should be dealt with separately, but all other costs of pavement, including resurfacing, should be allocated in proportion to axle-load equivalents.

According to the axle-load-equivalent approach, the portion of the costs of pavements that is observed to depreciate through use would be allocated exclusively on the basis of the relative amounts of wear caused by trucks and by cars. It is not clear what percentage of federal expenditures for pavement is associated with this portion, nor, is it clear that the existing data on relative responsibility for wear will prove to be appropriate. The cost-allocation study should be directed toward determining which subcomponents of pavement deteriorate, the extent to which this deterioration is attributable to use of the pavement by vehicles, and the relative amount of the deterioration for which each class of vehicles is responsible.

Comparison of the Incremental Method and the Wear-Based Method

The two methods of allocation described above could produce drastically different results because of an unusual feature of the costs of pavement. In the AASHO road test, it was found that the number of loads that a pavement could withstand increased as the seventh power of the thickness of the pavement. This implies that the last inch of pavement offers inordinately more strength to the total pavement than does the first inch. It is similar to a one-cent sale, in which the first bottle of aspirin sells for 29 cents and the second bottle sells for one cent. When the incremental cost method of allocation is used, the basic road corresponds to the 29-cent bottle and the truck increment corresponds to the one-cent bottle. Thus, all vehicles buy the basic road on the basis of axle miles, while trucks alone buy the "bargain" increment.

When the axle-load-equivalent method is used, costs are computed as if two bottles of aspirin sold for 30 cents, and the price per tablet is computed on that basis. In other words, the life of a pavement is equivalent to some large fixed number of applications and one truck application is equivalent to a large number of automobile applications. The number of load applications that the pavement can withstand can be compared with the number of tablets in the two bottles of aspirin. Following the axle-load-equivalent method, vehicles would pay, in effect, in proportion to the number of tablets consumed. According to this interpretation, it is irrelevant that the basic road that would have been built for cars alone would have required the greater part of the expenditure. After all, a basic road built for trucks alone would also require the greater part of the expenditure. What would matter is the way the road was consumed by the vehicles that used it, once the expenditure had been made. If pavement can withstand 10 million truck applications, it seems fair to charge each truck that uses the road 1/10,000,000 of the costs of the pavement; if pavement can withstand 100 million car applications, then it seems fair to charge each car that uses the road 1/100,000,000 of the costs of the pavement.

The contrasting view is that once a road has been built to last for 20 years if used only by cars for example, any improvements made in its design so as to allow the road to last 20 years if it were used also by trucks represent the only additional costs that should be assigned to trucks.

The trouble with this argument is its assymetry: If trucks were considered to be the basic vehicles instead of cars—that is, if roads were assumed to be built primarily for trucks—then trucks would be assigned almost all the costs of pavement, since the incremental cost of improving an all-truck road to carry cars as well would be virtually nil. And it is not unreasonable to consider trucks as the basic vehicles. If the results of the AASHO road test are valid, then each truck loaded to the Interstate limit causes wear equal to that caused by 2,500 cars. Even if such loaded trucks made up only 5 percent of all traffic, they would nonetheless inflict more than 99 percent of all the wear sustained by the pavement. 2/ It is thus hardly stretching a point to argue that the vehicles causing 99 percent of the wear on the road are basic to its design. Under the axle-load-equivalent approach, these costs of wear are assigned to the vehicles that cause the wear.

The argument against allocations according to axle-load equivalents is often linked to a disclaimer of responsibility for the premature deterioration of roads. If, after the actual use of the road has begun, the road does not last the length of its design life, the argument from this point of view is that it is unfair to require the trucks to pay more because of the heavy deterioration of roads that appears to accompany their use. If trucks paid for the road once when it was first constructed and if the original estimates have proved to be in error, then it should not be the responsibility of the truckers to make up the difference. A similar argument is that neither should it be the responsibility of the automobile users to make up the difference. The actual life of some roads is shorter than their design life, and these roads require additional work and additional expenditures to make them last as long as they were expected to last. The actual life of others is longer than their design life, and these roads require less repair and less additional expenditure in the long run than was expected. To some degree, these two situations may offset each other. Even if they do not, the difference between actual and expected deterioration represents an error in estimated costs. To the degree that the estimated costs of the original design are in error, the costs attributable to trucks and to automobiles are both in error. To require both these groups of vehicles to pay for the additional costs that have been incurred but were not allowed for in the design is not to make anyone pay twice; it is simply to adjust for the fact that all groups of vehicles were undercharged.

No matter how they are designed, roads require additional resurfacing if they are to remain usable after some number of years. Even when resurfacing is required, part of the original investment in the roads is still serviceable. The long-run costs of a road include both the costs of the initial paving and the costs of periodic resurfacing. To require that users pay the cost of resurfacing in addition to the original cost of the road is not to require them to pay twice for the same thing, but rather to pay for

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2/ That is,

$$\begin{array}{rll} \text{truck wear} = & 0.05 \text{ @ } 2500 = & 125.00 \\ \text{auto wear} = & 0.95 \text{ @ } 1 = & 0.95 \\ \hline \text{total wear} = & & 125.95 \\ \text{truck share} = & \dfrac{125.00}{125.95} = & 0.9925 \end{array}$$

different stages of the life of the road. No road is designed to last forever, and the life-cycle cost of a road always includes both the original capital investment and the periodic expenses of resurfacing.

Life-Cycle Costs

If the part of the original pavement that eventually deteriorates does so as a function of traffic use in the same way that resurfacing deteriorates with traffic use, then whether life-cycle cost accounting is done within cost allocation or not seems irrelevant, since the occasioned portion of the original construction cost of pavement and the full cost of resurfacing show the same relationship to use by each type of vehicle. It would not be surprising, moreover, if the depreciable part of the original pavement and the resurfacing were to behave similarly with respect to wear by various categories of traffic, since similar physical processes are at work in both cases. Data are not available, however, that would make it possible to test this assumption; more detailed empirical findings should be collected from carefully monitored segments of road, however.

If the wear caused to new pavement by trucks in relation to that caused by cars happens to be significantly different from the wear caused to resurfacing by trucks in relation to that caused by cars, analytical difficulties may arise. One solution would be to include the costs of both new pavement and resurfacing in proportion to their actual expenditures over the life of the road. In this instance, the wear caused to new pavement by trucks in relation to that caused by cars is not applicable to the full cost of keeping the pavement in repair throughout the life of the road, nor is the corresponding wear caused to resurfacing applicable. Indeed, since the possibility exists of spending less on new construction and doing more frequent reconstruction of the road, there is a tradeoff between spending more money on initial construction and less on resurfacing, and spending less in the beginning and more on occasional resurfacing throughout the life of the road. When the cost responsibility of cars and trucks differs with respect to both these components, the long-term responsibility of various classes of vehicles could only be determined by looking at the long-term pattern of resurfacing projected in the design of the road. This would entail looking at data on expenditures covering many years, and complications would arise because of changing techniques of repair and changing costs.

Although the attempt could be made to develop, on some basis, the optimal tradeoff between original costs and resurfacing costs for each type of road, such a split between first costs and subsequent costs might not be in accord with practice, if the states should for any reason deviate from this analytically derived optimum procedure. Because of differences in the availability of federal funds for various kinds of work or the paperwork required for federal assistance generally, there may be some tendency for the states not to follow a theoretical optimum in the attempt to minimize the life-cycle costs of roads. If theoretically minimized life-cycle costs are not representative of practice, then it would be necessary in a cost-allocation study to consider the actual amount of money spent for new construction and for resurfacing. As long as the cost allocation is updated periodically whenever the balance between new pavement and resurfacing shifts, it appears that differences in cost responsibility for these two categories of work would be reflected fairly.

Conclusion

The costs of pavement should be allocated in proportion to axle-load equivalents, with two exceptions: costs attributable exclusively to weather and other environmental factors, and costs of a permanent, nondepreciating nature. In order to allocate pavement costs on the basis of axle-load equivalents, however, several questions need to be answered through further research:

- What fraction of the deterioration of roads is attributable to weather and other environmental factors independent of the wear attributable to traffic?
- What fraction of the costs of new pavement depreciates over time?
- Are the axle-load equivalents that were developed in the AASHO road test reliable, for all climatic conditions, in view of today's construction practices?

These questions can be answered through the special investigations outlined in Chapter V, and these investigations should be begun immediately. If need be, professional judgments from a panel of pavement experts may suffice. In any event, the incremental technique applied in earlier studies is not judged to be an equitable procedure for allocating the costs of pavement in view of current programs, and this approach should be abandoned.

APPENDIX E. SHOULDER COST ALLOCATION

The costs of paving shoulders are addressed in this appendix. Other costs associated with shoulders, such as those incurred in grading and in the acquisition of rights-of-way, are dealt with in other appendixes, as are shoulder paving costs occasioned by increases in shoulder width to accommodate design-hour traffic.

In earlier highway cost-allocation studies, shoulders and pavements have been grouped together on the assumption that shoulder costs and pavement costs are occasioned by the same vehicles in the same proportions. For two reasons this may not be so. First, trucks make disproportionate use of the shoulders. In various studies of shoulder use on both urban and rural highways, it has been found that, per vehicle-mile traveled, trucks are from 2.5 to 6.5 times as likely as automobiles to make leisure or emergency stops on shoulders. 1/ In other studies, it has been found that trucks in outside traffic lanes have a high rate of encroachment on shoulders, far higher than automobiles. 2/ Corresponding wear and tear on affected portions of shoulders, though comparable to that on pavements, is more heavily attributable to truck traffic.

1/ W. Bellis, "Shoulder Use," Highway Research Board Bulletin 170, 1958, pp. 51-53; R. Blensley and W. Byars, "Discussion: Shoulder Occupancy on Rural Highways," Highway Research Board Proceedings, 38th Annual Meeting, 1959, pp. 570-75; S. Bergsman and C. Shufflebarger, "Shoulder Use on an Urban Freeway," Highway Research Record 31, 1963, pp. 1-19; and M. Cheeseman and W. Voss, "Interstate Highway Shoulder Use Study in South Dakota," Highway Research Record 162, 1966, pp. 134-45. Other papers on shoulder use fail to provide figures on travel by class of vehicles, making it impossible to estimate relative use of shoulders.

2/ A. Taragin, "Driver Behavior Related to Types and Widths of Shoulders on Two-Lane Highways," Public Roads, 1957, pp. 197-215; N. Jorol, "Lateral Vehicle Placement as Affected by Shoulder Design on Rural Idaho Highways," Highway Research Board Proceedings, 41st Annual Meeting, 1962, pp. 415-32; and R. Hicks and others, "Design Practices for Paved Shoulders," Transportation Research Record 594, 1977, pp. 48-56.

Second, shoulders on most highways have less structural capacity than do pavements. 3/ The California Department of Transportation, for example, designs its shoulders to withstand 1 percent of wheel loads from the adjacent traffic lane. 4/ Some states use tapered shoulders. Others use thinner asphalt in shoulders than in pavements. Still others use lower-quality base materials in shoulders than in pavements. With their limited structural capacity, shoulders are more susceptible to distress under heavy axle loads than are pavements. 5/ On the other hand, with so little traffic using shoulders, climatic factors may be responsible for more of the overall distress in shoulders than in pavements. 6/

Conclusion

Notwithstanding differences in the use and structural capacity of shoulders and pavements, shoulder and pavement costs should be allocated together as in earlier studies. Present shoulder-design practices do not vary with anticipated traffic. As of 1973, only two states, California and Iowa, had design-load criteria for paved shoulders, and both based shoulder designs on loads in adjacent traffic lanes. 7/ In most states, shoulders are overdesigned to the point that any implicit relationship between shoulder design and shoulder use is lost. Accordingly, the costs of paving shoulders probably cannot be precisely related to traffic. Probably the best that can be done is to assume that the costs of paving shoulders are occasioned in the

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3/ Hicks and others, "Design Practices for Paved Shoulders."

4/ J. Portigo, "State-of-the-Art Review of Paved Shoulders," Transportation Research Record 594, 1977, pp. 57-64.

5/ The AASHTO road test found that while all loads cause more wear to thin pavement than to thick pavement, heavy loads cause more deterioration in a relative sense to thin pavements. AASHTO, AASHTO Interim Guide for Design of Pavement Structures 1972, 1974, Tables C. 2-1 through C. 2-4.

6/ The overriding contribution of climatic factors to shoulder distress is described by L. McKenzie, "Shoulder Structural Design and Construction Considerations," Highway Research Circular 142, 1973, pp. 8-10.

7/ Portigo, "State-of-the-Art Review of Paved Shoulders," p. 60.

same way as the costs of paving the road itself. Nonetheless, it may be desirable to investigate shoulder and pavement costs separately in any research or experimentation on pavement that is conducted as part of a cost-allocation study. Such studies could provide a basis for differentiating the costs of paving shoulders.

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APPENDIX F. RIGHT-OF-WAY COST ALLOCATION

In federal highway cost-allocation studies in the past, right-of-way costs have been treated as purely common costs on the assumption that the width of the right-of-way is independent of the volume and characteristics of traffic. As common costs, right-of-way expenditures were allocated across classes of vehicles in proportion to vehicle-miles traveled by each class. This approach can be refined by treating some part of right-of-way costs as being occasioned jointly by all classes of vehicles For example, as the volume of traffic increases, highways of greater capacity are needed. Typically, capacity is increased by widening the pavement, shoulders, and other components of the right-of-way. Since some 20 percent of current federal highway expenditures are for right-of-way acquisition and roadside development, this refinement could affect the allocation of highway costs significantly.

The available literature on the factors that affect right-of-way width is summarized in this appendix. Each of the elements in the typical right-of-way cross section--pavement, shoulders, median, and borders--is discussed in turn, and the important methodological questions are then presented.

Design-Hour Volumes and Passenger-Car Equivalents

The American Association of State Highway and Transportation Officials (AASHTO) states that:

> Knowledge of ADT (average daily traffic) is important for many purposes such as determining annual usage as justification for proposed expenditures or for design of structural elements of a highway, but its direct use in the geometric design of highways is not appropriate because it does not indicate the significant variation in the traffic occurring during the various months of the year, days or weeks and hours of the day. 1/

1/ American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Rural Highways (1966), p. 54.

Instead, AASHTO recommends that geometric design be based on the design-hour volume, generally taken to be the 30th highest hourly volume for some future design year. In urban areas, this volume represents peak-hour traffic. In rural areas, it represents an upper bound to the normal fluctuation of daytime traffic.

Passenger cars make relatively heavy use of highways during peak hours in urban areas and during daylight hours in rural areas. AASHTO recommends that, in the designing of rural highways, passenger cars and light trucks be assumed to represent 91 to 93 percent of design-hour volumes, while they represent only 87 percent of average daily traffic. 2/ Passenger cars and light trucks represent an even higher percentage of design-hour volumes in urban areas. Thus, when highways are designed to accommodate traffic during the design hour, the high percentage of traffic at that hour represented by passenger cars tends to increase the responsibility of passenger cars for capacity-related costs.

The high percentage of passenger cars in the composition of design-hour traffic is offset, at least in part, by the greater capacity required for trucks, buses, and recreational vehicles because of their size and low power-to-weight ratios. Design-hour volumes are usually expressed in passenger-car equivalents per hour, where a truck, for example, is equivalent to between two and three passenger cars in the amount of highway capacity that it uses in level terrain. 3/

The use of design-hour volume and passenger-car equivalents in highway cost allocation represents a departure from past practice in the United States, though it has been suggested in some of the recent literature on highway cost allocation in the United States and it figures in the allocation of highway costs in Great Britain. 4/

2/ Ibid, pp. 60-61.

3/ Highway Research Board, Highway Capacity Manual (1965), Tables 9.3a, 10.3a, 10.9a.

4/ K. Bhatt and others, An Analysis of Road Expenditures and Payments by Vehicle Class (1956-1975) (The Urban Institute, 1977), pp. 245; J. Covil and Others, Development of Strategies and Procedures for Highway Cost Allocation (Wilber Smith and Associates, 1977), pp. 133-44; Ministry of Transport, Road Track Costs (HMSO, 1968); and Department of Environment, "The Allocation of Road Track Costs," in Transport Policy (HMSO, 1976).

Overall Right-of-Way Width

AASHTO highway design standards, state highway design standards, surveys of state highway design practice, and studies of highways all indicate that the width of right-of-way is related to the design-hour volume measured in passenger-car equivalents. In the National Highway Inventory and Performance Study of 1976, it was found that the average right-of-way width of rural multilane highways in the United States, 269 feet, is nearly three times the 90-foot average of two-lane and three-lane highways. 5/ Since throughout 98 percent of the mileage of rural multilane highways there are only four lanes, each typically 12 feet wide, this large difference in right-of-way width must be accounted for by shoulders, medians, and borders.

The relationship between the width of highways and design-hour volume becomes less direct as pavements, shoulders, medians, and finally borders are considered. The width of each element in the cross section of the highway appears, nonetheless, to bear some relationship to design-hour volume, although not necessarily the same relationship with respect to each element.

Width of Pavements

AASHTO has set level-of-service standards for highways by number of lanes, type of terrain, and urban or rural location. These standards are specified in average running speeds at design-hour volumes. To quote AASHTO:

> Highways should be designed so that the designated average running speeds can be maintained during the design-hour; that is, when the design-hour volume is using the highway. During other hours, when the traffic volume is lower than the design-hour volume, speeds higher than these will prevail. 6/

This means that through-traffic lanes are widened and additional through-traffic lanes are added until the capacity is great enough to meet relevant level-of-service standards at design-hour volumes. An increase in

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5/ FHWA, National Highway Inventory and Performance Summary (1977), Table IX-1.

6/ AASHO, A Policy on Geometric Design of Rural Highways (1966), pp. 99-100. Before 1973, AASHTO was known as the American Association of State Highway Officials (AASHO).

the width of two-lane highways results in a substantial increase in highway capacity. A 24-foot highway has, for example, nearly one-third greater capacity than an 18-foot highway with the same lateral clearance. 7/ Thus, as design-hour volume increases from less than 100 to more than 400 vehicles an hour, AASHTO design standards require a corresponding increase in the width of two-lane rural highways. 8/ Further increases in design-hour volume could require the addition of lanes 12 feet wide, thereby doubling, tripling, or even quadrupling the total width of the pavement.

Width of Shoulders

Three of the four principal functions of shoulders—delineation, drainage, and structural support—require that they be of only minimal width. It is the fourth function, the maintenance of safe operation and full capacity during emergency occupation of shoulders by vehicles, that generally determines the width of shoulders. While recommending wider shoulders, AASHTO states:

> In difficult terrain and on low-volume highways usable shoulders of this width (about 10 feet) may not be feasible. . . . There is considerable (though less) advantage in narrower shoulders. When a vehicle forced to stop can drive onto the shoulder so as to occupy only 1 to 4 feet of traveled way of adequate width, the remaining pavement width can be used, even though restricted, for the intended number of traffic lanes. 9/

In practice, then, the width of shoulders represents a compromise between considerations of economy, safety, and capacity.

Considerations of safety and capacity argue for wider shoulders at higher design-hour volumes. It has been found that increases in hourly volume cause increases in the average lateral distance between vehicles

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7/ Highway Research Board, Highway Capacity Manual (1965), Table 5.1.

8/ AASHO, Policy on Geometric Design of Rural Highways, Table V-1.

9/ Ibid., pp. 235-36.

passing one another on two-lane and multilane highways. 10/ The result is that vehicles ride closer to shoulders at higher hourly volumes. As hourly volumes increase, so must shoulder widths if adequate lateral clearance between through traffic and vehicles making emergency use of shoulders are to be maintained.

Maintenance of adequate lateral clearance is essential for safe and efficient movement of traffic at high hourly volumes. As lateral clearance from the edge of the pavement to obstructions declines from 6 to 0 feet, the effective width of a 24-foot highway is reduced to 17 feet and the effective capacity is reduced 28 percent. 11/ Such reductions in lateral clearance force through traffic to slow down as it passes vehicles on the shoulder and, at hourly volumes approaching capacity, the result can be degradation of service and high accident rates. This is the principal reason that consideration of design-hour volume is essential in shoulder design. Other reasons have to do with certain ancillary functions of shoulders, notably the following:

- Provision of aesthetic value as an aid to the comfort and security of drivers, four feet of paved shoulder width increasing the effective width of pavement as much as an extra foot of lane width.

- Provision of space for slower-moving vehicles to facilitate passing maneuvers.

- Provision of extra lanes for additional capacity during peak periods.

- Provision of extra lanes for conversion of two-lane highways to four-lane highways. 12/

10/ A. Taragin, "The Effect of Roadway Width on Vehicle Operation," Public Roads (1945), pp. 146-47; C. Billion, "Effect of Median Dividers on Driver Behavior," Highway Research Board Bulletin 37, 1956, pp. 7-14.

11/ Highway Research Board, Highway Capacity Manual (1965), Table 5.2.

12/ J. Portigo, "State-of-the-Art Review of Paved Shoulders," Transportation Research Record 594, 1977, pp. 58-60.

In a recent survey of state shoulder design practices, it was found that design-hour volume is one of several factors commonly considered in the design of shoulders. 13/ AASHTO design standards are probably indicative of current design practices. As the design-hour volume increases from fewer than 100 to more than 400 vehicles an hour, the minimum width of shoulders increases from four to ten feet. Further increases in design-hour volume have no effect on the width of outside shoulders, but when design-hour volumes become high enough to justify divided highways, with multiple lanes, inside shoulders must be added and widened. On divided highways with two lanes in each direction, inside shoulder strips at least four feet wide are required. On those with three or more lanes in each direction, inside shoulders at least six feet wide, and preferably eight to ten feet wide, are required, since vehicles in the inside lane cannot be expected to cross two or more lanes of traffic to reach the right shoulder when they are in distress. 14/

Width of Median

The functions of medians, as summarized in one annotated bibliography on the design and function of medians, include the following:

- The separation of opposing traffic streams so as to influence the behavior of vehicles favorably, particularly under accident conditions, increase the capacity of the road, and increase the comfort and convenience of drivers.
- The provision of appropriate stopping or recovery conditions and space for vehicles running on the left edge of the pavement under various degrees of control.
- The provision of storage or refuge space for disabled vehicles, the importance of which varies with the density and volume of traffic and the number of traffic lanes.
- The provision of space for drainage and for the storage of snow, the importance of which varies with climate, topography, and number of traffic lanes.

13/ Ibid., p. 59.

14/ AASHO, Policy on Geometric Design of Rural Highways, p. 279.

- o The provision of space for future expansion of the road or the installation of other types of transportation facilities, the importance of which varies with predicted development and transportation demands.

- o The provision of protection for left turning or crossing vehicles, the importance of which varies with the intended use of the road. 15/

Any of these functions could, under certain circumstances, require an increase in width of the median to accommodate high design-hour volumes.

Design-hour volume is less directly related to width of the median than to the width of pavement or shoulders. The standards of median width of AASHTO do not vary with the volume and composition of traffic, or with any simple correlative of the volume and composition of traffic in service. 16/ Nor do state standards of median width. 17/

The width of medians is, nonetheless, indirectly related to design-hour volume, since medians are required only on multilane highways, and multilane highways are required only at high design-hour volumes. Further, certain states require wider medians on higher performance highways--that is, highways with full access control, high design speeds, and the like. 18/ Multilane highways are typically designed to such high standards only when design-hour volumes are relatively high.

15/ Hutchinson and others, Medians of Divided Highways (1963), pp. 1-2.

16/ AASHO, Policy on Geometric Design of Rural Highways, pp. 252-56 and 277-82; AASHTO, Highway Research Board Bibliography 34, 1973, pp. 366-72 and 433-37. The apparent variation in median width with number of lanes on urban freeways (see p. 431 in the latter reference) is attributable to inclusion of inside shoulders in the definition of medians of AASHTO.

17/ This conclusion is based on a review of highway design manuals from eight representative states, conducted for CBO by the Geometric Design Branch of FHWA.

18/ Ibid.

Width of Borders

Border width, like median width, may be indirectly related to design-hour volume. As design-hour volume increases and highways are built to higher standards, a wider border may be required to:

- Keep to tolerable levels the social and environmental effects of highways on activities in the neighborhoods through which they pass.

- Achieve an acceptable standard of safety with gentle side slopes and wide lateral clearances for high-speed traffic.

- Provide room for frontage roads next to highways with full access control.

- Provide room for the addition of lanes at some future date.

The relationship between design-hour volume and border width is embodied in AASHTO design standards for rural highways. Moving from "low" to "intermediate" to "high" two-lane highways, the minimum width of pavements increases from 18 to 20 to 24 feet; the minimum width of shoulders increases from 4 to 8 to 10 feet; and the minimum width of borders increases from 18 to 20 to 25 feet. 19/ Moving to "high" four-lane highways, the minimum width of borders under unrestricted conditions increases to 50 feet. Many states have comparable design standards. 20/

Relationship between Design-Hour Volume and Highway Cross Sections

It has been demonstrated in the foregoing sections that design-hour volume in passenger-car equivalents is, either directly or indirectly, related to the width of each element in the cross section of the right-of-way. The nature of the relationship between the two must be defined, however, before costs of rights-of-way can be allocated across classes of vehicles.

One possibility is to assume that the width of cross-sectional elements is simply proportional to design-hour volume in passenger-car equivalents. This assumption would greatly simplify the allocation of

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19/ AASHO, Policy on Geometric Design of Rural Highways, p. 21.

20/ Ibid., p. 22.

highway costs since the costs of the acquisition of rights-of-way and roadside development could be assigned to classes of vehicles in proportion to their design-hour volumes in passenger-car equivalents on the highway system in question. One drawback to this approach is that design-hour volumes come to dominate geometric design only at higher volumes of traffic. The decision to build a road in the first place rests on the expectation that the average daily traffic that it will bear will be sufficient to justify proposed expenditures, as was pointed out near the beginning of this appendix. The composition and peaking characteristics of traffic have little effect on these decisions. And if roads are to be built at all, they must be built with some minimum widths for pavements, shoulders, and borders. So long as traffic volumes are well below the capacity of roads of minimum width, other characteristics of traffic have little effect on these decisions. It is for this reason that, until average daily traffic exceeds 100-200 vehicles an hour, AASHTO standards of pavement and shoulder width vary with average daily traffic rather than with design-hour volume. 21/

In sum, the right-of-way needed for a road of minimum width is independent of the composition and peak volume of traffic. This is the common cost portion. The remainder of the costs of rights-of-way are occasioned jointly by vehicle classes which, by virtue of their peaking characteristics or their need for extra capacity, require a wider right-of-way in order to maintain the desired levels of service at design-hour volumes.

The common portion of the costs of rights-of-way need not, in every instance, correspond to a minimum width of right-of-way. Some multilane urban freeways would require more than the minimum width to meet level-of-service standards at hours when the volume of traffic is much lower but its composition is very different from that of the design hour. Such a situation may exist if, for example, a highway carries a greater number of trucks in off-peak hours than in the design hour. Although such highways should, perhaps, receive special treatment in highway cost allocation, they do seem to be exceptional in this respect.

In particular, nearly all rural highways could make do with minimum widths of right-of-way were it not for the volume of automobile traffic at peak periods and the extra use of capacity made by truck traffic. AASHTO notes that the design-hour volume on main rural highways is about 15 percent of average daily traffic, that trucks on main rural highways constitute about 8 percent of peak-hour traffic, and that one truck in rolling terrain--the dominant type of rural terrain--is equivalent to about five

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21/ Ibid., p. 261.

passenger cars. 22/ Thus, design-hour volumes in passenger-car equivalents on such highways are 4.75 times average hourly volumes. 23/

The 94.6 percent of the mileage of rural highways in the United States that has two lanes and the 5.4 percent of the mileage of rural highways that has four could almost certainly make do with the minimum right-of-way width if the highways were designed to accommodate average hourly volumes rather than design-hour volumes in passenger-car equivalents. 24/ The remaining 0.1 percent of the mileage of rural highways that has six or more lanes might require additional right-of-way width to accommodate average hourly volumes, but it is unlikely that this would have any effect on the allocation of costs of rights-of-way since the composition of traffic on main rural highways does not vary significantly between the hours of 8 A.M. and 6 P.M., hours when the volume of traffic is above average. Only in the early morning hours, when the total volume of traffic is very low, does the percentage of truck traffic differ markedly from that in the design hour. 25/

Methodological Issues

There are six principal methodological issues in the development of guidelines for the allocation of right-of-way costs.

Issue: *Should cross-sectional elements be combined or dealt with individually when right-of-way costs are allocated across classes of vehicles?*

Considering the width of the right-of-way as a whole has the advantage of simplicity, but it is necessarily less precise than analyzing each element individually, because widths of entire rights-of-way are not specified in design standards with as much precision as are widths of cross-

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22/ Ibid., pp. 56, 61, and 266.

23/ The figure 4.75 is arrived at as follows: 24 hours x 0.15 x (0.92 + 5 x 0.08).

24/ FHWA, National Highway Inventory and Performance Summary, Table I-1.

25/ This conclusion is based on a computer printout of hourly traffic volumes by vehicle class and highway system, made available to CBO by the Highway Statistics Division of FHWA.

sectional elements such as pavements and shoulders. The data now available from the FHWA are similarly less precise for total right-of-way widths. It will be necessary, in any event, to deal with cross-sectional elements individually when it comes time to allocate the costs of pavement, shoulders, and roadside development across classes of vehicles.

Issue: *Should the "common" portion of right-of-way width be estimated from design standards or from data concerning design and function of highways?*

Again, the former approach has the advantage of simplicity, the latter of precision. The common portion of the width of the pavement could be set at, say, 22 feet, since it is at 22 feet that design-hour volume replaces average daily traffic as the principal determinant of pavement width in AASHTO design standards. Alternatively, the common portion of pavement width could be established by relating width of pavement to volume and composition of traffic for a sample of existing highways. Only if design standards were followed to the letter--and of course they are not--would the two approaches necessarily yield comparable results.

Issue: *What allocation criteria should be used to allocate right-of-way costs?*

After dividing width of the right-of-way into two components, one commonly occasioned and one jointly occasioned, various criteria could be used to allocate right-of-way costs. The common portion could be allocated across classes of vehicles on the basis of, say, vehicle-miles traveled, axle-miles traveled, or number of registered vehicles. The first of these appears to be the soundest criterion for allocation of the commonly occasioned portion, since the decision to build a road in the first place and the width of the road at low volumes of traffic are determined by average daily volume of traffic. The remainder of the costs of the right-of-way could be allocated across classes of vehicles on the basis of highest hourly volumes, peak-period volumes, or daytime volumes, in passenger-car equivalents. Using peak-period volume has the advantage of washing out variations in the composition of traffic that occur during peak hours of nearly constant total volume and at the same time distinguishes between peak hours and midday, when the total volume of traffic falls off sharply in urban areas.

Issue: *How should highways be classified for the purpose of right-of-way cost allocation?*

The simplest way to classify highways for the purpose of the allocation of right-of-way costs is by system. The most complex is by system, type of terrain, and urban or rural location. The latter, while requiring more input data and computation, would account for significant differences in the volume and composition of traffic, differences in cross-sectional design, and differences between flat and mountainous areas and between urban and rural areas expressed in passenger-car equivalents.

Issue: *How should incidental costs of right-of-way acquisition, such as legal fees and assistance with relocation, and of roadside development, such as clearing costs and utility adjustment costs, be allocated across classes of vehicles?*

The easiest way to allocate incidental costs is in the same proportions as land costs are allocated, assuming that such costs are proportional to overall right-of-way width, an assumption that is approximate at best. Utility adjustment costs are probably proportional to total width when utility lines cut across highways but may not be when utility lines run parallel to highways.

Issue: *What additional information is required to allocate right-of-way costs across classes of vehicles?*

The U.S. Department of Transportation already has considerable information on cross-sectional widths, hour-by-hour patterns of traffic, and passenger-car equivalents. 26/ These data can be used to crosscheck whether the minimum road suggested in design standards is in fact the minimum road that is constructed. Data on the width of right-of-way for new construction could be gathered as new requisitions for new construction are filed with the FHWA. Passenger-car equivalents are now available only for broad groups of vehicles, and additional research will be needed to develop this measure for a more refined classification of vehicles.

26/ That information is available, respectively, in the 1976 National Highway Inventory and Performance Study data file, the Annual Truck Weight and Vehicle Classification data file, and various documents prepared for the Federal Highway Administration under Contract No. DOT-FH-11-9336, "Freeway Capacity Analysis Procedures."

APPENDIX G. BRIDGE COST ALLOCATION

New bridges are one of the largest single components of federal highway expenditures and the allocation of their costs will have an important influence on the results of the new highway cost-allocation study. Bridges are more complex to design and build than almost any other element of the highway system.

Bridges have two principal components, substructure and superstructure, each of which is designed on the basis of highly complex relationships. The substructure supports the superstructure and the vehicles that use the bridge and carries the bridge over whatever obstacle is beneath it. The superstructure carries the highway traffic and transmits the resulting loads to the substructure. The superstructure may consist of one or more spans, the number of substructure supports increasing with the number of spans.

Many factors enter into the design of bridges. Some of these are site-specific and are thus independent of the number and types of vehicles that are expected to use the bridge. Site-specific factors are more likely to influence the costs of substructures than the cost of superstructures. Unless stated otherwise, the construction material and the number and lengths of spans are considered as given in the discussion that follows. Other site-specific problems that may affect costs, such as potential water scour, are excluded from consideration.

Three essential elements that affect the design—and thus the costs—of bridges are the dead load, the stress produced by the mass of the bridge structure itself; the live load, the stress produced by the weight of the vehicles on the bridge; and the impact load, the stress resulting from the movement of vehicles on the bridge. There are other types of loads that must be considered under certain conditions and with respect to certain parts of the bridge structure—wind stress, for example—but, with a few exceptions, they are of relatively little concern in bridge design.

The stress on the bridge is proportional to the total load—the dead load plus the live load plus the impact load. Typically, the impact load is by far the smallest of these and for bridges of very long span can probably be ignored, since the live load is at the maximum when traffic is not moving and there is consequently no impact load. 1/ For a given length of span, the design live load depends on the weight of the design vehicle, or the heaviest vehicle that the bridge is meant to carry under routine circumstances. For very short bridges with spans shorter than the length of the design vehicle, the critical factor is the combined weight of the heaviest axles that could be on the bridge at any one time.

The dead load is determined by three factors: the construction materials used, the length of the span, and the live load. The dead load and the live load interact significantly. As the weight of the design vehicle for the bridge increases, so does the maximum live load that the bridge must be designed to support. To support this additional load, the bridge must be strengthened, thereby increasing the dead load. The dead load also increases dramatically as the length of the span increases. Doubling the length of the span requires substantially more than twice the construction material and thus more than doubles the dead load. For example, the dead load of a precast concrete I-beam bridge increases from 378 kips at a span length of 40 feet to 943 kips at 80 feet and 1,508 kips at 120 feet. 2/

Figure G-1 shows the dead load, the live load, and the impact load as percentages of the total load of a steel-beam bridge as the span is increased from 40 feet to 120 feet. In this example, the dead-load share of total load almost doubles, increasing from 29 percent to 54 percent. The live-load share decreases from 55 percent to 38 percent, despite the fact that it increases in absolute magnitude. Extrapolation of the relationship shown in this figure means that for bridges of very long span the live load is almost negligible. Conversely, for bridges of short span, the effect of live load dominates.

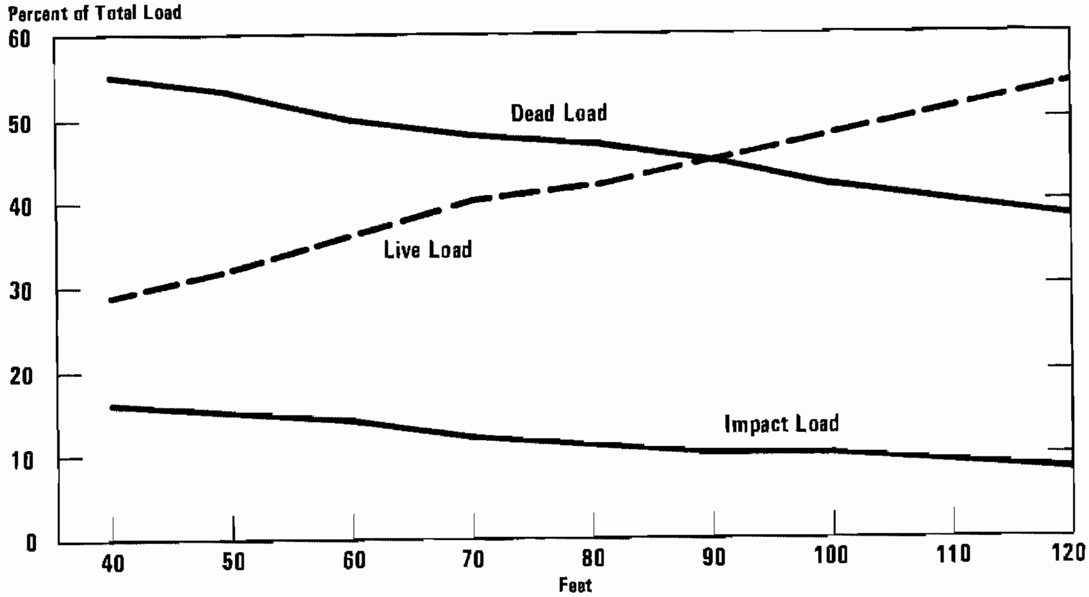
From the point of view of cost allocation, a fact that must be noted is that the live load depends directly on the gross weight of the vehicles. A significant portion of the cost of a bridge thus also depends on gross vehicle weight. Gross vehicle weight has, in fact, been used in earlier federal cost-allocation studies as the principal factor in allocation of the jointly occasioned costs of bridges.

1/ P. G. Buckland and others, "Traffic Loading of Long Span Bridges," in Transportation Research Record 665, Transportation Research Board, 1978.

2/ Figures apply to a bridge designed for an HS20 truck (72,000 lb. gross weight) with a 44-foot roadway. FHWA, "Standard Plans For Highway Bridges," vol. 1, Concrete Superstructures, Sheet No. 602, January 1976.

Figure G-1.

Share of Total Load for Steel-Beam, Single-Span Bridge



SOURCE: FHWA, Bridge Division.

The possibility of cracks attributable to metal fatigue is an important consideration in the design of steel bridges. Metal fatigue is caused by a fluctuation in stress which results from the passage of heavy loads. As the fluctuation or range of stress increases, the number of cycles required to produce cracks in metal decreases. The effect is cumulative and in time will produce cracks in the metal, particularly at welds. Eventually the bridge will fail, unless the weight limit for vehicles using the bridge is reduced or costly repairs are undertaken.

The fatigue life of a steel bridge, measured in the number of stress cycles to which it is subjected, is inversely related to the third power of the stress range. Stress range, in turn, is a linear function of gross vehicle weight. In recent years, however, the potential danger of metal fatigue has been widely recognized, and bridges are usually designed conservatively to avoid it. Use of the standards set by the American Association of State Highway and Transportation Officials means that "the minimum life expectancy under the worst possible combination of loading cycles . . . is between

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60 and 70 years if all stress cycles are assumed to cause damage." 3/This is a conservative statement, since many stress cycles do not cause damage. Some additional costs are involved in meeting these standards, however, and these costs are attributable to heavy vehicles (almost exclusively those of more than 20,000 pounds gross vehicle weight). 4/

Some bridge costs can also be traced to volume of traffic, in that narrower, somewhat simpler bridges could be used safely on roads that carry low volumes of traffic. 5/ It is unlikely, however, that very many bridges on the federal-aid system would be included in this category. In addition, the costs of added width are a small fraction of total federal expenditures for bridges.

Earlier Method of Bridge Cost Allocation

Five cost increments for allocation of the costs of bridges were developed in the 1965 federal cost-allocation study. These increments were based on theoretical engineering studies of bridges designed for vehicles of various weights. The five design vehicles considered were the H5 (10,000-pound single-unit truck), H10 (20,000-pound single-unit truck), H15 (30,000-pound single-unit truck), H20 (40,000-pound single-unit truck), and HS20 (72,000-pound combination truck). 6/ Studies of hypothetical bridges were needed because no bridges designed for the H5 and very few for the H10 were reported by the states. There was some disagreement as to the appropriate design vehicle for the basic or first increment. Suggestions by state highway departments ranged from H1.56 (3,020-pound vehicle) to H10 (20,000-pound vehicle), with a median of H3.8 (7,600-pound vehicle). The H5 was selected because it corresponded to the 10,000-pound weight limit that was being used elsewhere in the 1965 study for the first increment in allocation of the costs of lane and shoulder width.

3/ J. W. Fisher, "Bridge Fatigue Guide" (American Institute of Steel Construction, 1977), p. 16.

4/ Ibid., p. 15.

5/ R. Tokerud, "Economic Structures for Low-Volume Roads," Transportation Research Record 665, Transportation Research Board 1978.

6/ These alphanumeric designations refer to standard design vehicles specified by the American Association of State Highway and Transportation Officials.

It was recognized that the costs of bridges vary significantly with the type of bridge and length of span. Six combinations of type of bridge and length of span were therefore selected for the design studies and subsequent cost analysis of the designs. The six types of bridges considered were:

- reinforced concrete slab with 25-foot span,
- reinforced concrete I-beam with 50-foot span,
- prestressed concrete beam with 90-foot span,
- steel I-beam with 70-foot span,
- steel I-beam with 60-80-60-foot continuous span, and
- welded steel-plate girder with 50-foot span.

These six types of bridges were selected because they represented 87.3 percent of the bridges built by the states in 1956. It is unclear how closely these span lengths corresponded to the span lengths of the bridges actually being built, although they are stated to be somewhat longer, on the average, than the spans of the bridges actually built in 1956.

In all, 60 hypothetical designs were used in the 1965 study: separate substructure and superstructure increments for six combinations of type of bridge, and length of span with five vehicle-weight increments for each. The substructure and superstructure increments were combined in different proportions for grade separations, since 64 percent of the costs of grade separations reported by the states were for superstructures, and for other types of bridges, since 55.7 percent of the costs of other types were for superstructures.

Common costs, which may be considered to be the same as the first cost increment, accounted for between 72.6 percent and 81.3 percent of the costs of a bridge built to carry the HS20 design vehicle.

Comments on the Incremental Cost Method

The five-step incremental cost method used in the past in cost-allocation studies can be criticized on several grounds. The most significant drawback is one that is common to the incremental approach in general--inequitable assignment of economies of scale among classes of vehicles.

Most construction projects exhibit economies of scale, so that the unit costs of increasing the capacity of a facility decrease as the size of the facility increases. For example, in the 1965 federal cost-allocation study, it was found that a 25-foot, reinforced concrete slab bridge could be built to carry 10,000-pound vehicles (H5) for 81.3 percent of the costs of a bridge that would carry 72,000-pound vehicles (HS20). For only an additional 5.5 percent of the cost of an HS20 bridge, the design capacity of the H5 bridge could be doubled to H10. An additional 50 percent increase in capacity (to H15) could be provided for 4.1 percent of the costs of an HS20 bridge.

Figure G-2 is a plot of the average cost of a bridge in 1965 per 10,000 pounds of design capacity as the weight of the design vehicle is increased. If there were no economies of scale in bridge construction, such a plot would be a horizontal line; if there were actual diseconomies of scale, it would become an upward-sloping curve at some point.

The existence of economies of scale is not surprising given the large amount of material required merely to support the dead load of a bridge. Doubling the weight of the design vehicle results in a much smaller increase in the total load on the bridge and thus a much smaller increase in cost.

The way in which economies of scale are distributed is crucial in the allocation of bridge costs, as it is in the allocation of the costs of other elements of the highway, such as pavement. As the design capacity of a bridge is increased, the incremental costs assigned to vehicles that require the increased capacity will, in general, be less than the incremental costs of earlier increases in capacity.

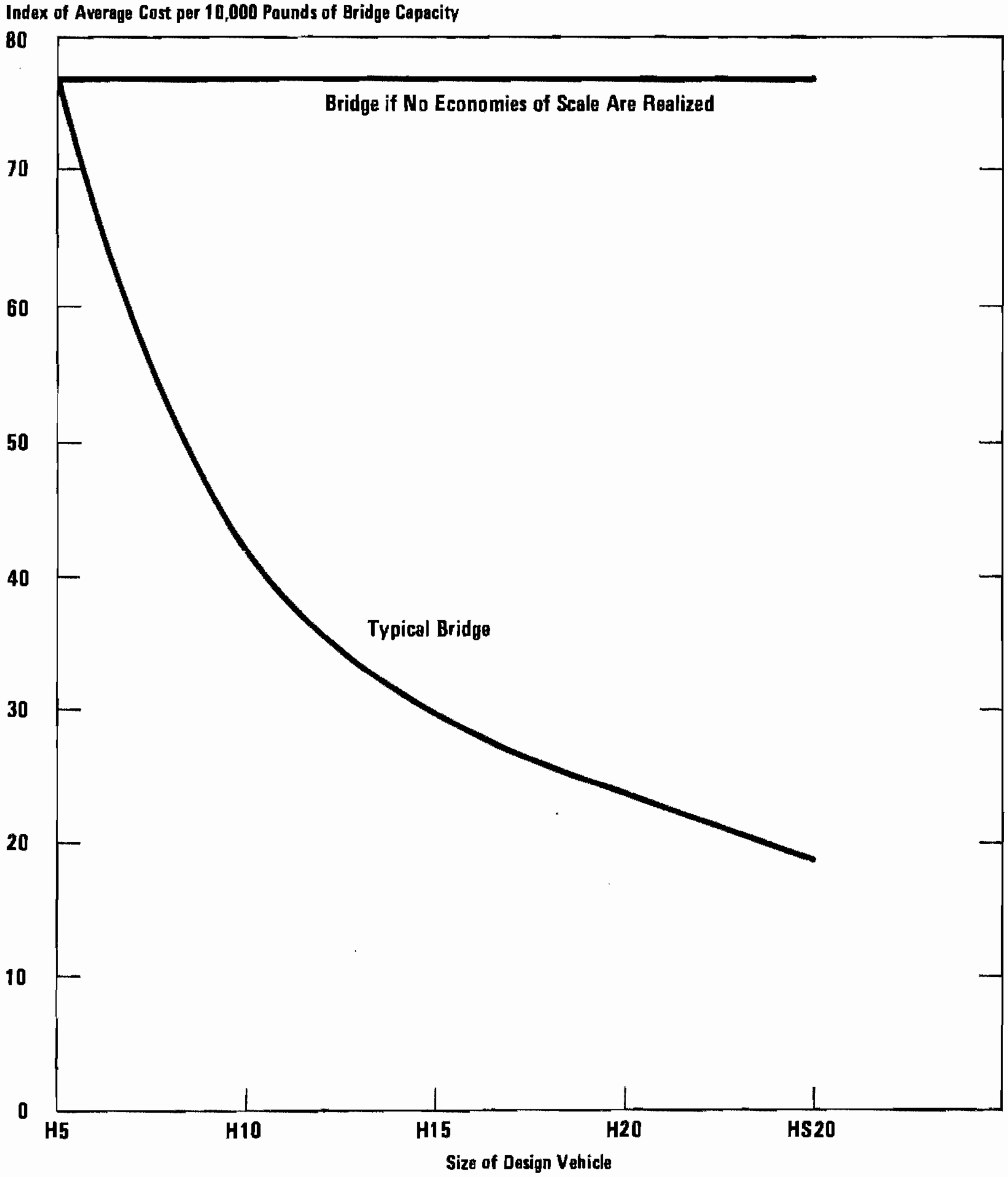
Using the incremental method as it was used in cost-allocation studies in the past, the later in the process that a particular class of vehicles is considered, the smaller is the share of costs allocated to it. That is, the classes of vehicles to which costs are allocated late in the process receive a disproportionate share of the benefits of economies of scale. It might be more equitable to share the benefits of economies of scale more evenly among all classes of vehicles.

The earlier incremental cost methodology can be criticized on several other points as well, but most of these have to do with the way the increments were developed rather than with broad principles. For example, the bridge designs for lighter vehicles appear to have been made by changing the designs of bridges originally designed for heavier vehicles, rather than being innovative designs for bridges meant to carry only light vehicles. Evidence that the costs of bridges designed for lighter vehicles (H10 and H15) may have been overestimated in the design studies can be seen in the lower costs reported by the few states that actually built bridges to these design standards.

Figure G-2.

Example of Economies of Scale in Bridge Construction

Based on 1965 Cost Increments



SOURCE: CBO, Calculated from FHWA 1965 Cost Allocation Study.

Possible Improvements in Allocation Methodology

Two approaches to allocating bridge costs are explored here. The first represents a slight modification in the earlier methodology, while the second is a somewhat more radical departure but is easier to apply.

Two-Step Incremental Cost Method. Unlike most other parts of the highway, there is some logic to allocating bridge costs on the basis of full-scale design studies rather than on a more detailed analysis of individual components of bridges. First, it is difficult to isolate the cost of many components from the costs of the overall structure. Second, bridge designs are quite varied, and it would be difficult to specify a typical design process.

As noted in the preceding section, the chief drawback of the five-step incremental cost approach used in the past is probably the assignment of most of the benefits of economies of scale to a few classes of vehicles. One way around this problem is to divide the costs of a bridge into two components—those incurred in building the basic parts of the bridge required by light weight vehicles and those that accrue as the bridge is designed to carry heavier and heavier classes of vehicles. The first category represents the common costs of the bridge and includes whatever economies of scale may be realized in constructing a basic bridge independent of the nature and volume of traffic. 7/ The second category embodies the economies of scale that are jointly occasioned by all classes of vehicles.

It is proposed here that a two-step incremental method would solve the problem of economies of scale and would be easier to implement than the five-step incremental method. The first increment would correspond to the first increment in earlier studies. In the 1965 study, the first increment, averaged over all six bridge designs considered in the study, accounted for 76.8 percent of the costs of a bridge. These are common costs and they would be allocated along with the common costs of other parts of the highway.

The second increment under this proposal would represent the added costs of building a bridge for mixed traffic. The costs of the completed bridge would vary according to the design vehicle that is typical of the vehicles using the road system. For example, all new Interstate bridges and most primary-system bridges are designed to be able to carry HS20 vehicles (72,000-pound combination trucks), while most other federal-aid bridges are designed to carry H20 vehicles. The difference between the costs of the

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7/ The definition of the basic bridge is an important issue that will be discussed later in this appendix.

first increment and the costs of the second increment represents the jointly occasioned costs. Since gross vehicle weight is the principal vehicle characteristic used in bridge design, it makes sense to allocate these jointly occasioned costs in proportion to gross vehicle weight times vehicle-miles traveled or ton-miles. The formula used for allocation of each increment in earlier studies was similar.

If such a two-step incremental procedure is selected, there are a number of important issues still to be resolved. These include the definition of the first increment (common costs), the selection of the number and types of bridge designs to be considered, and the decision whether or not certain details of bridge construction should be allocated separately; these details include bridge decks, bridge railings, the added height required to allow high-bodied vehicles to pass under grade separations, and the additional costs attributable to metal fatigue. Alternative ways of handling each of these are discussed at the end of this appendix.

Dead-Load Ratio Method. A simpler method of separating the common cost portion from the jointly occasioned portion of bridge costs requires examination of the ratio of dead load to total load. Since the dead load represents the weight of the bridge structure itself, it can be considered common to all traffic. Live load and impact load are results of the expected vehicular use of the bridge. Thus common costs could be approximated by multiplying total costs by the ratio of dead load to total load. The remaining costs of the bridge—the product of the total costs of the bridge and the ratio of live load plus impact load to total load--would be allocated as jointly occasioned costs.

As before, common costs would be allocated with the common portion of the costs of other elements of a highway and jointly occasioned costs would be allocated according to ton-miles. An important alternative to be considered here is the allocation of the jointly occasioned portion of steel superstructures--the element in which metal fatigue is a major design consideration—according to gross vehicle weight raised to the third power. As discussed earlier, there is a third-power relationship between vehicle weight and metal fatigue. Because of the need to isolate the costs of the superstructure, this method would require separate determination of the common and jointly occasioned portions of the substructure and the superstructure. This seems a minor complication when the full-scale design studies that would be required by the two-step incremental method described above are considered. Steel bridges represent only 37 percent of the bridges built since 1970 on the federal-aid system, so the majority of jointly occasioned costs would still be allocated according to gross vehicle weight.

A key factor in determining the ratio of dead load to total load is the length of the span. As shown in Figure G-1, as length of span increases, dead load becomes a large proportion of the total load. While Figure G-1 represents only one type of construction material (steel beam), a similar plot of the dead-load ratio averaged across all types of bridges could be prepared—although separate plots might be needed for simple-span bridges and for continuous-span bridges. Such plots would make the dead-load-ratio method even easier to apply, since only information on the span lengths of bridges would be needed.

There remains a serious question as to whether the dead load used to estimate common costs should be the dead load of the bridge actually built—typically, one built for HS20 vehicles—or the dead load of a basic bridge—in earlier studies, one built for H5 vehicles.

Methodological Choices

Two-Step Incremental Cost Method versus Dead-Load-Ratio Method. There are significant differences between the two alternative methods of allocating the costs of bridges discussed in this appendix. While the two-step incremental cost method is more complex and its application would require more effort, particularly on the part of experts in bridge design, the result is likely to be a more accurate and therefore more equitable allocation of bridge costs than the dead-load-ratio method. To the extent that the designs for bridges meant to carry the HS20 can use standard bridge plans, moreover, the task will be easier. While it represents only a modest change from the methods used in the past, because of the way economies of scale are handled it should bring about a real improvement in the quality of the result. Also, because of its close similarity to methods used in the past, it may be more readily accepted by the transportation community. On the other hand, the dead-load-ratio method is much easier to apply. While its use is likely to result in a somewhat smaller share of the costs that are considered to be common than those that result from the use of the two-step incremental cost method, the differences may not be dramatic.

Definition of the First Increment (or Basic Bridge). The purpose of selecting a type of bridge for the first increment is to determine the portion of bridge costs that should be considered common costs. This is quite different from specifying the minimum-size bridge that could or should be built in the federally aided system. In theory, it might be argued that a bridge designed to carry no live load would be appropriate. Such a bridge would only have to support its own dead load and withstand the effects of the environment. This approach presents some problems, however. Such a bridge is hypothetical and how it should be designed is not obvious. In theory, the deck could be extremely thin, since no traffic would ever use it.

Thus, as a practical matter, the first increment should probably be based on a bridge designed to carry some live load, even if the load is quite small. Most earlier cost-allocation studies have followed this approach and used a bridge designed for 10,000-pound vehicles (H5) as the prototype for the first cost increment. As part of the 1965 cost-allocation study, state highway departments, on the average, suggested that a bridge designed for the H3.8 be used. As a practical matter, a bridge designed to carry 5,000-10,000-pound vehicles (H2.5 to H5) is probably the minimum-size bridge that is conceptually valid. A design for such a bridge would result in an estimate of common costs that incorrectly includes only a small portion of the jointly occasioned costs.

An alternative approach to specifying the first increment would be to use the bridge of the minimum size that is now being built. In the federal-aid system, this would be a bridge designed to carry an H15 vehicle. A few bridges are built for the H10—only 150 on the federal-aid system since 1970. Some bridges are still built for the H10 on off-system roads and on National Park Service roads, but their number is small.

It is also argued that bridges designed to carry an H15 vehicle would be built even on roads serving automobiles primarily, inasmuch as certain public service vehicles such as school buses, garbage trucks, and road-maintenance trucks would have to use them in any case. Depending upon the exact definition of a basic bridge, it could be argued that the minimum bridge—and therefore the basic bridge—is one designed to carry an H15 vehicle.

Use of the H15 design would result in the allocation of a significantly larger portion of costs as common costs. In the 1965 federal cost-allocation study, the cost increment between the bridge designed to carry the H5 and the bridge designed for the H15 accounted for more than 50 percent of the total difference in cost between the bridges designed for the H5 and the HS20. 8/ If similar results are applicable today, as seems likely, this would

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8/ The corresponding percentage for the H10 is more than 25 percent. These figures are based on the weighted average cost increments of the six bridge types considered in 1965. In terms of the percentage of the cost of a bridge designed for the HS20, these average cost increments are:

H5:	76.8 percent
H10:	83.1 percent
H15:	89.0 percent
H20:	94.6 percent
HS20:	100.0 percent

mean that more than 50 percent of the costs that were formerly considered to be occasioned jointly would be allocated as common costs.

An important advantage to be gained from use of the designs of actual bridges would be some simplification of the task of estimating costs, since data could be obtained for the costs of bridges actually built. This should also make possible more realistic cost estimates.

Selection of Bridge Types. If the two-step incremental cost method is used, a decision must be made as to the types of bridges and lengths of span that are to be selected for the detailed design studies required for development of the cost increments. In the 1965 federal study, six types, which accounted for 87.3 percent of reported bridges, were selected. Table G-1 shows the structural types of bridges built on the federal-aid system since 1970. The 10 most common types of structure account for 80.9 percent of all bridges. It may be possible to reduce this number by combining similar types of bridges. In any case, additional analysis is needed with respect to selection of the appropriate types of structures.

For each type of bridge, one or more typical lengths of span need to be specified. Since the proportion of common costs varies considerably with length of span, this specification could influence results significantly. For several types of bridge, it may be desirable to select more than one length of span in order to reflect the variation in costs. In particular, at least one bridge of medium-to-long span should be considered. The longest span included in the 1965 study was 90 feet.

Allocation of Costs of Selected Components of Bridge Construction.

It may be possible to improve the allocation of costs by treating some parts of bridges independent of the main structure. This would mean adjusting the costs to be allocated according to whatever primary method is selected. Several suggestions for independent allocations are made and considered briefly here. Additional analysis is needed with respect to each.

Bridge Decks. In cold climates, highway salt is applied to aid in removing snow and ice. This salt is the principal cause of corrosion of bridge decks and thus of the need to replace decks. If, given the same ice and snow conditions, the application of highway salt were related to volume of traffic--or some other vehicle-related variable--then it might be possible to allocate the deck costs for colder parts of the country in a more equitable manner than if they are considered part of the bridge as a whole.

Metal Fatigue. The additional costs required to avoid bridge failure attributable to cracks caused by fatigue can be handled in at least two ways:

As part of the dead-load-ratio method, the costs of steel superstructures could be allocated in proportion to the gross vehicle weight raised to the third power, since this is the empirical relationship between fatigue damage and vehicle weight. Separate design studies could be undertaken to identify specific features—for example, thicker beams or designs in which welds that are particularly given to fatigue are avoided--that might be used to avoid fatigue problems, and these costs could be allocated in proportion to gross vehicle weight to the third power. As is true of other specific details of bridge construction, there is always a third possibility, that of allocating costs in combination with the other costs of the bridge.

Grade Separations. Bridges over other highways must be high enough to allow high-bodied vehicles to pass underneath. While the amount of extra height that must be added to the substructure is a matter of judgment, trucks and other high-bodied vehicles—buses, recreational vehicles, and the like—clearly require a larger clearance than do automobiles. In a 1977 cost-allocation study by the Urban Institute automobiles were assumed to require a clearance of only 10 feet, while trucks needed 14 feet. 9/ More analysis will be required before specific values can be selected.

Conclusion

The foregoing discussion introduces several ways in which allocation of the costs of bridges might be accomplished. Each of these avoids the uneven allocation of economies of scale implicit in earlier studies. The cost-allocation study should include further investigation of the question of which technique is the most equitable and the most workable.

9/ K. Bhatt and others, An Analysis of Road Expenditures and Payments by Vehicle Class (The Urban Institute, 1977).

TABLE G-1. STRUCTURAL TYPES OF ALL HIGHWAY BRIDGES ON THE FEDERAL-AID SYSTEM BUILT AFTER 1970

Type of Structure	Number	Percent
Concrete		
Slab	1,119	5.7
Stringer/multibeam or girder	760	3.9
Tee Beam	437	2.2
Other	470	2.4
Subtotal	2,786	14.2
Concrete Continuous		
Slab	1,288	6.5
Boxbeam or girder—multiple	467	2.4
Tee beam	310	1.6
Other	265	1.3
Subtotal	2,330	11.8
Steel		
Stringer/multibeam or girder	3,181	16.2
Girder and floorbeam systems	263	1.3
Other	285	1.4
Subtotal	3,729	18.9
Steel Continuous		
Stringer/multibeam or girder	3,283	16.7
Other	319	1.6
Subtotal	3,602	18.3

(CONTINUED)

TABLE G-1. (CONTINUED)

Type of Structure	Number	Percent
Prestressed Concrete		
Stringer/multibeam or girder	3,670	18.7
Boxbeam or girder—multiple	991	5.0
Slab	201	1.0
Other	409	2.1
Subtotal	5,271	26.8
Prestressed Concrete Continuous		
Stringer/multibeam or girder	710	3.6
Boxbeam or girder—multiple	387	2.0
Other	210	1.1
Subtotal	1,307	6.6
Timber	209	1.1
Other	439	2.2
TOTAL	19,673	100.0

NOTE: Detail may not add to totals because of rounding.

SOURCE: From data provided by FHWA from National Bridge Inventory, September 1978.

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APPENDIX H. ALLOCATION OF GRADING COSTS

In earlier highway cost-allocation studies, nearly all grading costs have been assigned to the category of common costs--91 percent, for example, in the 1965 federal highway cost-allocation study. 1/ Yet there is ample evidence that grading costs are occasioned in a number of ways hitherto overlooked. It is important to account for them in cost allocation since some 15 to 20 percent of total federal highway expenditures are for grading. 2/ Grading typically adds more to the total costs of highways than does paving. 3/

The ways in which grading costs are occasioned are reviewed in the following sections. The discussion is limited to grading of roadway; grading of interchanges is dealt with in Appendix I.

Basic Grading Operations

There are two basic grading operations: excavation, which includes cutting or removing earth from the roadbed and filling or adding earth to the roadbed, and compaction or compressing earth in the roadbed to achieve greater stability. In earlier highway cost-allocation studies, excavation has been the focus of attention, yet compaction accounts for one fifth or more

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1/ Bureau of Public Roads, Supplementary Report of the Highway Cost Allocation Study, H. Doc. 124, 89 Cong. 1 sess. (1965), p. 106.

2/ Grading and drainage together accounted for 27 percent of total costs for federal-aid highways in 1964 and 25 percent over the period from 1956 through 1975. Drainage appears to account for 5 to 10 percent of total costs, leaving about 15 to 20 percent for grading. Bureau of Public Roads, Supplementary Report, p. 323; K. Bhatt and others, An Analysis of Road Expenditures and Payments by Vehicle Class (1956-1975). (The Urban Institute, 1977), p. 45; California Department of Transportation, Heavy Vehicle Cost to State Highways in California (1976), p. 10; Bolt, Beranek, and Newman, Highway Noise, Generation and Control, NCHRP Report 173 (1976), Table C-6.

3/ Cost estimates prepared by the Federal-Aid Division of FHWA.

of total grading costs and, as described below, is fundamentally different from excavation in the way costs are occasioned. 4/ Compaction costs are related to the weight and number of wheel load applications. Subgrade soils are compacted, in effect, to keep the structural requirements of the pavement to a minimum as wheel loads increase. Excavation costs are related to peak-traffic volume and climbing ability. Roads are widened and grades are leveled to maintain acceptable levels of service as traffic at peak periods increases and vehicles with limited climbing ability are added to the traffic stream.

Compaction

In the early days of highway building, it was standard practice to let subgrade soils settle naturally for about a year before paving was begun. 5/ This stabilized soils to some extent, but not enough to prevent some shifting of subgrade soil under wheel loads once highways were open to traffic. It therefore became standard practice in later years to "compact" subgrade soils before paving--that is, to apply thin layers of moistened earth to the roadbed and run heavy rolling equipment over successive layers to achieve the desired density of material. That desired density, and the compactive effort required to obtain it, have gradually increased over the years as the loads borne by highways have increased in weight and number. 6/

4/ There are no current figures on the comparative cost of compaction. The only available figures come from a sample of highway projects undertaken in the early 1950s in Colorado. There compaction accounted for just over 20 percent of total grading costs. In less mountainous states, the percentage would presumably be higher. W. Walsh, "Compaction Methods for Highway Embankments and Subgrades," American Association of State Highway Officials Committee Proceedings, 1953, pp. 39-45.

5/ This brief history of subgrade engineering practices draws on an account in C. Oglesby, Highway Engineering (John Wiley & Sons, 1975), pp. 518-23.

6/ Walsh, "Compaction Methods for Highway Embankments and Subgrades", p. 44.

All states now compact subgrade to rather high standards of density. 7/ All but 10 states specify a minimum depth of 6 to 18 inches of subgrade compaction. Density standards are generally higher for subgrades than for embankments and are often higher in the upper 1 to 6 feet of embankments than in the lower strata. States with differential density standards have them, to quote one survey of state highway compaction practices, because "the stresses produced by wheel loads are greater in the upper strata of the embankments." 8/

Compaction of soils in the lower regions of embankments is independent of the volume and composition of traffic. It is done to avoid the natural settlement of soils. Associated grading costs fall into the category of common costs. In contrast, compaction of soils in the subgrade immediately below pavements is dependent, if indirectly, upon the volume and composition of traffic. It is done primarily to reduce the structural requirements of the pavement and should thus be incorporated into the allocation of pavement costs. Compaction standards developed by the Army Corps of Engineers in the late 1950s related the depth and degree of compaction in subgrades to the weight of wheel loads using pavements. 9/ It has since become common to compact subgrades of most highways to the same high standards of density, with little regard for the volume and composition of traffic. Yet associated grading costs are still occasioned by heavy loads, since the subgrade has effectively become part of the pavement system, designed to resist heavy wheel loads.

Allocating Costs of Compaction

In order to allocate compaction costs across classes of vehicles, it will first be necessary to separate the costs of compaction from those of excavation, a relatively simple task since a number of states separate the

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7/ The following description of state highway compaction practices is based on a survey by H. Wahls, "Current Specifications, Field Practices and Problems in Compaction for Highway Purposes," Highway Research Record 177 (1967), pp. 98-111.

8/ Ibid.

9/ C. Foster and R. Ahlvin, "Compaction Requirements for Flexible Pavements," Highway Research Board Bulletin 298 (1961), pp. 1-20.

two in bid tabulations; and then to separate compaction costs in the upper and the lower strata of the subgrade is a second more difficult task requiring some engineering judgment. Compaction costs in the lower regions of the subgrade should be treated as common costs up to the basic width of roadways and their embankments. Beyond that width, compaction costs are occasioned by design-hour traffic and should be allocated across classes of vehicles the same way as the costs of excavation in level terrain are allocated (see below).

Compaction costs in the upper strata of subgrades should be treated as part of the total cost of the pavement. Instead of having three structural layers, pavement can be thought of as having four—surface, base, subbase, and subgrade. The same principles used to allocate the costs of other layers of the pavement apply as well to compaction costs of the subgrade (see Appendix C).

Excavation

Excavation costs could be occasioned in any of the following ways: through increases made in the width of the road surface to accommodate wide-bodied vehicles; through increases made in the width of the road surface to accommodate design-hour traffic; through increases made in the depth of the road surface to accommodate heavier vehicles; and through leveling of grades done to accommodate vehicles with limited climbing ability. While each type of cost occasioning is reviewed for its potential impact on highway cost allocation, only the widening of highways done to accommodate design-hour traffic and the leveling of grades done to accommodate vehicles with limited climbing ability are judged to be significant.

Surface Width

In federal highway cost-allocation studies, a half foot of lane width and a corresponding share of grading costs on intermediate- and high-type highways have been assigned to wide-bodied vehicles. The inherent arbitrariness of this assignment is demonstrated by other studies, in which, with no less justification, anywhere from 0 to 2 feet of lane width have been assigned to wide-bodied vehicles. 10/

The practice of assigning an increment of lane width to wide-bodied vehicles is based on intuitive arguments about the requirements of wider lanes for wider vehicles and on the fact that some parkways have lanes 10 feet wide rather than the standard 12 feet. Neither offers a particularly sound justification for the practice. The width of a vehicle is only one characteristic that might affect the lane width required to meet safety and service standards. There is evidence that passenger cars are subject to more lateral displacement in crosswinds than are trucks, are subject to more lateral displacement (swerving) when braking suddenly than are trucks, and require more lateral clearance in passing other vehicles than do trucks--reflecting, in part, the greater experience and professionalism of truck drivers generally and the lower average speed of trucks. These characteristics tend to offset the difference in the widths of passenger cars and trucks, a difference which, in any event, amounts to less than 2 feet. 11/

As for the existence of parkways with 10-foot lanes, as long ago as 1954, the minimum width for pavements on parkways with moderately high design speeds and design-hour volumes were set by the American Association of State Highway Officials (AASHO) at 24 feet, the same width as that

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10/ In the study by Bhatt and others, two feet of lane width was assigned to wide-bodied vehicles. In the New Mexico highway cost-allocation study, on the other hand, no increment of lane width was assigned to wide-bodied vehicles because "New Mexico design criteria determine the required pavement width on the basis of total traffic volume, regardless of the vehicle size or width." Roy Jorgensen Associates, State of New Mexico Highway Cost Allocation Study (New Mexico State Highway Department, 1972), p. 43.

11/ The most recent data on the dimensions of trucks and automobiles date from 1959 and 1970, respectively. There is no reason to believe, however, that the dimensions of vehicles have changed significantly since then. At that time, a vast majority of standard passenger cars were more than 6 feet wide, and a vast majority of truck combinations were less than 8 feet. M. Kent and H. Stevens, "Dimensions and Weights of Highway Trailer Combinations and Trucks, 1959," Highway Research Record 26 (1963), pp. 24-65; E. Seger and R. Brink, Trends of Vehicle Dimensions and Performance Characteristics 1960 through 1970 (Milford, Mich.: General Motors Proving Grounds, 1971).

required for highways carrying mixed traffic. 12/ It has since become standard practice to design parkways with 12-foot lanes. 13/

In federal highway cost-allocation studies, 2 feet of shoulder width and a corresponding share of the costs of grading on high-type highways have been allocated to wide-bodied vehicles. This, too, is essentially arbitrary. AASHTO recommends 10-foot shoulders on high-type facilities as a "compromise" between the 9-foot or 10-foot width that is required if passenger cars are to have adequate working space on shoulders, and the 11-foot or 12-foot width required for trucks and buses. 14/ The 10-foot standard is exceeded on only 2 percent of the mileage of the nation's highways, excluding local roads. 15/ Thus, the increment of cost potentially allocable to wide-bodied vehicles is only one-sixth of the costs of shoulders--2 feet of 12-foot shoulders—on 2 percent of the nation's highways, and even this increment cannot be unequivocally allocated to wide-bodied vehicles, since wider shoulders serve a variety of functions. They provide space for maintenance equipment, for slower-moving traffic so that passing can be

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12/ American Association of State Highway Officials, A Policy on Geometric Design of Rural Highways 1954, p. 223. AASHO changed its name in 1973 to the American Association of State Highway and Transportation Officials (AASHTO).

13/ While the Merritt Parkway in Connecticut, the Garden State Parkway in New Jersey, and a few other older parkways were designed with 12-foot lanes, they were the exceptions. A survey of parkways proposed or constructed in more recent years indicates, moreover, that 12-foot lanes have become the norm. Even the oft-mentioned parkways fanning out from New York City, many of which have 10-foot lanes, fail to support the thesis that automobiles can make do with narrow lanes. As one report noted: "The New York City parkways, though still attractive, are not capable of carrying high-volume and high-speed traffic . . . . With the transfer of the Parkways to the State in 1961, an extensive modernization and repair program was begun. The program includes widening and straightening." U.S. Department of Commerce, A Proposed Program for Scenic Roads and Parkways, prepared for the President's Council on Recreation and Natural Beauty (1966), p. 107.

14/ AASHO, A Policy on Geometric Design of Rural Highways (1966), p. 235.

15/ This percentage is based on unpublished tabulations from the National Highway Inventory and Performance Study of 1976.

expedited, for additional lanes of traffic at peak hours, for recovery of vehicles that have gone out of control, and for passenger cars stopped on shoulders so they do not disrupt through traffic. 16/

The available evidence suggests that the widths of pavements and shoulders are determined not by the dimensions of vehicles but by volumes of traffic. The decision to build a road in the first place rests on the expectation that it will be used by enough vehicles to justify the proposed expenditures. The composition and peaking characteristics of traffic have little effect on such decisions. And if roads are built at all, there must be some minimum widths for pavements and shoulders. So long as traffic volumes are below the capacity of roads of minimum width, the composition and peaking of traffic have little effect on service or safety. Excavation costs associated with the minimum width of roadway should therefore be considered common costs.

As traffic volumes increase, however, the widths of both pavements and shoulders come to depend on design-hour volumes, expressed in passenger-car equivalents. AASHTO sets level-of-service standards for highways according to number of lanes, type of terrain, and urban or rural location. 17/ These standards are specified with reference to average running speeds at design-hour volumes. The practical meaning of these standards is that pavements are widened until capacity is great enough to meet appropriate level-of-service standards at design-hour volumes. As design-hour volumes increase from fewer than 100 vehicles an hour to more than 400, AASHTO design standards require a corresponding increase in the widths of two-lane rural highways. 18/ Further increases in design-hour volumes require the addition of 12-foot lanes--thereby doubling, tripling, or even quadrupling the overall widths of pavements.

While the width of the shoulder is less directly related to design-hour volume than is the width of the pavement, the two are indeed related. The effective width and capacity of a highway declines as lateral clearance from

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16/ J. Portigo, "State-of-the-Art Review of Paved Shoulders," Transportation Research Record 594 (1977), p. 58. Obstructions on shoulders, including passenger cars, require at least six feet of lateral clearance if they are not to disrupt through traffic. Highway Research Board, Highway Capacity Manual (1965), pp. 89-90.

17/ AASHTO, Policy on Geometric Design of Rural Highways, pp. 99-100.

18/ Ibid., Table V-1.

the edge of the pavement to obstructions, including stopped vehicles, decreases. 19/ At low volumes of traffic, stopped vehicles have almost no effect on the speed of traffic, since traffic can and does move laterally away from stopped vehicles as it passes them; at higher volumes of traffic, however, stopped vehicles disrupt the flow of traffic and create safety hazards, since traffic rides closer to shoulders and the opportunity to move laterally away from stopped vehicles is reduced. 20/ Thus, to avoid degradation of service and maintain safe lateral clearance around stopped vehicles, shoulder width must increase as design-hour volume increases.

In a recent survey of state shoulder design practices it was found that design-hour volume is one of several factors commonly considered in shoulder design. 21/ AASHTO design standards are probably indicative of current design practices. As the design-hour volume increases from fewer than 100 vehicles an hour to more than 400, the minimum width of shoulders increases from 4 to 10 feet. 22/ Further increases in design-hour volume have no effect on the width of outside shoulders, but when design-hour volume becomes high enough to justify divided highways, inside shoulders must be added, and they must be widened as more lanes are added. 23/

In sum, a portion of the width of the roadway and the associated costs of excavation are allocable to vehicles that, by virtue of their peak volume, their use of extra capacity, or both, make the widening of pavements and shoulders necessary. This is one way in which excavation costs are occasioned. Others are described below.

19/ Highway Research Board, Highway Capacity Manual, pp. 89-90.

20/ The following studies relate speed and placement of vehicles to volume of traffic and lateral distance from obstructions: A. Taragin, "Driver Behavior as Affected by Objects on Highway Shoulders," Highway Research Board Proceedings (1955), pp. 453-72; A. Taragin "Effect of Roadway Width on Vehicle Operation, Public Roads (1945), pp. 143-60; and C. Billion, "Effect of Median Dividers on Driver Behavior," Highway Research Board Bulletin 137 (1956), pp. 1-17.

21/ Portigo, "State-of-the-Art Review of Paved Shoulders," p. 59.

22/ AASHO, Policy on Geometric Design of Rural Highways, Table V-2.

23/ Ibid., p. 279.

Surface Thickness

A study done for the Federal Highway Administration (FHWA) entitled Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights, while not a cost-allocation study in itself, deals with many related issues. An increase in the allowable weight of vehicles would, it was assumed, require an increase in the thickness of pavements and that, in turn, would require an increase in the depth of subgrade excavation. The cost of extra excavation was computed by applying the unit cost of excavation per cubic yard to the added depth of pavement required by heavier axle loads for a distance equal to one-half of total highway mileage, the presumption being that one-half of excavation consists of cuts, the other half of fills. 24/

A similar method could be used in the allocation of excavation costs. The cost of cutting a notch for pavement would be allocated across classes of vehicles on the basis of the amount of the total thickness of the pavement for which each is responsible. The allocation criterion would be some function of axle loads. 25/ Whatever the conceptual merits of this approach, it has limited practical value, since the additional amount of excavation involved is almost certainly negligible. It has been estimated that increasing weight limits on the nation's highways from 18 kips for single axles to 26 and from 32 kips for tandem axles to 44 would increase the costs of earthwork and drainage by a mere 0.1 percent. 26/

Slopes and Sight Distances

The cost of grading and drainage per mile of highway is two to three times higher in mountainous terrain than in rolling terrain and one-third higher in rolling terrain than in flat terrain. 27/ Differences between the

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24/ R. Winfrey and others, Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights, vol. 1, Federal Highway Administration Report No. FHWA-RD-73-69 (1968), p. 8-5.

25/ Following AASHO, Interim Guide for Design of Pavement Structures (1972), the amount of the total thickness of pavement for which a given class of vehicles is responsible is a rapidly increasing function of axle weight.

26/ Winfrey and others, Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights, Table 10-28N.

27/ Cost estimates prepared by the Federal-Aid Division of the FHWA.

grading and drainage in flat terrain and those in mountainous terrain are so substantial, in fact, that they nearly double the total cost of highway construction, excluding the costs of engineering and the acquisition of rights-of-way.

These differences are largely a result of the additional excavation required on highways in rolling and mountainous terrain to maintain high levels of service and safety of operation when vehicles have widely varying climbing ability. Nearly all passenger cars can ascend grades of 6 to 8 percent without appreciable loss of speed. In contrast, an average tractor-semitrailer combination, which weighs 45,000 pounds, can sustain a speed of only 23 miles an hour on a 6 percent grade. 28/ Were it not for the additional excavation on highways in rolling and mountainous terrain, traffic flows would be substantially impeded by slow-moving vehicles and safety hazards would arise as fast-moving vehicles sought to pass slow-moving vehicles in areas having inadequate sight distance for passing.

AASHO established maximum grade standards on main rural highways to moderate the disruptive effect on traffic flows of vehicles with limited climbing ability. 29/ As part of its 1939 convention, AASHO held a symposium on gradients to address the question "What Standards Should be Used in Different Types of Topography?" The paper entitled "Grades in Relatively Level and Slightly Rolling Topography" emphasized the sight distance required for stopping and snow protection as controlling factors in grading. 30/ All other papers emphasized the sight distances needed for passing and the climbing ability of trucks, however. In the paper entitled "Grades in Heavy Rolling Topography," for example, it is stated:

> Grades which do not require changing of gears are minor grades and exert little influence on the movement of traffic and the capacity of the road. In accordance with this

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28/ P. Claffey, "Vehicle Operating Characteristics," Transportation and Traffic Engineering Handbook (1976), Table 2.6.

29/ The maximum grade standards set by AASHO are based on speed-distance curves for a typical heavy truck. Policy on Geometric Design of Rural Highways (1966), pp. 194-97.

30/ R. Wills, "Grades in Relatively Level and Slightly Rolling Topography," Symposium on Gradients: What Standards Should Be Used in Different Types of Topography? AASHO, Convention Group Meetings, Papers, and Discussions (1939), pp. 80-92.

definition practically all of our grades are minor, especially when considering the modern passenger car, but this situation is changed when heavy commercial traffic is intermixed with passenger traffic.

The grade of a highway in itself obtains practically all of its importance from its effect on the movement of traffic. Grades which tend to materially slow down the heavier vehicles and thereby impede the free flow of lighter traffic create a hazard. When fast moving traffic is made to slow down and follow slow moving vehicles for any length of time, the anxiety for passing is greatly increased and a condition is created in which cars may pass one another without due regard for safety. Therefore, the aim in either case should be toward safety whether this is accomplished by cutting the hills and thereby furnishing greater sight distances or by widening the roadway at hill tops to provide an additional lane for slow moving vehicles. 31/

Whether extra excavation is done on highways in rolling and mountainous terrain to increase the operating speeds of slow-moving vehicles or to facilitate the passing of slow-moving vehicles, the associated costs are occasioned by vehicles with limited climbing ability.

Allocating Costs of Excavation

It has been argued in the preceding sections that excavation costs are occasioned in two ways: first, through increases in the width of the roadway to accommodate design-hour traffic, and second, through adjustments in the grade of the roadway to accommodate vehicles with limited climbing ability. Ways in which the occasioned portions of excavation costs can be separated from the common portions and subsequently allocated across classes of vehicles are outlined in this section.

The graded portion of right-of-way width consists primarily of pavements and shoulders but does include a portion of side slopes. AASHTO, in Highway Design and Operational Practices Related to Highway Safety,

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31/ H. Coons, "Grades in Heavy Rolling Topography," Symposium on Gradients: What Standards Should be Used in Different Types of Topography? AASHO Convention Group Meetings, Papers and Discussions (1939), pp. 83-85.

notes that side slopes on embankments and cuts must have slope ratios of 6:1 or more to be negotiated by an errant vehicle with a good chance recovery. 32/ In A Policy on Geometric Design of Rural Highways, AASHO states that slope rates of 3:1 or more are required to prevent erosion of certain types of soil and to facilitate maintenance operations. 33/ Where side slopes are graded to such standards, the width of graded right-of-way extends well beyond the outside shoulders. As a practical matter, the width of graded right-of-way consists of the full width of pavements and shoulders plus half the width of side slopes, the latter being roughly triangular in shape and typically requiring half as much excavation per foot of width as do pavements and shoulders.

Tables H-1 through H-3 provide, respectively, data on the average costs of grading and drainage for rural highways, by administrative system and type of terrain; the average right-of-way width for rural highways, by functional system and type of terrain; and the minimum right-of-way width for rural highways, by general type of highway. To allocate excavation costs across classes of vehicles, data on the average cost of excavation and the average and minimum widths of graded right-of-way, by administrative system and type of terrain, would be required. For purposes of illustration, however, the figures in Tables H-1 through H-3 will suffice.

Level Terrain

It is relatively easy to separate the occasioned component from the common component of the costs of excavation in level terrain. Excavation costs are occasioned only through the need for wider roads to accommodate design-hour traffic and are, to a first approximation, proportional to the width of graded right-of-way. Thus, the common portion of the costs of excavation in level terrain is equal to the total cost of excavation times the ratio of minimum width to actual width of graded right-of-way.

Taking rural primary medium-type highways as an example and using figures in Tables H-1 through H-3 for purposes of illustration, the average cost of grading and drainage in flat terrain is $97,000 a mile, the average width of right-of-way is 127 feet, and the minimum width of right-of-way is

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32/ AASHTO, Highway Design and Operational Practices Related to Highway Safety (1974), p. 39.

33/ AASHO, Policy on Geometric Design of Rural Highways, pp. 246-47.

TABLE H-1. ESTIMATED AVERAGE COSTS OF GRADING AND DRAINAGE FOR RURAL HIGHWAYS IN 1977: BY ADMINISTRATIVE SYSTEM AND TYPE OF TERRAIN, IN THOUSANDS OF DOLLARS A MILE

Administrative System	Type of Terrain		
	Flat	Rolling	Mountainous
Interstate	506	596	1,071
Other Primary			
High type	104	138	328
Medium type	97	130	311
Secondary	65	86	206

SOURCE: Federal Highway Administration, Federal-Aid Division, Interstate Reports Branch.

TABLE H-2. AVERAGE WIDTH OF RIGHT-OF-WAY OF RURAL HIGHWAYS IN 1975: BY FUNCTIONAL SYSTEM AND TYPE OF TERRAIN, IN FEET

Functional System	Type of Terrain		
	Flat	Rolling	Mountainous
Interstate	312	338	370
Other Principal Arterial	158	148	153
Minor Arterial	127	116	100
Major Collector	84	79	74

SOURCE: Federal Highway Administration, National Highway Inventory and Performance Summary, 1977, Table IX-1.

TABLE H-3. MINIMUM WIDTH OF RIGHT-OF-WAY FOR RURAL HIGHWAYS

Highway Type	Width in Feet
Interstate (four lanes)	
Without frontage roads	150
With frontage roads	250
Non-Interstate (four lanes)	
Intermediate type	140
Non-Interstate (two lanes)	
High type	100
Intermediate type	80
Low type	66

SOURCES: AASHO, A Policy on Design Standards, Interstate System, 1966, p. 4; AASHO, A Policy on Geometric Design of Rural Highways, 1966, pp. 21-22.

80 feet. 34/ The common component of costs in this example amounts to 63 percent (100 x 80/127) of total grading and drainage costs, or $61,000 a mile. The remainder of the costs of grading and drainage, 37 percent of the total or $36,000 a mile, is occasioned by design-hour traffic.

Rolling and Mountainous Terrain

It is far more difficult to separate occasioned costs from common excavation costs in rolling and mountainous terrain than it is in level terrain. Indeed, this is one of the most difficult analytical tasks in highway

34/ In arriving at these figures it has been assumed that the medium-type primary highways of Table H-1 correspond closely to the minor arterial highways of Table H-3.

allocation. The line between the two cannot be drawn with much precision because the alignment chosen for a route is itself dependent upon the type of road and the type of traffic anticipated. A road built to carry cars and trucks might follow a different alignment from one built for cars only. Similarly, an Interstate highway built to one set of service standards might follow a different alignment from a secondary road built to another set of standards. In consequence, any method of separating the occasioned component of the costs of excavation in rolling and mountainous terrain from the common component is bound to involve an exercise of judgment.

Nonetheless, with the additional costs of grading and drainage in rolling and mountainous terrain amounting to about 30 percent of the total costs of grading and drainage in rural areas, it is essential that the component of excavation costs occasioned by vehicles with limited climbing ability be estimated in some manner. 35/ Two simple ways of doing so are presented in this section. Further study of these, as well as of other possible approaches, is needed.

Excavation costs in rolling and mountainous terrain may be occasioned through increases in the width of the roadway to accommodate vehicles with limited climbing ability, through reductions in steepness of grade, or both. Both ways of estimating the occasioned component of the costs of excavation in rolling and mountainous terrain reflect the assumption that excavation costs on secondary roads can be occasioned only through increases in the width of the roadway to accommodate design-hour traffic. Some additional excavation is required on secondary roads in rolling and mountainous terrain to achieve smooth vertical curves, adequate sight distances for stopping, and moderate superelevations, but the costs of this additional excavation fall into the category of common costs, since the same adjustments in curvature, sight distance for stopping, and superelevation are required by all vehicles if they are to operate safely on highways in such terrain. 36/ Likewise, some additional excavation is required on

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35/ As shown in Table H-1, the costs of grading and drainage are typically three times higher in mountainous than flat terrain and one-third higher in rolling than flat terrain. Since about 10 percent of rural roads are classified as being in mountainous terrain, and 60 percent in rolling terrain, the added cost of grading and drainage in such terrain is about 30 percent of total grading and drainage costs.

36/ For a discussion of the relationships between vehicle operating characteristics and geometric design details, including curvature, sight distances for stopping, and superelevation, see M. Weinberg and K. Tharp, Application of Vehicles Operating Characteristics to Geometric Design and Traffic Conditions, National Cooperative Highway Research Program, Report 68 (1969), pp. 4-12.

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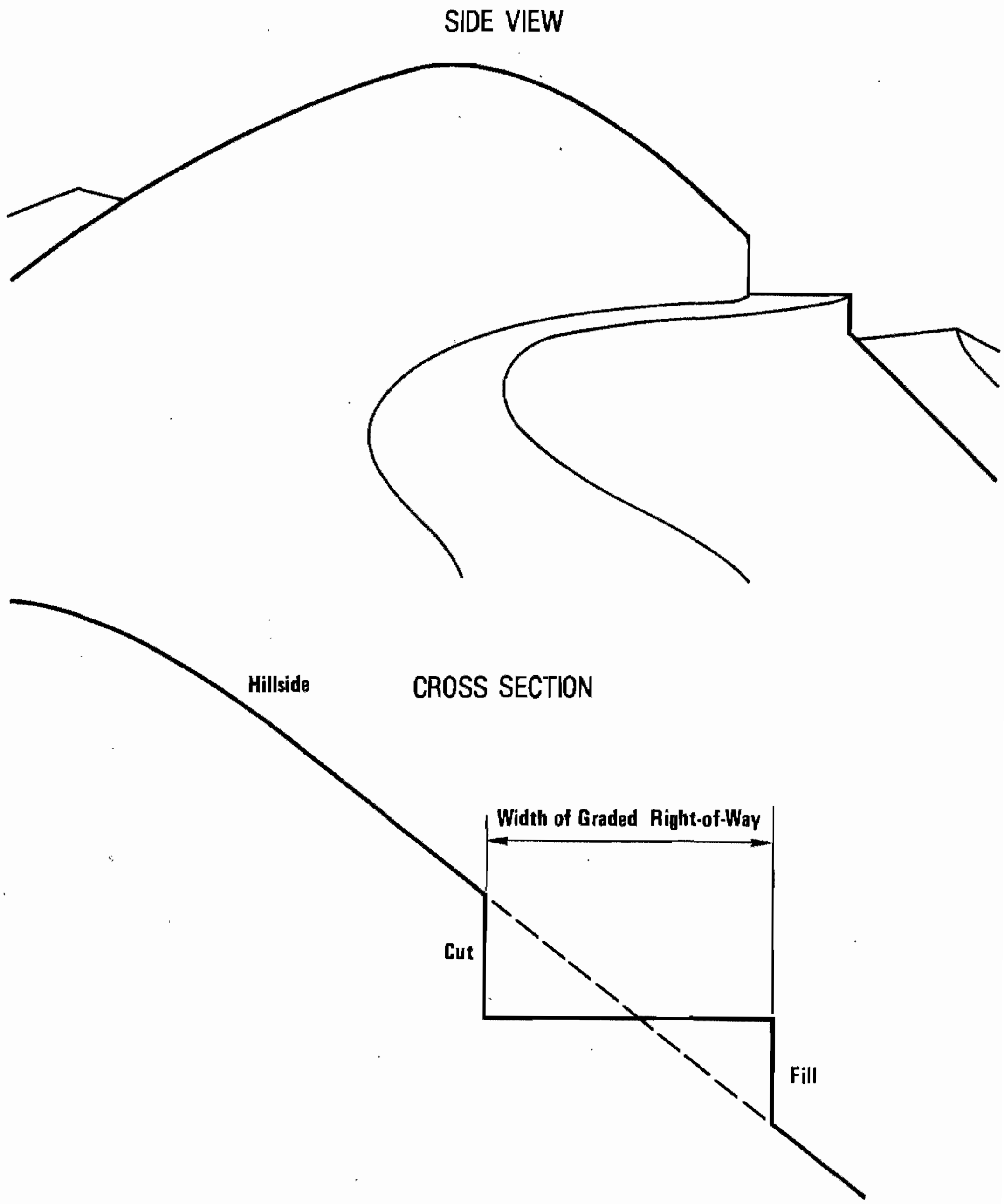
secondary roads in rolling and mountainous terrain to maintain moderate grades and occasional passing areas, but again the bulk of the related costs fall into the category of common costs, since such features of geometric design are required even on low-level secondary roads that carry minimal truck traffic. In essence, both ways of estimating the occasioned component of excavation costs in rolling and mountainous terrain reflect the assumption that if a road is built at all, it must at least be built to the geometric design standards of secondary roads. To the extent that additional excavation is done on secondary roads to accommodate vehicles with limited climbing ability, estimates of occasioned costs on other systems will be understated.

The first method of estimating excavation costs occasioned in rolling and mountainous terrain reflects the assumption that roads of all types go around hills by one path or another, as depicted in Figure H-1. It further reflects the assumption that all have cross sections. It is clear from Figure H-1 that the amount of excavation required in hilly terrain increases progressively with each additional foot of roadway width. More precisely, the amount of cutting and filling increases with the square of the width of graded right-of-way. Knowledge of this relationship, along with the assumptions that roads of all types go around hills and that secondary roads have no occasioned costs of excavation other than those associated with width, makes it possible to estimate the component of the total costs of excavation on higher-type highways that is occasioned by either design-hour traffic or vehicles with limited climbing ability.

Taking rural primary, medium-type highways as an example and using figures from Tables H-1 through H-3 for purposes of illustration, the average cost of grading and drainage in rolling terrain is \$130,000 a mile and the minimum width of right-of-way is 80 feet. If secondary roads in rolling terrain, with average grading and drainage costs of \$86,000 a mile and average right-of-way width of 79 feet, were built to the minimum width of primary medium-type highways, the cost of grading and drainage would be $\$86,000 \times (80/79)^2$ or \$88,000 a mile. These costs are considered the minimum incurred for any traffic flow and thus are common costs. The occasioned component of the costs of grading and drainage on primary medium-type highways in rolling terrain would be total costs less common costs, or \$42,000 a mile, which is 32 percent of the total costs of grading and drainage. The comparable figures for primary medium-type highways in mountainous terrain are \$70,000 a mile and 23 percent of the total costs of grading and drainage.

A second method of estimating the occasioned component of the costs of excavation in rolling and mountainous terrain reflects the assump-

Figure H-1.
Road Going Around a Hill



tion that roads of all types go over or through hills, and that each has a cross section, as shown in Figure H-2. The higher the type of road, the deeper the cuts and fills will be. In this case, the amount of cutting and filling required is proportional to the width of graded right-of-way. Knowledge of this relationship, along with the assumptions that roads of all types go over or through hills and that secondary roads have no occasioned costs of excavation other than those associated with width, permits an estimation of the component of the total costs of excavation of higher type highways that is occasioned by either design-hour traffic or vehicles with limited climbing ability.

Again, taking primary medium-type highways as an example, the cost of grading and drainage in rolling terrain is $130,000 a mile and the minimum width of right-of-way is 80 feet. If secondary roads in rolling terrain, with average grading and drainage costs of $86,000 and average right-of-way widths of 79 feet, were built to the minimum width of primary medium-type highways, the cost of grading and drainage would be $86,000 x 80/79, or $87,000 a mile. This is an estimate of common costs. Thus, the occasioned component of the costs of grading and drainage on primary medium-type highways in rolling terrain would be total costs less common costs, or $43,000 a mile, which figure is 33 percent of the total costs of grading and drainage. Comparable figures for Interstate highways in mountainous terrain are $88,000 and 28 percent.

The figures arrived at in the foregoing examples are summarized in Table H-4. Three conclusions can be drawn from that table. First, a significant percentage of grading and drainage costs in all types of terrain appears to be occasioned. Of course, if the actual costs of excavation were substituted for the costs of grading and drainage in the preceding example and the width of graded right-of-way were substituted for the width of total right-of-way, the results could change significantly. Second, the two methods of estimating the occasioned component of the costs of excavation may produce significantly different results. Their disparate results need to be reconciled in some manner if they are to provide a basis for highway cost allocation. Finally, it is possible to estimate, albeit crudely, the amount of occasioned costs. Neglect of such costs cannot be justified on the basis of practicality.

Both ways of estimating occasioned costs of excavation are extremely crude, and neither could be said to portray excavation cost in a completely realistic or precise way. Certain refinements could lead to more precise estimates, among them the selection of more realistic and representative cross sections—with side slopes, for example—and the use of cost data from a sample of projects to determine minimum excavation requirements in rolling and mountainous terrain. Even then, however, any division

Figure H-2.
Road Going Over a Hill

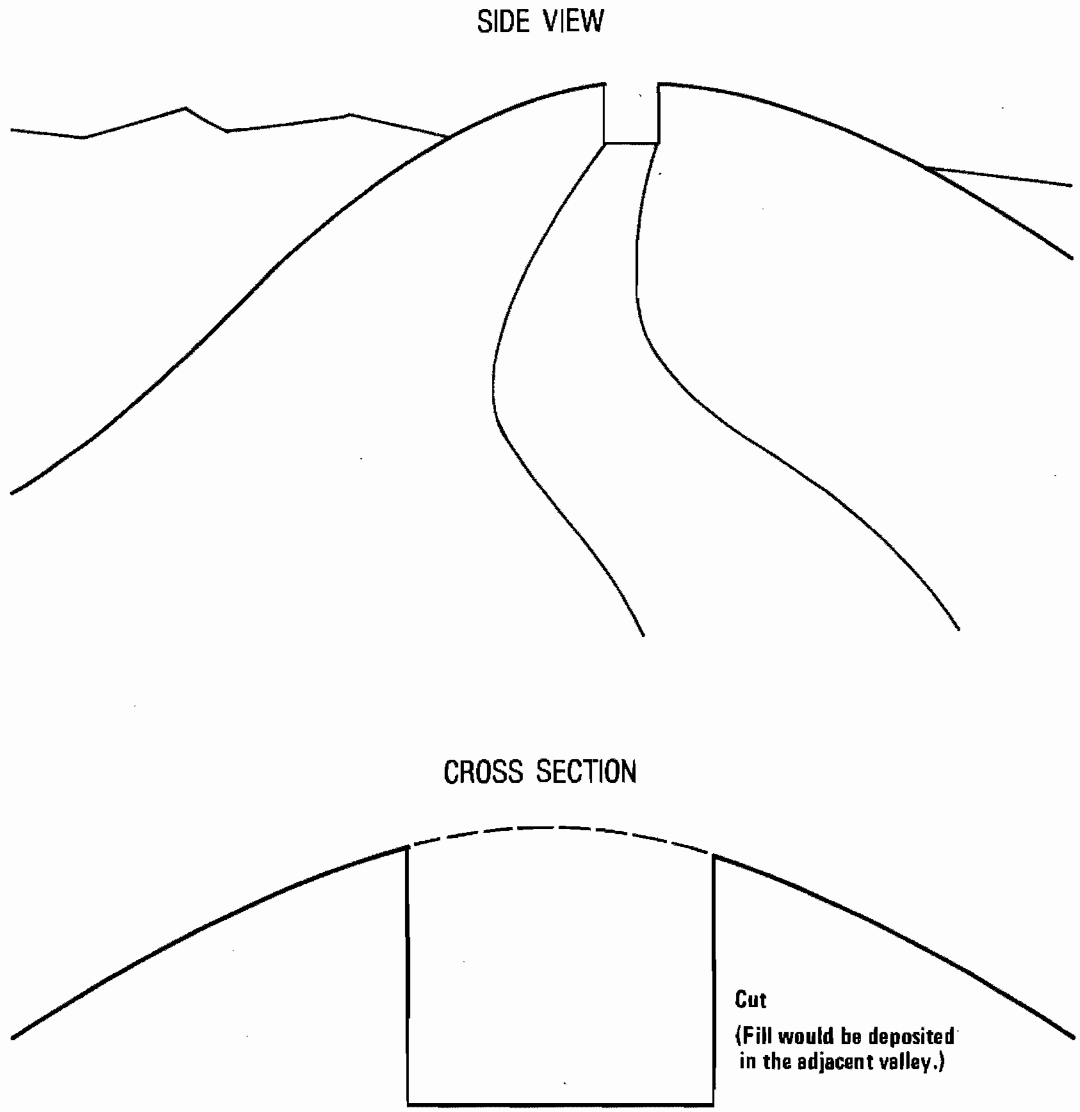


TABLE H-4. THE PERCENTAGE AND DOLLAR AMOUNTS OF THE COSTS OF GRADING AND DRAINAGE OCCASIONED ON PRIMARY MEDIUM-TYPE HIGHWAYS, BY TYPE OF TERRAIN

Type of Terrain	Percentage of Total Costs	Cost per Mile (in dollars)
Flat	37	36,000
Rolling		
1st Model	32	42,000
2nd Model	33	43,000
Mountainous		
1st Model	23	70,000
2nd Model	28	88,000

of excavation cost in rolling and mountainous terrain into the common and occasioned components will necessarily call for the exercise of judgment, and many conflicting judgments will be possible.

Once excavation costs have been separated into a common component and an occasioned component, it is necessary to allocate the occasioned costs across classes of vehicles. As noted above, excavation costs in level terrain are occasioned by design-hour traffic, while the bulk of the costs of excavation costs in rolling and mountainous terrain are occasioned by vehicles with limited climbing ability. It appears, however, that the same criterion—design-hour volume, expressed in terrain-specific passenger-car equivalents—can be used to allocate the occasioned component of excavation costs in all types of terrain.

AASHTO sets policy for average running speeds, by type of highway and type of terrain. 37/ Highways must be of sufficient capacity to meet those standards at design-hour volumes. The standards can be met in rolling and

37/ AASHO, Policy on Geometric Design of Rural Highways, p. 99.

and mountainous terrain either by widening roads to increase their capacity or by reducing grades. A more nearly level roadway has a much greater capacity, measured in passenger-car equivalents, just as a wider road has greater capacity. Thus, the two approaches, widening roads and reducing grades, effectively substitute for one another; both are taken to improve the flow of traffic and reduce safety hazards in passing at design-hour volumes.

APPENDIX I. ALLOCATING THE COSTS OF INTERCHANGES

Interchanges consist of ramps, speed-change lanes, overpass structures, and graded rights-of-way. The cost of each of these features has one or more occasioned components that have been neglected in earlier federal highway cost-allocation studies. The aim of this appendix is to identify those components.

Ramps

The costs of ramps are occasioned in a variety of ways. First, vehicles of various types "offtrack" to widely varying degrees on ramps with a high degree of curvature. 1/ The American Association of State Highway and Transportation Officials (AASHTO) recommends varying widths of pavement depending upon, among other things, the composition of traffic using the ramp. As the volume of truck traffic increases, the required width of ramps increases anywhere from 3 to 6 feet. 2/ In a survey of state highway design practices it was found that the median width of lanes on ramps is 16 feet, 6 feet more than the width required by automobiles with maximum offtracking. 3/ A corresponding increment of lane width on ramps is occasioned by vehicles which, by virtue of their length of wheelbase,

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1/ "Offtracking" is the difference between the paths of the inside front wheel and the inside rear wheel as a vehicle negotiates a curve.

2/ American Association of State Highway Officials, A Policy on Geometric Design of Rural Highways (1966), pp. 332-40 and p. 540. In 1973, AASHO changed its name to American Association of State Highway and Transportation Officials (AASHTO).

3/ D. Loutzenheiser and E. Holahan, "Ramp Design: A Survey of State Practices," AASHO Proceedings (1970), pp. 91-98.

spacing of axles, turning radius, and front-wheel track, have wide track widths. 4/

Second, the costs of ramps are also occasioned through the addition of lanes to accommodate peak traffic. AASHTO has no specific design warrants for multilane ramps but, in general, recommends their use "where traffic is too great for single-lane operation." 5/ In a survey of entrance-ramp design practices in the United States and Canada, it was found that two-lane entrance ramps were receiving increasing consideration in design as a result of the growing volume of freeway traffic. By 1968, as many as 300 such ramps were in use. 6/ This represents a small percentage of all freeway ramps, but it is one that cannot automatically be dismissed if the trend is indeed toward multiple lanes on ramps. The cost of added lanes would be occasioned by peak-hour traffic and allocated accordingly.

Finally, ramp costs are occasioned through increases in length to accommodate vehicles with limited climbing ability. The AASHTO policy states that, while ramp gradients of 4 to 6 percent are generally acceptable, where "an effective proportion of the ramp traffic consists of heavy trucks or buses, the gradients should be limited to 3 or 4 percent." 7/ Ramps must be longer, of course, to maintain such gentle grades. 8/

4/ The degree of offtracking by various vehicles and simple ways of estimating it are presented in AASHO Proceedings (1970), pp. 334-37; Western Highway Institute, Offtracking Characteristics of Trucks and Truck Combinations, Research Committee Report No. 3 (1970); G. Pilkington and P. Howell, A Simplified Procedure for Computing Vehicle Offtracking on Curves, Federal Highway Administration Report No. FHWA-RD-74-8, (1973).

5/ AASHTO, A Policy on Design of Urban Highways and Arterial Streets (1973), p. 561.

6/ R. Pfeifer, "Two-Lane Entrance Ramps," Traffic Engineering (November 1968), pp. 18-23.

7/ AASHO, Policy on Geometric Design of Rural Highways, p. 535.

8/ Ramp lengths are, at a first approximation, inversely proportional to ramp gradients for the moderate gradients under consideration.

Acceleration Lanes

Some of the cost of acceleration lanes is occasioned through increases in the length of lanes to accommodate vehicles with limited acceleration capability. The AASHTO policy states that while the lengths of acceleration lanes are generally "based on passenger vehicle operation [where] a substantive number of large vehicles are to enter a high-speed highway, the length should be increased." 9/ The Transportation and Engineering Handbook indicates that passenger cars leaving an on-ramp at 30 miles an hour on a level grade can accelerate to 50 miles an hour in about 250 feet; a typical 12,000-pound, single-unit truck, in contrast, requires more than 1,500 feet to reach the same speed. 10/ Of course, automobiles do not always accelerate at the maximum rate possible when entering a freeway and cannot always merge immediately when the traffic is heavy. Nonetheless, virtually all passenger cars do merge with through traffic in the first 500 feet of acceleration lanes. 11/ Thus, any length of acceleration lanes beyond, say, 500 feet is occasioned largely by vehicles that consistently require greater distance to reach safe merging speeds. The increment of cost thus occasioned could be quite significant since the once-common 400- to 700-foot acceleration lanes have been superseded by acceleration lanes of 800 to 1,600 feet. 12/

9/ AASHTO, Policy on Geometric Design of Rural Highways, p. 354.

10/ P. Claffey, "Vehicle Operating Characteristics," in Transportation and Traffic Engineering Handbook (Prentice-Hall, Institute of Traffic Engineers, 1976), Figure 2.1.

11/ N. Jouzy and M. Michael, "Use and Design of Acceleration and Deceleration Lanes in Indiana," Highway Research Record 9 (1963), pp. 25-51; D. Blumenfeld and G. Weiss, "Merging from an Acceleration Lane," Transportation Science (May 1971), pp. 161-68.

12/ State design standards for acceleration lanes in 1970 were much higher than those prevailing before 1961. See J. Cirillo, "The Relationship of Accidents to Length of Speed-Change Lanes and Weaving Areas on Interstate Highways," Highway Research Record 312 (1969), Table 3; and Lontzenheiser and Holahan, "Ramp Design," Figure 4.

Bridges

Some of the costs of underpasses at interchanges is occasioned through increases in the height of structures to accommodate high-bodied vehicles and some is occasioned through increases in the length of structures made necessary by the wider roadways that are needed to accommodate design-hour traffic.

Most states allow trucks up to 13.5 feet high to operate on state highways. AASHTO has consequently set the minimum vertical clearance at underpasses on all highways carrying mixed traffic at 14 feet. This, of course, is far in excess of the clearance required by passenger cars and makes it clear that part of structure costs is occasioned by high-bodied vehicles. In a recent study, it was estimated that, if the vertical clearance on underpasses were reduced from 14 feet, the present standard, to 10 feet, the clearance judged sufficient for passenger cars and light trucks, the cost of interchange and grade-separation structures would decline by 7.5 percent. 13/

The assumptions underlying such estimates and assignments are problematic. All rural highways and some urban Interstate highways must be built to a 16-foot standard of vertical clearance to accommodate military traffic, and parkways intended "exclusively" for passenger cars must be built to a 12.5-foot standard of vertical clearance to accommodate maintenance vehicles. 14/ It is thus debatable whether high-bodied vehicles can be held responsible for any of the vertical clearance on Interstate highways and whether passenger cars have joint responsibility for only 10 feet of vertical clearance on all highways. Suffice it to say that at least some of the costs of structures at interchanges on some highways are occasioned by high-bodied vehicles.

In addition, some of the costs of bridges at interchanges on some highways are occasioned by design-hour traffic. As a rule, the entire width of pavement, shoulders, and medians is carried through an underpass without change. At the very least, the width of pavement is maintained. Thus,

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13/ K. Bhatt and others, An Analysis of Road Expenditures and Payments by Vehicle Class, 1956-1975 (The Urban Institute, 1977), p. 243.

14/ Bureau of Public Roads, Instructional Memorandum 20-2-60, January 1960; AASHTO, Policy on Geometric Design of Rural Highways, pp. 521-22.

where pavement, shoulders, or medians have been built to extra width to accommodate design-hour traffic, a substantial portion of the cost of an underpass may be occasioned by design-hour traffic. In the study referred to in footnote 13, it was estimated that, if lane width were reduced by a half foot and shoulder width by 2 feet, the cost of interchange and grade-separation structures would decline by 16 percent. 15/ On many multilane divided highways, the increment of roadway width attributable to design-hour traffic is much larger than a half foot per lane and 2 feet per shoulder, and the portion of the costs of structure occasioned by design-hour traffic is correspondingly higher. The relationship between the width of the roadway and design-hour volume is described in detail in Appendix F.

Grading and Right-of-Way

Finally, some grading and right-of-way costs at interchanges should be considered occasioned costs. Earlier federal highway cost-allocation studies have accounted for grading costs occasioned by high-bodied vehicles through increases in vertical clearance at interchanges; in the 1965 study, it was determined that 12 percent of the costs of grading and drainage at interchanges were so occasioned. 16/ This type of occasioned cost should continue to be recognized. The portion of grading costs occasioned through increases in ramp width to accommodate vehicles with substantial off-tracking on curves and vehicles traveling during peak periods has in the past been neglected in cost-allocation studies, as have the portion occasioned through increases in ramp length to accommodate vehicles with limited climbing ability and the portion occasioned through increases in the length of acceleration lanes to accommodate vehicles with limited acceleration capability. In earlier studies, right-of-way costs incurred through such increases have also been neglected.

A variety of ways in which interchange costs are occasioned have been identified in this appendix. The determination that each is or is not significant enough to warrant consideration in the highway cost-allocation study and the precise means of separating occasioned costs from common costs and allocating occasioned costs across classes of vehicles requires further analysis by the Department of Transportation.

15/ Bhatt and others, Analysis of Road Expenditures and Payments, p. 247.

16/ Bureau of Public Roads, Supplementary Report of the Highway Cost Allocation Study, H. Doc. 124, 89 Cong., 1 sess. (1965), p. 103.

APPENDIX J. ALLOCATION OF THE COST OF CULVERTS

The costs of highway drainage appear to be related to the composition of traffic in two ways: First, increases in the structural capacity of culverts is required by heavy loads riding over them. Second, increases in the lengths of culverts are made necessary by the widening of pavements and shoulders to accommodate design-hour traffic. The first of these is discussed below. The second is related to the width of the right-of-way and is discussed in Appendix F.

In earlier highway cost-allocation studies, the costs of grading and drainage have been grouped together for purposes of cost allocation. While the two have one thing in common--their dependence upon the width of the pavement and the shoulders--drainage costs may in some instances be occasioned in a manner more like the occasioning of bridge costs than grading costs. The cost-allocation procedures developed for bridges should be extended to the allocation of the costs of long-span culverts. 1/

It is only smaller pipe and box culverts that warrant special treatment in highway cost allocation. Not only do they differ from bridges in the way their costs are occasioned, they also account for a vast majority of the costs of culverts. For example, while more than 17 million linear feet of culverts were installed in the United States in 1972, 2/ less than 0.1 percent

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1/ Long-span culverts are substitutes for bridges under certain circumstances and have been treated as flat slab bridges in at least one study. See R. Tokerud, "Economic Structures for Low-Volume Roads," Transportation Research Record 665 (1978), pp. 214-21; and R. Whiteside and others, Changes in Legal Vehicle Weights and Dimensions: Some Economic Considerations, National Cooperative Highway Research Program Report 141 (1973).

2/ Transportation Research Board, Durability of Drainage Pipe, NCHRP Synthesis of Highway Practice Report No. 50 (1978), p. 3.

of that linear footage was in long-span culverts measuring more than 20 feet in distance along the center line of roads. 3/

Comparison of Culverts and Bridges

Culverts, like bridges, are designed to support the maximum load to which they will be subjected during their functional lives. Standard methods of culvert design make allowance for overstresses produced by heavy vehicles, such as H20 or HS20 trucks. 4/ Yet culverts, being covered by earth fill and having their inside surfaces exposed to sediment-carrying water, may differ from bridges in two important respects: First, the dead load on many culverts so far exceeds the live load that the latter can be neglected in culvert design. Design specifications of the American Association of State Highway and Transportation Officials (AASHTO) allow live loads to be disregarded when the depth of fill over culverts is more than 8 feet and exceeds the length of the span, as is usually the case with today's geometric design standards. 5/ Second, the service life of most culverts appears to be determined by the combined action of corrosion and abrasion on their surfaces rather than the frequency and weight of load applications, as the service life of steel bridges is determined. Culverts are typically

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3/ From the National Bridge Inventory, 250 culverts measuring more than 20 feet in width and having minimal earth cover, as long-span culverts nearly always do, were constructed on the federal-aid system in 1972. These culverts averaged 60 feet in length, for a total linear footage of 15,000 feet.

4/ Federal Highway Administration, Corrugated Metal Pipe, Structural Design Criteria and Recommended Installation Practice (1976), p. 5; American Concrete Pipe Association, Concrete Pipe Design Manual (1976) pp. 33-37; R. La Tona and others, "Computerized Design of Precast Reinforced Concrete Box Culverts," Highway Research Record 443 (1973), pp. 40-51; E. Selig and others, Review of the Design and Construction of Long-Span Corrugated Metal, Buried Conduits, Federal Highway Administration Report No. FHWA-RD-77-131 (1977), pp. 7-15.

5/ AASHTO, Standard Specifications for Highway Bridges (1977), p. 45; G. Kirk, "Economics in Drainage Design Practices," AASHO Convention Group Proceedings (1965), pp. 74-78; L. Herr, "Philosophy of Service Life in Culvert Design," Journal of the Highway Division, American Society of Civil Engineers Proceedings, March 1966, pp. 1-9.

perforated by corrosion or abrasion within 10 to 50 years, depending on the materials of which they are made and the characteristics of the soil and water to which they are exposed. 6/

These differences between culverts and bridges cause the costs of culverts to be far less dependent upon traffic loads than are the costs of bridges. It is often assumed, in fact, that the effect of traffic loads on the costs of culverts—with the exception of long-span culverts—is negligible. 7/

At this stage, it seems appropriate to assign the costs of all deep-fill culverts as common costs and to assign the costs of long-span, shallow-fill culverts in accordance with allocation procedures for the costs of bridges. Additional research may be needed to determine a method of allocating the costs of short-span, shallow-fill culverts, as well as to determine the share of the total costs of culverts associated with each type of culvert.

6/ Nearly all states have conducted culvert-durability studies. Some of the more significant studies are reviewed by J. Haviland and others, "Durability of Corrugated Metal Culverts," Highway Research Record 242 (1968), pp. 41-65; Transportation Research Board, Durability of Drainage Pipe, pp. 3-19 and 24-28.

7/ See, for example, R. Winfrey and others, Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights, Vol. 1, Report No. FHWA-RD-73-69 (1968), pp. 8-5 and 8-6; and R. Whiteside and others, Changes in Legal Vehicle Weights and Dimensions, p. 72.

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APPENDIX K. ALLOCATING THE COST OF WIDENING ROADS

Widening now accounts for about 7 percent of federal highway expenditures, and that percentage is almost certain to increase in the future as the federal-aid highway program continues to shift its emphasis from construction of new highways to improvement of existing highways. Widening appears to be one of the few significant items of highway construction costs that is almost entirely occasioned. For these reasons, the costs of widening, which were not isolated in highway cost-allocation studies in the past, should be given special attention in the new study.

The bulk of federal expenditures for the widening of roads are incurred in major widening—that is, in the addition of full lanes to existing highways. Such lanes are often added to reduce traffic congestion and travel time during peak hours. 1/ Much as new pavements are designed to some width beyond the accepted minimum for the system in question to accommodate design-hour traffic, so are pavements widened to accommodate design-hour traffic. Associated costs can be assigned to vehicles traveling during the design hour, or its functional equivalent, the peak period. This assignment should be done in proportion to the capacity of the road used by each type of vehicle—that is, proportioned to passenger-car equivalents.

Minor widening—that is, the widening of lanes on existing highways—constitutes a much smaller component of the total costs of widening than does major widening, but in the way in which its costs are occasioned it is similar to major widening. In a 1973 survey of state highway design practices, it was found that much minor widening is done specifically to

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1/ A computerized search of the Highway Research Information Service file turned up a number of articles and reports on major widening projects. Nearly all emphasized reductions in travel times at peak periods following the addition of lanes. See, for example, California Division of Highways, Interstate 80 Widening Distribution Structure to Ashby Avenue (1968); G. Russell, "Freeway Operations in California," American Association of State Highway Officials Proceedings, 55th Annual Meeting (1969); "First Completed Topics Project is Successful," Public Works (August 1969), pp. 101-03.

increase the capacity of two-lane rural and suburban roads. 2/ The associated costs of minor widening can be assigned to vehicles traveling during the design hour or peak period.

There are exceptions to the general rule that roads are widened to accommodate design-hour traffic. Safety, rather than increased capacity, is often the justification for the addition of turning lanes or the widening of exceedingly narrow roads. Similarly, widening done to add lanes for car pools could be construed as having increased capacity of the road or it could be interpreted as a special cost uniquely occasioned by the vehicles using the added width. In general, however, the costs of widening should be allocated on the basis of design-hour volume, expressed in passenger-car equivalents. Exceptions to this role, if they are significant and can be isolated, should be dealt with on a project-by-project basis.

2/ Transportation Research Board, Partial-Lane Pavement Widening, National Cooperative Highway Research Program Synthesis of Highway Practice No. 28 (1975), p. 3.

APPENDIX L. DETERMINATION OF TAX RECEIPTS FROM USERS OF HIGHWAYS

The equitable allocation of highway costs among different groups of highway users requires many judgments about the approaches and data used to allocate cost responsibility to specific classes of users. In addition to the difficult issues of cost responsibility, there are also questions as to the exact amount of highway taxes that is paid by each groups of users. The incidence of each highway tax across various groups of users needs to be estimated before it can be determined whether or not the total payments by each class of users are in balance with the cost responsibility of each class.

In principle, the determination of tax receipts by group of users is not controversial: No one disputes the assumption that setting equitable taxes among groups of users requires accurate information about the payments that are made by each group. Questions arise, however, as to how to delineate groups of users and how to estimate the taxes paid by each.

Vehicle Type

In earlier federal cost-allocation studies, visual types--five-axle tractor-trailer combinations, for example—have generally been relied on as the primary basis for delineating groups of users. Visual type is easily observed, and it bears a fairly close correspondence to average vehicle weight. Many design characteristics, such as thickness of pavement, are acknowledged to be closely related to vehicle weight, while others, such as the provision of climbing lanes, are related to features of vehicle performance—power-to-weight ratio, for example—that tend to exhibit some predictable association with vehicle weight. Gross vehicle weight is cumbersome to measure, however, in relation to visual type. Accordingly, visual type has been used, supplemented by vehicle weight, as the basis for classification in earlier cost-allocation studies. This combined classification, in which each visual type is subdivided according to several weight-based subtypes, is referred to here as the conventional classification. It appears to be an acceptable approach, particularly if it is extended to include the set of weight categories that was applied in the 1975 Cost Allocation Study.

There is some incongruity associated with using classes of vehicles selected primarily because of their association with weight. For example, automobiles with studded snow tires appear to cause damage to the pavement in excess of that normally associated with vehicles of their weight. Another example is recreational vehicles, many of which have limited hill-climbing ability and which thereby contribute to the costs of grading and of climbing lanes. At present, such cases appear to be exceptions, and most of the vehicle-specific responsibility for highway costs can be explained directly by gross vehicle weight or indirectly by some vehicular feature for which weight is a reasonable proxy.

It is possible that imperfections of the classification of vehicles used conventionally will become more critical in the future. For example, sales and use of recreational vehicles have increased significantly in recent years. The limited climbing ability of such vehicles could diminish still further in future years as the standards set under the Energy Policy and Conservation Act of 1975 become increasingly stringent. At the same time, the use of these vehicles might grow with increased affluence and leisure time. If recreational vehicles or other such special cases appear to present serious shortcomings for the conventional delineation of vehicle classes, then it would be reasonable to supplement it with one or more additional special categories.

At present, it does not seem clear that any quantum jump in the precision of classification would be gained by abandoning the conventional classification used in earlier federal cost-allocation studies, but in a new cost-allocation study the use of this classification should be reconsidered if future events or further study should suggest that other classifications would coincide better with divisions of cost responsibility.

Source of Highway Trust Fund Revenues

The chief sources of revenues for the Highway Trust Fund are the excise taxes on motor fuels, tires, trucks, buses, and trailers. Together, these taxes accounted for 92 percent of all Trust Fund revenues in fiscal year 1977, as shown in Table L-1.

Of the seven taxes shown in Table L-1, all but one, the heavy-vehicle use tax, are collected from the manufacturer of the product rather than from the user. 1/ Taken together, these manufacturer-paid taxes represent

1/ Some of the tax on diesel fuel is paid by trucking firms that buy bulk supplies of diesel fuel tax free and then pay the tax themselves. Another minor exception is user-built truck modifications. Such modifications can be taxable, but they represent a negligible portion of Highway Trust Fund revenues.

TABLE L-1. HIGHWAY TRUST FUND RECEIPTS: FISCAL YEAR 1977

Type of Tax	Net Taxes Transferred (millions of Dollars)	Percent of Total
Gasoline, Diesel Fuel, and Special Motor Fuels	4,707.4	70.2
Trucks, Buses, and Trailers	708.1	10.6
Tires	758.0	11.3
Heavy Vehicle Use Tax	239.7	3.6
Lubricating Oils	76.3	1.1
Truck and Bus Parts and Accessories	164.7	2.5
Inner Tubes and Tread Rubber	55.0	0.8
Total	6,709.2	100.0

SOURCE: U.S. Department of the Treasury, "Highway Trust Fund Twenty-Second Annual Report," 1978.

96 percent of Highway Trust Fund revenues. The Internal Revenue Service (IRS) collects these taxes, but they are reported to the IRS in total, and no detail on receipts by type of vehicle can be inferred from IRS data.

Even the use tax on heavy vehicles, which is also collected by the IRS, is reported in total. The number of vehicles of each type cannot be inferred directly from tax forms.

Thus the IRS, while it collects the taxes for the Highway Trust Fund, does not at present gather any information that identifies the types of vehicles associated with them. 2/ Highway tax payments for each individual class of vehicles must be inferred from other information. In particular, most highway taxes—those on motor fuels, tires, lubricating oils, inner tubes, and tread rubber—are paid, by any particular type of vehicle, in rough proportion to use of the vehicle. Accordingly, the number of miles traveled by each group of vehicles is a significant factor in estimating the tax payments of each.

Vehicle-Miles Traveled

Vehicle-miles traveled (VMT) can be estimated by using two methods:

- By counting the number of vehicles of each type passing various checkpoints and multiplying by scale factors to estimate VMT by each class of vehicles (now done in the annual classification counts by state highway departments), and

- By taking a survey of owners or operators of vehicles to determine typical patterns of use, then using data on the number of registered vehicles to scale the results upward for the estimation of national VMT (now done by the Bureau of Census in its Truck Inventory and Use Survey).

The first source of data is the annual classification counts made by each state highway department for a 24-hour period. These counts record

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2/ The IRS makes some minor adjustments to reflect fuel, tire, and oil use by airplanes (whose tax receipts go into the Airport and Airways Trust Fund) and highway vehicles (whose receipts go into the Highway Trust Fund). These adjustments, which are a small fraction of 1 percent of all Highway Trust Fund revenues, can be ignored for the purposes of this paper.

the number of vehicles of each visual type passing a set of checkpoints. As part of this annual classification survey, some data on actual vehicle weight are collected at truck-weighing stations, of which there are about 700 across the country. 3/ Although this annual survey yields by far the most complete data on vehicles in operation, it appears to be limited in four respects:

- It may not be representative in its coverage of overloaded vehicles, which may tend to bypass the survey point;

- It may not be representative in its coverage of weekend recreational travel, since it is typically conducted on weekdays;

- Its stations tend to be concentrated on the Interstate and primary-road systems and in rural areas, which means that coverage of urban routes and of the secondary road system is sketchy; 4/ and

- It may be unduly sensitive to weather and seasonal variations in the mix of traffic, since it is a 24-hour survey and since it is typically conducted during the summer.

Special studies could be undertaken to determine the extent of these problems and to explore ways of adjusting the survey data to correct for them. The cost and usefulness of such extensions should be explored further within the cost-allocation study.

The second important source of data on VMT, the Truck Inventory and Use Survey, is conducted by the Bureau of the Census on the basis of a stratified sample drawn from records at state licensing bureaus and similar organizations. In this survey, information is collected on the annual mileage of the vehicles as well as on maximum gross weights of vehicles. In addition, the 1977 survey also gathered data on vehicle fuel economy that could be valuable in relating VMT to fuel-tax payments by classes of vehicles.

3/ Data on overall VMT by all classes of vehicles is gathered at about 4,000 automated counting stations throughout the country. These data are also useful in scaling the classification counts upward to reflect volumes on each road system, although they themselves contain no information on the composition of traffic.

4/ Of the 700 weighing stations, only about 30 are on secondary roads and only about 10 are on urban portions of the Interstate system.

Any survey of this sort is inherently limited in its description of vehicle weight, however, since this characteristic fluctuates widely among carriers and from one trip to the next. Vehicles may travel loaded and return empty, or they may carry a light commodity one day and a heavy one the next. Pick-up-and-delivery operators have difficulty estimating their average weights, since the weight of a vehicle may change numerous times between the time it leaves a terminal and the time that it returns to it.

In addition, the Truck Inventory and Use Survey does not specify the road system on which travel occurs. If in a highway cost-allocation study some of the costs of a road system were to be distributed on the basis of VMT—the common costs of the primary road system, for example—then data on VMT by road system could help to accomplish this task. (Alternatively, common costs could be summed across all road systems and then divided by total VMT, but this would be considerably less precise.) Another limitation of the Truck Inventory and Use Survey is that it is conducted only once every five years, so that information for any current year must be projected by means of annual registration data.

Because of the separate limitations of the annual classification counts and the Truck Inventory and Use Survey, it appears that both must be used in developing a cross tabulation of VMT by road system and by type of vehicle. In addition to developing a cross tabulation by means of which these two sources of data are reconciled, it also appears reasonable to reconcile them with total fuel consumption, using estimates of fuel economy by class, as discussed below.

Fuel Economy

The tax on motor fuels, which yields more than two-thirds of all Highway Trust Fund revenues, produces more than six times as much revenue as the next largest tax paid by federal highway users. Payments of taxes on motor fuels depend on two things: VMT, as discussed above; and fuel economy, or the amount of fuel consumed per mile of travel. In spite of the enormous importance of fuel economy and VMT in determining payments of taxes on motor fuels, sufficient effort may not have been devoted to developing a good data base on this subject in earlier studies of cost allocation, particularly in view of the fact that some surprisingly large discrepancies between estimated VMT and the VMT implicit in the motor fuels tax collections reported by the Treasury Department were uncovered in these earlier studies. In particular, tax collections for diesel fuel, paid mostly by large trucks, have sometimes been far above the amount estimated by VMT and fuel economy. A discrepancy of this sort could be evidence that VMT estimates are in error, possibly distorting the balance between cost responsibility and highway tax payments significantly for the classes of vehicles involved.

By virtue of the intensified national interest in energy, there is now a greater body of information on the fuel economy of vehicles than was available for earlier studies. In particular, data on this characteristic began to be gathered in the Truck Inventory and Use Survey in 1977. There have also been more detailed investigations of fuel economy conducted as part of studies of energy conservation. Together, these should help to develop a sounder set of estimates of fuel economy.

Once a set of fuel economies of various vehicles has been estimated, it should be combined with estimates of VMT to determine the implied total fuel consumption. Comparing this total with the total fuel-tax collections reported by the Internal Revenue Service provides another means of checking whether estimates of VMT are reasonable and consistent with estimates of fuel economy.

Unlike some of the more controversial areas of highway cost allocation, the desirability of assembling accurate data on fuel economy and VMT is probably not disputed by anyone. Nonetheless, collection of such data for all states and all functional classes of highways would be an expensive undertaking. To the extent that sources of data now available are used, it should be recognized that technical reconciliations of data on VMT and fuel economy can have profound consequences on the tax burdens recommended in a cost-allocation study. For this reason, it is crucial that the technical judgments required to reconcile disparate sources of data be made in as well-informed and objective a manner as possible.

The improvisatory nature of the data-reconciliation process makes it impossible to offer, in advance, firm methodological guidelines as to the way VMT and fuel economy can best be estimated. Two procedural guidelines seem to be appropriate, however. First, the process of reconciling diverse estimates of fuel consumption, fuel economy, and VMT should not be left to any single person or agency, but should incorporate the views of persons who are fully acquainted with the nuances of each source of data. This could include representatives of the Department of Transportation, the Federal Highway Administration, the Department of Energy, the Bureau of the Census, the Internal Revenue Service, the Department of the Treasury, state highway departments, manufacturers of vehicles, and operators of vehicles. Second, the reconciliation process should be recorded in sufficient detail to present and evaluate all the basic data that are referenced and to describe all the steps that are taken to arrive at a "best guess" as to each characteristic that is estimated.

The fuel economy of future vehicles, particularly automobiles and light trucks, is expected to be significantly different from that of the vehicles now in use, as a result of high fuel prices and the fuel-efficiency standards set through the Energy Policy and Conservation Act and subsequent legislation. Part of this change is expected to come about through the increased use of diesel-powered automobiles. Both the type of fuel used by different classes of vehicles and their characteristic fuel economies will be changing during the course of the next highway cost-allocation study. These anticipated changes underscore the need for a careful, broad-based, explicit consideration of future fuel economies within the cost-allocation study.

Use of Tires, Tread Rubber, Inner Tubes, and Oil

The statistics in Table L-1 show that taxes on tires, tread rubber, inner tubes, and oil together account for about 15 percent of the revenues of the Highway Trust Fund, most of it coming from the excise tax on tires. As is true of the tax on motor fuels, it is assumed that consumption of these four commodities is closely related to VMT, although the rate of consumption may be changing because of new products, such as radial tires and synthetic oil. There are some trade statistics and data from manufacturers that can help in making direct estimates of the number of units of these commodities sold to each class of vehicles—something that cannot be done with respect to motor fuels. At the same time, taxes on tires, rubber, tubes, and oil represent a significantly smaller fraction of Trust Fund revenues than do taxes on fuel. Nevertheless, the pattern of consumption of these items may be shifting, and care should be taken to incorporate representative and up-to-date data, even though no major problems are anticipated.

Truck Sales and Use

In 1977, 13.1 percent of highway tax receipts came from the tax on trucks, buses, trailers, and associated parts and 3.6 percent came from the tax on the use of heavy vehicles. The tax on vehicles and parts, while not reported to the IRS by type of truck, could be separated into payments by each truck type by the use of data on new truck registrations. Similarly, the incidence of the tax on parts could also be estimated from data on truck registrations. 5/ It appears that existing sources of data offer an adequate

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5/ Several nongovernmental sources of data may prove useful in this area. The Motor Vehicle Manufacturers Association reports statistics on production, imports, and exports of new trucks. Several commercial sources, including R.L. Polk and MacKay and Co. collect data on truck registrations and the market for parts.

basis for producing a reasonable estimate of taxes paid on new vehicles and parts, by type of truck.

In the effort to estimate the incidence of the tax on the use of heavy vehicles, the Truck Inventory and Use Survey can be of some help. During the course of the cost-allocation study, this survey will provide data on the use of trucks of each type in 1977. These data can be updated by state registration and licensing data to estimate the stock and use of vehicles, as well as to estimate the tax paid for the use of heavy vehicles, for the years upon which the cost-allocation study is to be based.

Coordination

The Department of the Treasury is directed in the Surface Transportation Assistance Act of 1978 to conduct a study of the administrative aspects of highway taxes, and the tax on the use of heavy vehicles is expected to be one of the principal subjects of concern in that study. In addition, the act also calls for the Department of Transportation to examine the effects of certain changes in existing weight limits for trucks. These studies should be coordinated in an effort to produce reliable estimates of travel by classes of vehicles and the most detail possible on payments of the heavy-vehicle use tax. It is important to ensure the maximum amount of consistency among these studies because of the close relationship between the subjects involved.

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