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U.S. Department
of Transportation

Federal Highway
Administration

Methods for Allocating Highway Costs

April 1981

Final Rept. No. FHWA/PL/81/017

Notice

n Page

1. Report No.
FHWA/PL/81/017

2. Government Accession No.
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3. ---

4. Title and Subtitle
Methods for Allocating Highway Costs

5. Report Date
April 1981

6. Performing Organization Code
DTS-241

7. Author(s)
Douglass B. Lee

8. Performing Organization Report No.
SS-24-U.3-181

9. Performing Organization Name and Address
U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center, Kendall Square
Cambridge, Massachusetts 02142

10. Work Unit No. (TRAIS)
---

11. Contract or Grant No.
PPA-HW-115

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Highway Administration
Office of Program and Policy Planning
Washington, D.C. 20590

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
HPP-12

15. Supplementary Notes The purpose of this report is to advise the Highway Cost Allocation Study Team on the attributes of an economically efficient structure of highway user charges. Contract Manager: D. Symmes - HPP-12

16. Abstract Microeconomic theory and other concepts related to pricing are reviewed and applied to the problem of designing highway user charges. In view of the emphasis in the Congressional request for the Highway Cost Allocation Study on setting charges in accordance with costs occasioned, economic efficiency should be a major study goal. The goal of equity, whichever of its many meanings that term may have, remains an important consideration but not one which provides direct guidance for user charges. In regard to highway transportation, efficiency and equity do not appear to conflict in any significant ways.

Efficient user charges are based on variable costs, primarily pavement damage, vehicle interference, and negative external costs. In the absence of scale economies and inefficient investment, such user charges will exactly recover the full costs of constructing and operating the highway system. If residual costs remain, it is recommended that these costs be allocated to users by one of several methods for minimizing consumption distortions or improving equity. The several levels of government responsible for financing highways complicate the implementation of efficient user charges. The implementation problem is discussed, but no simple solution can be offered.

17. Key Words
user charges, cost allocation, efficiency, equity, common costs, benefit-cost analysis

18. Distribution Statement
No restriction. Document is available to the public through the National Technical Information Service
Springfield, Virginia 22162

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	79	

Form DOT F 1700.7 (8-72)

PREFACE

This report was prepared for the Federal Highway Administrations's Office of Program and Policy Planning, Highway Cost Allocation Study Team. The purpose of the report is to review and evaluate alternative theories and methods that might be used by the Highway Cost Allocation study for recommending Federal highway user charges to Congress.

In an effort to incorporate as broad a technical perspective as possible, an Outside Review Committee was established to comment critically on the work in progress. The academics and professionals listed below each reviewed two previous drafts of this report and met once in Cambridge with TSC and FHWA staff:

Florence Breen, Director of Planning and Programming, Georgia Department of Transportation

Richard deNeufville, Professor of Civil Engineering, Massachusetts Institute of Technology

Donald Dewees, Professor of Economics, University of Toronto

Milton Kafoglis, Professor of Economics, Emory University

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Herbert Mohring, Professor of Economics, University of Minnesota

Richard Zettel, Professor of Transportation Engineering, University of California at Berkeley

The time, effort, and patience provided by these committee members is gratefully acknowledged. In addition, valuable review and criticism were contributed by members of TSC's National Transportation Research Division, Thomas Harvey, Division Chief, by Donald Symmes and Anthony Kane of FHWA, by Martin Wohl, Faculty Fellow at TSC, and by Dale Stahl, University of California at Berkeley. Preparation of this report was the responsiblity of the Urban and Regional Research Division, David Rubin, Division Chief.

CONTENTS

1.0 SUMMARY AND RECOMMENDATIONS[1]

A new highway cost allocation study has been requested by Congress,[2] and work on it is currently underway in the U.S. Department of Transportation[3], based in part on recommendations from the Congressional Budget Office.[4] The direct stimulus for initiating a national highway cost allocation study at this time is the increasing divergence between costs of needed restoration and revenues raised from user charges. Also, the pattern of expenditures is changing from construction to restoration as the system approaches maturity. The tasks of the highway cost allocation study are to evaluate the current user charge structure and to propose new instruments and rates as may appear to be needed.

As regulatory restrictions on transportation are reviewed and evaluated, and policies implemented to encourage mode choice and investment decisions based on market incentives (e.g., deregulation), highway cost allocation procedures need to be considered in a new light. Competition between trucks and railroads, for example, is unlikely to improve resource allocation if each mode is subject to different cost recovery constraints.

Decisions about the correct amount to invest in highways ought to be based on measures of costs and benefits that are consistent across all modes, and decisions about the amount of revenues to be diverted from private to government use through taxation ought to be based on comparable measures of productivity between the private and public sectors. These decisions are inherently economic, so that the concepts of economics are essential tools in formulating the problem and evaluating alternatives. Although much of the knowledge from highway engineering that has contributed to highway cost allocation studies in the past is still essential, a strong infusion of economic theory is also necessary.

Parallels are becoming evident among many public services and regulated utilities, in regard to user charges. Electric power, railroads, inland waterways, telephones, postal services, airports, and highways, for example, are gradually being viewed with the same set of basic principles. The major objectives of user charges in these industries should be to:

(1) Obtain efficient utilization of available resources by setting prices so that users pay in relation to (if not equal to) the marginal costs of their usage;

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[1]Many technical terms are used in the introduction without attempting to define them first. A glossary can be found in Appendix C, just ahead of the references, and more complete definitions are contained in the sections on theory and methods.
[2]Surface Transportation Assistance Act of 1978, Sec. 506, 507.
[3]Federal Highway Administration, (January 1981).
[4]Congressional Budget Office, (February 1979).

(2) Provide guidance for future investment by requiring higher (if not full) cost recovery from user charges in the long run.

Attention to the first objective has increased as it has become apparent that artificially low utility prices encourage overconsumption and waste. Not surprisingly, the second objective has been followed in regard to regulated private monopolies but not with public enterprises such as highways. The problem of setting user charges in these sectors -- whether privately or publicly owned and operated -- is to reconcile the two objectives in a practical context.

Efficiency gains from better pricing of highway services might well be large. Maintenance expenditures alone amount to almost eleven billion dollars per year for the highway system as a whole.[5] An improvement in efficiency might mean that fewer trips would be made for which the benefits were less than the social costs, and other trips could be made where the reverse was true. If increased highway prices enhance the efficient use of scarce resources, then the consequence could be lower overall inflation and lower local property taxes, despite higher prices for highway travel and perhaps for highway-dependent goods and services. Undermaintained roads mean higher costs for users, in vehicle wear, accidents, and increased travel time, and deferred maintenance may lead to higher total costs in the long run. Setting efficient user charges is an important step toward directing resources into their most productive uses, whether for highways or for other purposes.

1.1 Summary

A sensible approach to setting Federal highway user charges requires study of the entire highway system, and assignment of responsibilities to the participating levels of government. The Federal share of costs and revenues cannot be determined in isolation from the system as a whole, in anything other than an arbitrary manner. The highway system is a single large economic enterprise, and it should be regarded as such.

In figure 1, four major task areas are emphasized:

(1) The full long run costs of the highway system should be estimated. Costs should include hidden and opportunity costs as well as direct government expenditures, for all levels of government and for all highway systems. Future costs will depend upon policies chosen with respect to standards of service quality and the road mileage in the system. Within the total cost framework, variable costs should be distinguished from the remainder of all costs.

(2) Prices based on variable costs should be estimated so as to encourage efficient utilization of the system and to guide future investment. Ideally, the prices should be related directly to

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[5]<u>FHWA</u> (1979).

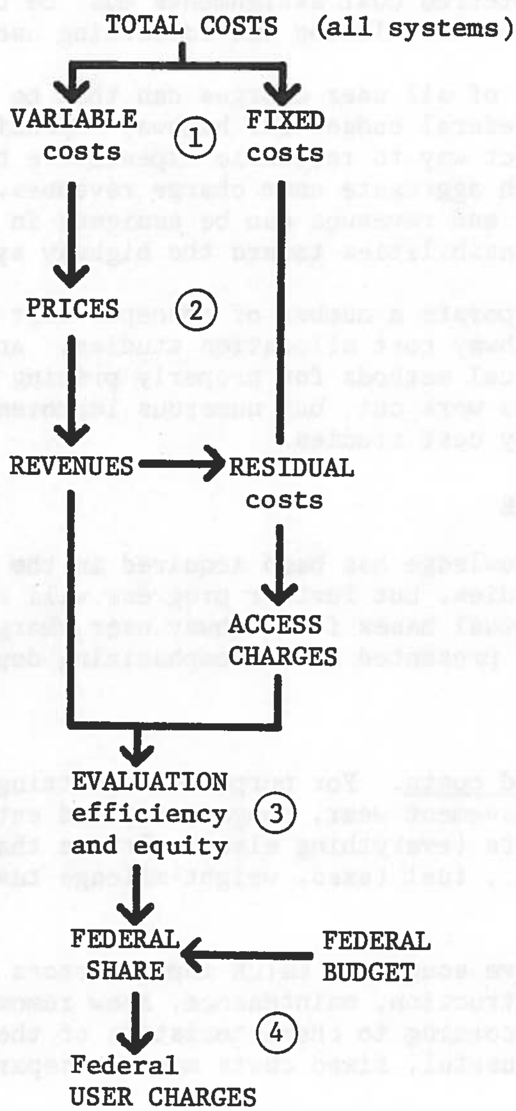

Figure 1. Schematic outline of Federal user charge determination.

usage, although access charges may turn out to be satisfactory practical compromises in some instances. Once prices are determined, the revenues raised by them can be subtracted from total costs to see if there is a residual.

(3) Both for prices and for any residual cost, alternative user charges and tax instruments should be evaluated against their efficiency, equity, and effectiveness in achieving stated public goals. Theoretically preferred cost assignments must be balanced against practical means for calculating and collecting user charges.

(4) The Federal share of all user charges can then be broken out, and compared to the Federal budget for highway expenditures. There is no uniquely correct way to reconcile expenditure needs for one level of government with aggregate user charge revenues, but the Federal portions of costs and revenues can be assigned in relationship to the Federal responsibilities toward the highway system as a whole.

These task areas incorporate a number of concepts that have not been implemented in previous highway cost allocation studies. An adequate information base and practical methods for properly pricing highway services will take time and effort to work out, but numerous improvements can be initiated in current highway cost studies.

1.2 General Recommendations

Considerable useful knowledge has been acquired in the process of conducting highway cost studies, but further progress will require restructuring of the conceptual bases for highway user charge analysis. General recommendations are presented below, emphasizing departures from traditional practice.

1.2.1 Variable versus fixed costs. For purposes of setting user charges, variable costs (primarily pavement wear, congestion, and externalities) should be separated from fixed costs (everything else). Prices that vary with the actual amount of usage (e.g., fuel taxes, weight-mileage taxes) should be based on variable costs.

Previous approaches have sought to match input factors (land in right-of-way, grading, pavement construction, maintenance, snow removal) with vehicle classes (autos, trucks), according to characteristics of the input factor. For this information to be useful, fixed costs must be separated from variable costs.

1.2.2 Residual Costs. If (as is likely to be the case[6]) there is a residual between revenues raised by variable user charges and full long run costs, the

[6]See the discussion of conditions leading to residual costs, in Section 4.1.

remaining costs should be financed according to the efficiency, equity, and effectiveness of alternative instruments.

Traditional methods have categorized subsets of fixed costs as "uniquely occasioned" and "jointly occasioned", assigning these costs to vehicle classes on the basis of incremental units of traffic or differential benefits to user classes. Other costs are identified as "common" and allocated to vehicles or classes according to some general indicator such as vehicle miles travelled. These methods are not firmly grounded in theory.

1.2.3 Full long run costs. All real costs should be accounted for within the highway planning and financing framework. These costs include depreciation (e.g., the wearing out of the highway even though nothing is spent on it), opportunity costs (e.g., interest or rate-of-return foregone on the investment in highway facilities), externalities (e.g., the damages resulting from noise and air pollution), and tax expenditures (e.g., services of general government for which the highway sector is exempted from paying).

Current practice in highway cost allocation regards only direct expenditures on highways as true costs. The costs just listed above are thought to be "phantom" or "intangible". Congestion costs are already paid by users, externalities can be regulated, and all these "unmeasurable" costs are thought to be more than offset by external benefits to the economy.

1.2.4 Breakeven criterion. Although economic theory does not necessarily require that highway users pay the full costs of building and operating the system, there are strong political, institutional, and economic rationales for imposing a full cost recovery constraint. Policy neutrality between modes and between public and private investment are two such reasons, both of which are especially important in the context of deregulation of transportation. Incentives for better resource allocation would be improved by asking highway users to pay the full costs directly. If the previous investment in the highway system was a sound economic decision, then current revenues from users should be capable of generating a healthy surplus over current expenditures.

The popular pay-as-you-go philosophy -- requiring each year's revenues to equal that year's expenditures -- has substituted for a more complete conception of a self-supporting public enterprise. Although equity has been interpreted to mean that each vehicle should pay for the costs it occasions, only current expenditures are treated as legitimate costs. The generally accepted notion that users should pay has not been extended to the point of asking users to pay the full bill.

1.2.5 Federal role. The institutional structure of fiscal and functional federalism is complex and in need of clarification. Highway cost responsibilities for each level of government are not based on a clear assignment of functional responsibilities, and revenue instruments are often divorced from cost responsibilites. Standards for truck sizes and weights, uniform accounting practices, and functional classification of highways are issues that probably should be resolved at the Federal level.

The scope of current efforts is limited to statutory obligations and expenditure budgets. Responsibilities are assigned according to system (e.g., Interstate, rural collector), yet functional classification and cost sharing are worked out largely on an ad hoc basis.[7]

1.3 Specific Recommendations

Applying the general principles listed above to the problem of setting highway user charges leads to the set of recommendations described below. Each recommendation includes (1) a list of the input factors that are relevant to estimating each major cost factor (pavement wear, vehicle interference, negative externalities, and administration), suggested methods for (2) measuring the cost and (3) attributing it to vehicles, (4) possible user charge instruments in descending order of likely preference, (5) proposed guidelines for establishing governmental responsibility, and (6) some practical obstacles to the implementation of user charges. The choice of the particular instruments and rates to employ will depend upon further evaluation of the impacts of the alternatives.

1.3.1 Pavement wear. Available evidence indicates that pavement damage for a given road segment is primarily a function of axle load applications, with damage increasing greatly with weight per axle. A strong conceptual basis exists for attributing the costs of restoring the pavement, and the costs incurred by other vehicles as a result of damaged pavement, to the vehicles causing the damage. Because the cost of the damage per axle load application is affected by the design strength of the roadway, the condition of the road, and weather, correct pavement charges should depend upon both the vehicle (axle weight, distance travelled), and the road (pavement thickness, structural number). Costs to other users are in the form of increased vehicle wear and operating costs due to reduced pavement quality.

(1) Input Factors: Cost items include pavement construction, restoration, rehabilitation, repairs, overlays, patching, maintenance, striping, safety markers, plus time and vehicle wear, excess travel time and accidents, and other private user costs from pavement damage.

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[7]So long as a coherent structure of cost and revenue responsibilities is lacking, it is conceivable that some level of government might have no residual costs even though the others did. If the Federal government, for example, set its user charges to recover the costs of all pavement damage on all Federal aid highways, revenues to the Federal government might exceed its budgetary requirements for highways. This could be because (a) the Federal government was collecting revenues for pavement damage but letting some other government carry the costs, or (b) Federal expenditures were less than the actual depreciation upon which the user charges were based, leaving deferred maintenance.

(2) Cost Measurement: Total input factor costs for a representative time period can be measured, for all highways or a representative sample. User costs from lowered pavement quality can be measured experimentally.

(3) Assignment to Vehicle Classes and Vehicles: Pavement stress is a function of vehicle weight, axle configuration, mileage by type and condition of highway, and weather conditions. Vehicle travel should be transformed into stress according to AASHO factors, and costs assigned in proportion to stress. User costs should be assigned in proportion to pavement damages. Opportunity costs (interest on the capital invested in pavement) should be excluded, as this is a fixed cost.

(4) User Charge Instruments: A weight-distance tax could be based ideally on actual weight and miles driven, for each vehicle, or based on gross vehicle weight and actual miles, or based on gross weight and average vehicle miles for vehicles in the class. As a crude approximation, the fuel tax could be used for part of the user charge, supplemented by annual or other use fees based on gross weight and average miles driven by vehicles in the class.

(5) Level of Governmental Responsibility: The Federal government should take primary responsibility for establishing standards for truck sizes and weights, measuring the relationships between weight and pavement damage, collecting data for determining user fees, and recovering the full costs of pavement wear from highway users. States might supplement Federal charges where, for example, weather conditions make pavements especially sensitive to damage, input cost factors are high, or maintenance practices differ from the norm. Both states and localities could impose charges and usage restrictions (seasonal, locational) on heavy vehicles (concrete mixers, bulk grain carriers) that use mostly local highways.

(6) Practical Problems: Knowledge of the pavement damage function is still weak, and AASHO factors do not cover all road types or all weather conditions. Data for a weight-mileage tax based on actual weight and actual miles driven, for each vehicle, are not currently collected, and a self-reporting system would require an enforcement effort adequate to ensure compliance. Costs based on historical maintenance and rehabilitation practices may be a poor estimator of future costs, although the user charge per unit of pavement stress could be adjusted in the future. Because major portions of the highway system are only now approaching the final stages of their original lifetimes, optimal pavement management techniques are still under development and may evolve in a form much different from current practices.

1.3.2 <u>Vehicle interference</u>. Congestion (excess travel time) and costs related to congestion (fuel consumption, accidents) reflect the competition between users for space on the highway. A user charge for congestion serves the purpose of efficiently rationing the available capacity, and offers a source of revenue that can be used to recover the fixed costs of the highway. If vehicle interference is present at moderate as well as high traffic volumes, congestion charges may be broadly applicable.

(1) Input Factors: Items include delay, driving strain and fatigue, accidents, and congestion-caused vehicle wear and operating costs.

(2) Cost Measurement: Delay can be measured by a number of methods, and can be simulated with existing quantitative models for some sets of conditions. Value of travel time has been imputed from actual travel behavior, although a wide range of uncertainty remains. Driving strain probably cannot be measured directly, but will have some effect on the value of travel time under congestion, as well as on the accident rate and severity. Property damage from accidents is reasonably well known on an actuarial basis, but considerable debate still surrounds the valuation of personal injury, especially fatalities. Selected congestion-related operating costs such as fuel consumption have been estimated in functional form.

(3) Assignment to Vehicle Class: Vehicle interference costs are primarily related to volume-to-capacity (V/C) ratios, with vehicle mix and type of facility having some effect as well. Mathematical relationships are required, because the correct price for user charges is the difference between marginal cost and average variable cost at the equilibrium level of usage. For a given level of congestion, the price charged per vehicle should be according to passenger-car-equivalent (PCE)-weighted vehicle miles.

(4) User Charge Instruments: Optimal tolls would be set for each facility to vary with demand, typically peak and off-peak. On facilities where usage is fairly constant and time of travel would not be elastic to the variations in price that would be efficient, a uniform variable charge such as a fuel tax could be an adequate approximation. Where daily demand variations are great, as in urban areas, congestion tolls might be approximated through parking surcharges and bridge or other special tolls. Capacity restrictions may substitute for tolls where other alternatives (e.g., exclusive bus lanes) are available.

(5) Level of Governmental Responsibility: Accident costs resulting from vehicle interference that are a consequence of vehicle characteristics (e.g., trucks vs. autos) may be charged at the national level, but most congestion-related costs vary greatly from place to place and hour to hour and could best be handled locally. Where nominally Federal facilities (e.g., Interstates) are used heavily for local commuting, congestion charges may be at least in part a Federal problem.

(6) Practical Problems: Although many persons regard congestion costs as real, only economists seem to accept the idea that congestion pricing is a suitable policy. Even within the professional community, the appropriateness of congestion tolls as a means for financing construction and maintenance is viewed with skepticism. Mechanisms for setting and collecting congestion-related user charges are currently very crude and limited, and more precise instruments will require substantial effort for both development and implementation. Cooperation will be required among all levels of government if congestion charges are actually collected.

1.3.3 Negative Externalities. The effects of noise pollution and other negative externalities from highway use constitute real costs to society and the individuals who suffer the impacts, but dollar amounts do not appear in government budgets. Highway user charges should include disincentives to the generation of these costs, even though the precise dollar value of the negative impact will probably never be known.

(1) Input Factors: Included are damage from air pollution, water pollution, noise, danger to non-users, and costs of cleanup and control.

(2) Cost Measurement: The three major methods are measured damage, revealed preferences, and optimal control costs. Sometimes these can be used independently and reconciled. Environmental economists have made progress in measuring environmental effects and placing values on those effects, although a large range of uncertainly still exists.

(3) Assignment to Vehicle Class: For those categories of negative externality resulting from vehicle emissions (air, water, and noise pollution), a charge based on actual emissions is ideal. For the others, actual impacts would need to be measured and priced. Each vehicle would pay according to the time and place of impacts.

(4) User Charge Instruments: A fuel tax increment would vary with the amount of travel for each vehicle, but would have several disadvantages. First, the relationship between cost incurred and charge paid would be very weak. Second, no incentive would be present to encourage reduction of the cost except insofar as this would result from less consumption of fuel. Annual or other access charges could be based on emissions characteristics of the type of vehicle (e.g., heavy dump truck used in urban areas) and the average amount and location of travel. Lower charges might be levied on individual vehicles possessing emissions characteristics lower than the class average. No incentive to reduce travel, however, is created by a tax on the emission rate.

(5) Level of Governmental Responsibility: For vehicle characteristics and operating conditions that are consistent across the country,

Federal user charges would be suitable. Congestion and externalities are generated primarily in urban areas, and charges for such localized impacts should be based on local conditions and collected locally.

(6) Practical Problems: As with congestion, the rationale for pricing externalities is not widely accepted. Negative externalities do offer an argument for increasing Federal user charges, and the revenues can be used for construction and maintenance purposes if there is no need to compensate those detrimentally affected. Dollar valuation of externalities can only be estimated indirectly, leading to numbers that have high variances relative to the true values.

1.3.4 Administration. Some of the costs of managing and administering the highway system vary sufficiently with usage to be regarded as variable costs, although they could also be treated as fixed costs. The dollar magnitudes are relatively small, and user charges should cover these costs one way or another.

(1) Input Factors: Major items are highway patrol, traffic police, litigation, accident costs not related to congestion, weather monitoring, and advisory services.

(2) Cost Measurement: Add up the applicable budget items.

(3) Assignment to Vehicle Classes: These costs can be assigned according to some measure of usage such as vehicle miles of travel, PCE-weighted VMT, or ESAL-weighted VMT.

(4) User Charge Instruments: A fuel tax will fall most heavily on VMT and secondarily on PCE- and ESAL-weighted VMT.

(5) Level of Governmental Responsibility: The Federal government should recover its own administrative costs, and the states and localities should do the same.

(6) Practical Problems: These costs may be variable in the short run in only a very rough way, so that a variable charge is not essential to efficiency. The magnitude of the costs and their imprecise relationship to travel suggests that the costs can be recovered in any one of several acceptable ways.

1.3.5 Equity impacts. The recommended strategy outlined above places heavy emphasis on efficient utilization of the existing highway system and guidance toward efficient future investment. Equity impacts, however, should not be ignored in this process. All proposed sets of user charge instruments should be analyzed with respect to their impacts on different groups. Potential groups include transportation disadvantaged, rich versus poor, competing transportation modes, capital versus labor, urban versus rural, and any other demographic or economic subgroups that may be identified as important. Where impacts are adverse or unacceptable for whatever reasons, efficient user charges may need to be adjusted to correct for the impacts. In general, many compromises will need to be made in setting efficient prices, and the numerous alternatives can be evaluated on equity as well as efficiency grounds. Although equity principles do not provide strong guidance for designing specific user charges, equity can be a major criterion in choosing among second-best user charge programs.

Efficiency goals and equity constraints are sufficient to completely resolve the user charge design problem without explicit consideration of, for example, any fixed cost components. For practical reasons, however, residual cost and intergovernmental problems are likely to remain.

1.3.6 Residual Costs. There is a distinct possibility that user charges based on short run marginal cost would recover full costs, and it is quite likely that correct prices would more than cover actual expenditures. Even if ideal instruments (e.g., a congestion toll) are not feasible, the corresponding revenues can be raised by some other user charge instrument (e.g., fuel tax or registration fee). An access or readiness-to-serve charge can be used to approximate what ideally should be a charge tied directly to usage, but the basis for setting the charge should still be the pricing of variable costs. Compromises can be designed so as to minimize distortions under the constraint of a given set of feasible user charge instruments.

Nonetheless, residual costs may remain after all variable costs have been priced as well as they can be. Depending upon the magnitude of the residual cost problem, different approaches can be elaborated and used in conjunction with each other.

(1) Subsidy from General Revenues. All, none, or some portion of residual costs may be covered by revenue from general taxes. A decision to use general revenues for highway purposes should be made on the basis of the justification for a subsidy (such as increasing returns to scale), and not on spurious arguments about non-user costs and external benefits.

(2) Incremental Fixed Costs. Many professionals and policy makers regard the assignment of certain expenditure items to associated vehicle classes as equitable. For example, the costs of weigh stations can be assigned to trucks and the cost of guardrails to autos. Such assignments have an inherent degree of arbitrariness to them, but methods are available for placing bounds on reasonable solutions. No group of users should have to pay more overall than they would pay for a separate system of their own. The preferred revenue instruments are access changes.

(3) Benefits. If emphasis is placed on the resource allocation that results from marginal cost pricing of the existing system, then residual costs should be covered by taxes that change resource use

to the smallest degree. To the extent that taxes are imposed on users, they can be scaled according to ability-to-pay, consumer surplus, the inverse of the consumer's demand elasticity, or benefits to the user. All these strategies are essentially similar.

(4) Long Run Marginal Cost. If the capital stock is far from what would be optimal for expected demand conditions, efficient prices may be nowhere near ideal prices in the long run. Instead of relying on the combination of short run marginal cost for setting prices and efficient investment programs for adjusting the scale of the highway system, prices can be set directly at long run marginal cost. The rationale for this strategy is to avoid misleading signals for investment in related activities as well as highway transportation. Housing and factories might be constructed in remote locations on the assumption of continuing cheap highway transportation, when long run costs were understated by current prices. Despite its intuitive appeal, long run marginal cost pricing is neither an alternative to efficient pricing nor a distinct method for cost estimation. No theory supports the efficiency of pricing <u>directly</u> at long run marginal cost, and the other apparent purposes are better handled by means of the concepts already described immediately above. If prices based on the existing capital stock are thought to be misleading, prices can be based on some planned future capital stock.

(5) Distributional Equity. Alternative access charge instruments can be compared as to which groups of the population ultimately bear the costs. Choices will depend upon judgments about which groups are more deserving.

(6) Effectiveness. Choices among user charge instruments can also be based on the effectiveness with which each attains various transportation and non-transportation public goals. Impacts on mobility of the elderly, employment, or urban revitalization may be considered, but the relationships are likely to be weak and the cost-effectiveness poor (see Appendix B).

Table 1 shows generally how the type of user charge should be matched with cost categories and revenue instruments. User charges based on variable costs are the most difficult to collect, while access charges are supported by the weakest technical rationale for setting the dollar amounts.

1.3.7 <u>Covering the Federal budget</u>. Technical analysis can provide some insight into prices (in the form of user charges), but not much guidance for establishing <u>portions</u> of prices. It is possible to comment on the efficiency and equity of a complete structure of user charges, but not on an isolated slice of that structure. The problem is greatly compounded by the constraint of raising revenues to meet an <u>expenditure</u> budget rather than a mandate to meet all costs. Thus the only suggestions that can be offered are nothing more than possible bases for gentlemanly intergovernmental agreement.

Table 1. Types of revenue instruments

type of revenue source	user charge ?	relevant cost categories	example revenue instruments
marginal cost prices	yes	variable costs	weight-distance tax
access charges	yes	residual costs	registration fee
general revenues	no	residual costs	property tax

(1) Total budget: Congress will determine the total Federal portion of the highway budget, in consideration of Federal-Aid highway system needs, the Federal share of cost responsibility in different expenditure categories, and national policies with respect to growth and consolidation of all transportation networks.

(2) Federal expenditures: About 90% of the eligible expenditures on the Interstate system and 75% on the remainder of the Federal-Aid system are paid from the Federal budget. Eligible expenditures include construction, reconstruction, and some types of maintenance, but these distinctions are awkward and are tending toward greater inclusiveness. Pavement wear is clearly included, but congestion and externalities are not covered in the budget.

(3) Federal user charges: A precise Federal pavement charge might be based, for example, on the actual ESAL stress placed on Federal highways, the share of pavement costs paid by the Federal government, and the cost per ESAL for the relevant pavement structure and condition, for each vehicle. Other levels of government would be assumed to raise the non-Federal portion and all charges on non-Federal highways. If this did not raise sufficient revenues to meet the budget, congestion and/or externality charges could be included up to the necessary level. A breakeven constraint for full costs (not just expenditures) would require that opportunity costs as well as expenditure categories be fully allocated.

1.4 Issues in Highway Finance

Mention of some of the issues that are related to the Federal highway cost allocation study will serve to illustrate the difficulty of the technical and political choices that need to be made:

(1) What share of costs should be borne by trucks versus autos, and heavy trucks versus light and medium trucks?

(2) Should the general taxpayer provide direct financial support to the highway system?

(3) What investment pattern would emerge if both railroads and heavy trucks paid the full costs of their travel?

(4) To what extent can and should highway user charges serve efficiency objectives as well as equity objectives?

(5) Should the national highway system continue to expand, stabilize at its present network, or become consolidated into a smaller and perhaps more cost-effective system?

(6) How should static or declining revenues from highway users (e.g., from the gas tax) be reconciled with inflating costs, by increasing revenues or decreasing costs?

(7) Should the highway system be self-supporting in the same way a private industry meets costs, or should highways be provided as a public service?

(8) To what extent should highway user charges attempt to serve indirect transportation and nontransportation objectives?

(9) Should costs be apportioned among vehicle classes according to capital costs "occasioned" or variable costs imposed?

(10) Should the existing system be regarded as something that has already been paid for and therefore free, or should user charges reflect an opportunity value of the system in place even though no expenditures are made, say, for new right of way?

2.0 GENERAL CONCEPTS[8]

Two guiding concepts -- efficiency and equity -- are useful in designing and implementing highway cost allocation methods. Short run efficiency is concerned with the utilization of given facilities and emphasizes variable costs; long run efficiency is concerned with the design of and investment in capital facilities and considers all costs. Equity is concerned with the distribution of costs and benefits among individuals and groups within society. Valuable theory is gradually evolving for designing cost allocation studies based on these two concepts, but the puzzle has many interrelated dimensions and compromises are inevitably required in applying the theory to practice.

2.1 Efficiency

Although efficiency is a term that is not mentioned in the Congressional request for the Federal study, the concept is highly relevant. An efficient use of resources is one for which no individual can be made better off without making someone worse off. Assuming exchange takes place in properly functioning markets, the efficiency goal is to maximize the net benefits to society as a whole from the initial endowment of resources.

The economists' notion of efficiency squares with the popular idea of fairness, which says that those who create costs should be the ones to pay for them. If, for example, pavement wears out because of the passage of heavy vehicles, then it seems fair that those vehicles should pay for the restoration of the pavement and other resulting costs. It is also efficient that they do so, because then they will consider the costs to society in making their decisions about using the highways. Charging vehicles according to the costs they occasion is efficient because it encourages users to reduce those costs (e.g., by carrying the same weight on more axles) and make sure that the benefits derived from travel are greater than the costs created.

2.1.1 Short run efficiency. Any period of time for which some input factor is fixed is considered to be the short run. For highway cost allocation, the fixed factors are those that pertain to the facility or facilities that are available at a given moment. Thus the short run applies to any length of time for which design characteristics and capacity cannot be altered to any significant degree. The time period involved might be anywhere from less than an hour (for peak congestion) to ten or twenty years (for a pavement restoration cycle).

The criterion for short run efficiency is price equal to marginal cost, i.e.,

$$P(q) = MC(q)$$

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[8]The brief explanations of efficiency and equity presented here are for purposes of review and defining terms. More thorough explanations can be found in such microeconomic texts as Nicholson (1979).

where price and marginal cost are both functions of the same measure of output, e.g., vehicle trips. Only costs which vary with output in the short run are relevant to this criterion. Some of the costs are paid directly by users (e.g., vehicle wear), some are paid by users but according to average variable cost rather than marginal cost (e.g., travel time), and others are not paid at all by the user unless the public sector charges a price (e.g., pavement wear). Thus the public sector has a reason to charge a price explicitly whenever the public sector is providing the input (the facility) or when marginal social cost deviates from private cost.

The major costs which fit this description are pavement wear, vehicle interference (congestion, accidents, and congestion-related operating costs), and external costs such as noise and air pollution. The major problems in implementing marginal cost pricing are (1) obtaining the empirical information upon which to base charges, and (2) devising effective and administratively feasible instruments for collecting the charges.

2.1.2 Long run efficiency. With all input factors variable in the long run, efficiency requires an additional criterion, which is

$$P(q) = LRMC(q)$$

i.e., price equals long run marginal cost. The long run efficiency criterion takes short run efficiency as given, so that the combined result is

$$P = SRMC = LRMC$$

In the short run, price is adjusted to equal marginal cost, but in the long run it is the supply side that is adjusted through investment or disinvestment. For example, if marginal cost prices yield revenues below total cost (under constant returns to scale), the system is too large and should be scaled down.

Obtaining the optimum investment in capacity and design attributes is accomplished through analysis of incremental costs and benefits. Identifying those who benefit from a particular change in investment does not imply that those who benefit should bear the costs, however; efficiency only requires that the correct investments be made and that short run prices (based solely on variable costs) be correct. The choice of quality and amount of investment will have an effect on the prices that should be charged, but there is no inherent connection between the justification for the investment and the charges levied on users. A connection can be made, but it is a matter of something other than pure efficiency. A fuller explanation of efficiency theory as it applies to highway cost allocation is contained in Appendix A.

2.2 Equity

In contrast to efficiency, equity is a term that is frequently mentioned in cost allocation studies. Unfortunately, usage of the term often implies meanings that are vaguely reasoned or inconsistent. As mentioned above, it is thought equitable if the users of the highways pay for the costs they occasion, although support for this principle is found in the efficient employment of scarce resources rather than in the equitable distribution of a tax burden. Equity provides very little positive guidance for setting user charges, leaving plenty of room for judgmental or political decisions.

Two broad concepts of equity can be drawn upon for evaluating and modifying user charges. One is horizontal equity, which refers to the equal treatment of equals. Two vehicles which are alike in all important aspects -- size, weight, miles traveled, location, and the like -- should be charged the same amount. Distinctions made on arbitrary grounds between classes of vehicles tend to create inequities if the distinctions are used for setting fees. The second equity concept is vertical equity, which suggests that consumers creating more costs or receiving greater benefits pay correspondingly more. The concept of vertical equity can also be extended to the indirect impacts of highway user charges, by considering the income circumstances of the person who ultimately bears the charge; a user charge scheme that creates benefits to the rich at the expense of the poor is said to be inequitable. Operationally, equity implies taxation on the basis of benefits received or ability to pay, not cost occasioned.

Assessing the equity impacts of a highway cost allocation scheme involves three elements: (1) determination of a reference distribution of who pays for the system and who benefits (which may be the current distribution or some other) to be used as a base alternative for comparison; (2) estimation of the transfers (who gains and who loses) that will occur as a result of the proposed cost allocation versus the base alternative; and (3) evaluation of the acceptibility of these transfers. The first two elements are largely technical problems, whereas the third is mainly political.

2.3 Equity Impacts on Efficiency

The major linkage between equity and efficiency is the effect of alternative distributions of income on the short and long run efficient outcome. For example, a set of user charges that leaves relatively more income in the hands of heavy freight shippers than commuters will result in more demand for heavy truck roads than for commuter facilities. Whether this demand shows up in a cost-benefit analysis or an expressed willingness to pay in a market, the efficient outcome will be more heavy truck roads in the one case than in the other. Non-highway activities are indirectly affected. Both outcomes can be efficient, but they depend upon different initial income distributions or resource endowments. For a given initial distribution of income, there is one efficient outcome.

Placing some of the costs of the highway system on property taxpayers instead of users will place relatively more resources in the hands of users and result in an efficient outcome that has relatively more highways and relatively less of something else. Thus the tradeoff between efficiency and equity is less a problem of giving up some of one in order to gain more of the other, than a problem of understanding how efficiency and equity goals are interrelated.

2.4 Second Best Compromises

Many compromises must inevitably be made in approximating an ideal set of user charges. Some problems arise because actual markets will not respond properly to correctly set prices, so that the prices need to be adjusted to compensate for the biases. Other problems arise because ideal user charges are effectively impossible or infeasible to implement. Despite the necessity for compromise, the normative goals of efficiency and equity are still useful in choosing among the welter of imperfect policies.

2.4.1 Market failure. The short run efficiency criterion relies upon proper functioning of all markets in order to optimize any given market. If some markets are distorted (e.g., through incorrect pricing, monopoly, external costs) then there is no assurance that setting price equal to marginal cost in the given market will improve net social benefits. For example, if prices of competing transportation modes are below their marginal costs, then raising the price of one of them will mistakenly divert consumers to the other modes. With perfect information it might be possible to calculate the correct prices under such conditions, but the task is substantially more difficult than under first best conditions.

Transportation modes in general -- both passenger and freight -- do not appear to be recovering their full long run costs from user charges. Because of the importance of the highway system within the transportation sector, pricing and investment policies governing highways affect pricing and investment on competing and complementary modes, while the reverse is less true. Improvements in highway cost allocation thus would have favorable effects on other modes and interrelated sectors of the economy.

Other market imperfections stem from the lumpiness of investment, which could prevent facilities from being sized at the optimum; from lags in or obstacles to the response of prices and capacity to demand; from long run scale economies, which require prices higher than marginal cost to maintain the firm in business; and from political and equity constraints imposed on resource allocation decisions.

2.4.2 Approximating the ideal. Even in the presence of numerous forms of market failure, it is still theoretically possible to calculate an ideal set of user charges. Perfection would require, however, that the prices vary instantaneously with changes in the volume of traffic, the mix of vehicles, the condition of the road, the design characteristics of the road, weather, and many other factors. The charges would be different from moment to moment and from place to place, for each vehicle, and the user would need to know much of this information in advance.

No reasonable person would advocate such precision. Telephone pricing is based on a three-tiered rate structure for time of day, and this variation only applies to long distance calls. Highway congestion charges might work effectively with two tiers (peak and off-peak), implemented only in large urban areas, or congestion tolls may be levied indirectly through fuel taxes. The first strategy will go much farther in encouraging efficient usage of urban commuter highways, but the second may be the best that can actually be accomplished.

The more restrictive the constraints, obviously, the greater the sacrifice in efficiency. For a given set of constraints, alternative sets of user charges can be evaluated by estimating the likely responses to the charges and tracing the impacts. If demand elasticity, for example, is so low that an access charge will produce essentially the same results as a charge based on actual usage, then whichever instrument is easier to collect can be employed. The costs of imposing a constraint (e.g., no weight-distance tax) can be estimated by comparing the efficiency and equity impacts of the best sets of user charges with and without the constraint. Achieving closer conformance to a theoretical ideal is of no benefit if the practical difference is insignificant. These practical differences can be of two kinds: improved utilization of the existing capital stock from more efficient pricing, and improved resource allocation in transportation and related sectors in the long run.

3.0 VARIABLE COSTS

The most important distinction that can be made in cost allocation is to separate variable from fixed costs. Variable costs are those that are directly related to usage in the short run, while fixed costs are those that do not vary with usage. In the long run, all cost factors are variable, so the distinction between variable and fixed costs depends upon having a particular short run perspective in mind. Because the primary purpose of a highway is to provide for vehicle trips, the most suitable guideline for defining variable costs is to consider those costs that will increase as the volume of traffic increases: pavement wear, congestion, accidents, fuel consumption, wear and tear on vehicles, noise, air and water pollution, traffic code enforcement, and other aspects of highway administration. Table 2 gives a more complete listing.

A misunderstanding of this principle has resulted in the application of variable cost concepts to fixed costs, and the converse, in previous cost allocation studies. In the long run, both right-of-way and pavement wear vary with the volume (or design volume, or capacity) of use. In the short run, however, right-of-way does <u>not</u> vary with traffic volumes, while pavement wear does. Lumping both variable and fixed costs together in the same bundle or treating the two types of costs in the same way means that at least some of the cost concepts being used are inapplicable or incorrectly applied.

For variable costs, the central concept -- users who create the costs should pay for them -- is relatively uncontroversial, and the remaining issues are empirical and practical. We need to know, for example, how to measure the damage done to various types of pavement by various types of vehicles and how to measure the interference effects of different mixes of vehicles at different volumes on different types of roads. Relationships need to be stated in functional form so that distinctions can be made between average and marginal costs if necessary. Most variable costs differ greatly by time and place, implying that very complex pricing instruments would be required to satisfy the ideal. In addition, the data and functional relationships upon which to base the charges leave many uncertainties, some of which are unlikely ever to be completely cleared away. Thus the benefits of efficient prices have to be judged against the costs of imposing them, and acceptable compromises found.

3.1 Pavement Wear

The best available information on the effect of vehicle weight and axle configuration on pavement wear comes from the AASHO Road TEST.[9] Given the design of a pavement, equivalent single axle load (ESAL) factors for each vehicle type can be used to compare the relative wear caused by each vehicle; if the lifetime of the pavement can be stated in units of standard axle loadings, the share of each vehicle in the lifetime cost of the pavement can

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[9]American Association of State Highway Officials, (1962).

Table 2. Variable costs

general category	cost components	measure of usage
pavement wear	pavement construction pavement restoration, rehabilitation, repair overlays maintenance, patching, chipseal, pavement markings,	standard axle load equivalent miles
administration	highway patrol, traffic police congestion reporting weather and conditions monitoring, reporting	vehicle miles or PCE miles
accidents	property damage injuries and fatalities policing and public medical service insurance administration safety markers	expected value of risk exposure
congestion	travel time, excess delay vehicle interference driving strain	passenger car equivalent miles
user costs	fuel consumption, fuel savings vehicle wear and tear oil, tires, spare parts damaged shipments discomfort	
external costs	noise air pollution water pollution physical danger visual intrusion litter	

be calculated. Assuming no interaction effects among vehicles with respect to pavement damage, the cost of each vehicle class is simply the result of summing the vehicle miles traveled by the class times the cost per vehicle mile for the class. In this manner, pavement costs can be "allocated" to vehicle classes.

The dollar value of the pavement damage caused by the passage of a vehicle over a pavement is not currently known, however, nor can the amount of damage caused by a single passage be measured except under extreme circumstances. What _is_ known is roughly this:

(1) For a given highway (cross section, geometry) and weather conditions, the amount of pavement life consumed by the passage of an axle increases with the fourth power of the weight on the axle (figure 2a);

(2) The number of axle load repetitions of a given weight a pavement will withstand before failing goes up with the seventh power of the thickness of the pavement (figure 2b);

(3) The lower is the pavement quality of a given highway type, the greater is the reduction in pavement quality caused by an additional axle load application (figure 2c).

The first relationship permits the amount of pavement "stress" caused by any vehicle to be stated in standard ESAL units.[10] The standard axle is taken to be a four-wheel single axle carrying a load of 18,000 pounds. Once the

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[10]Take for example, a one-mile segment of highway that serves the annual distribution of traffic shown in the table below. Each vehicle class exhibits a different amount of usage and creates a different amount of pavement stress per vehicle. By converting the amount of pavement stress caused by each vehicle into a single measure -- equivalent single axle load vehicle miles of travel -- the total pavement stress can be measured in one dimension. In the example, the 5.5 million vehicle miles of travel generated by all vehicle classes creates 1.2008 million ESAL-VMTs of pavement stress per year.

vehicle type	VMT/year (million)	ESAL factor	MEV
light	4.0	.0002	.0008
medium	1.0	.2	.2
heavy	.5	2.0	1.0
total	5.5		1.2008

VMT = vehicle miles of travel
ESAL = equivalent single axle load
MEV = million ESAL-VMT's

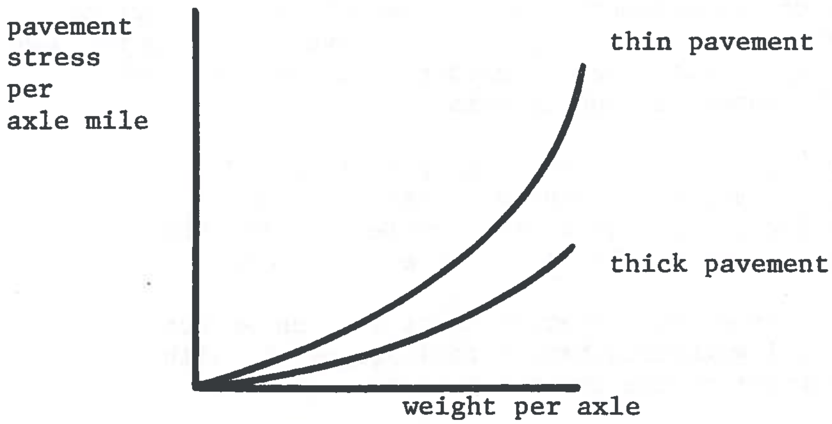

Figure 2a. Axle weight versus pavement stress.

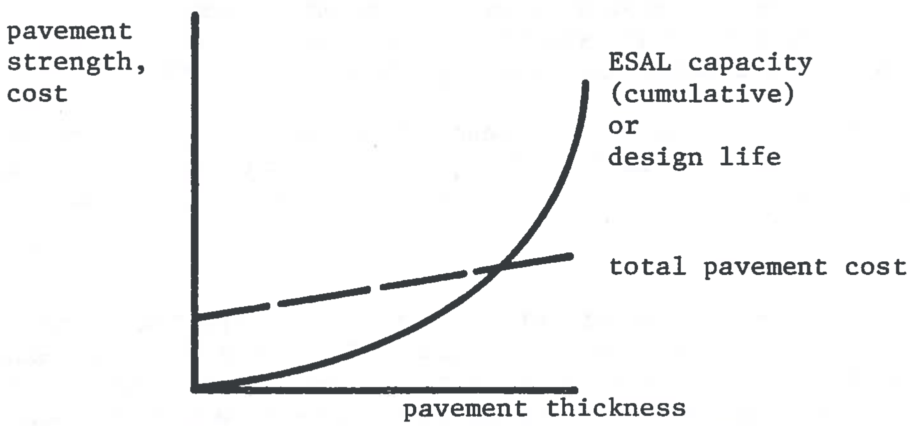

Figure 2b. Pavement thickness versus strength.

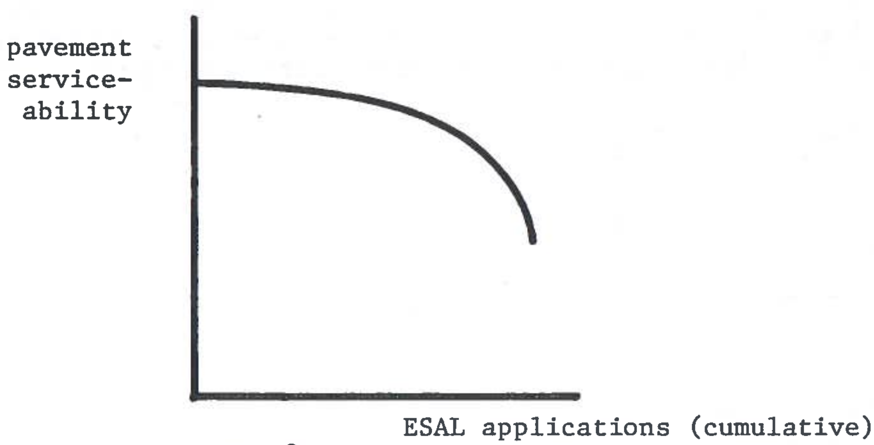

Figure 2c. Axle loadings versus pavement wear.

cost per ESAL is determined, the cost per mile for any type of vehicle can be calculated.

Because "damage" from one vehicle is so difficult to measure, a macroanalytic approach is required: the total cost for some aggregate amount of pavement capacity must be estimated, and allocated to the associated traffic on the assumption that each ESAL costs the same amount.[11] For a given road (design structure and present condition), the cost of maintaining the road at a constant strength and condition would be spread over the associated traffic load. Whatever the time period that constituted a complete restoration cycle for the type of road, the dollar cost of the maintenance program would be divided by the aggregate ESAL stress to determine a cost per ESAL for the road type.

Several sources of data can be drawn upon. The first is field experience, using estimates of maintenance and reconstruction costs for various actual highway segments, provided by highway engineers engaged in taking care of the system. The second is from laboratory tests that predict the amount of stress that can be withstood by a particular design under given weather conditions. The third is direct measurement of pavement serviceability, vehicle counts by type, weather, and actual costs for reconstruction and maintenance. These sources differ conceptually in subtle ways, but they should all be used and the estimates reconciled.

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[11]Suppose that pavement restoration on a given mile of highway goes through a three-year cycle, with two years of maintenance at \$10,000 per year and one major restoration at \$100,000. Assuming these values are measured in constant dollars, the total for the cycle is \$120,000 or \$40,000 per year. The pavement wear cost per ESAL will be approximately

$$\$/\text{ESAL} = \frac{\text{average annual cost}}{\text{average annual ESAL-VMTs}} = \frac{\$40{,}000}{1.2008 \text{ MEV}}$$

$$= \$.0333$$

A heavy truck would be charged 2 x .0333 = \$.067/vehicle mile of travel, a medium vehicle would pay \$.0067, and a light vehicle would pay \$.000007 per vehicle mile, for pavement wear.

Note that in neither case was interest or opportunity cost included. The greater the effective thickness of a pavement, the lower will be the wear per ESAL mile but the higher will be the total opportunity cost. Marginal cost pricing will only recover the wear cost, assumed to be constant per ESAL mile in the above calculations. The opportunity cost of the capital imbedded in the remaining service life of the pavement is a fixed cost that is either recovered through congestion tolls or left in the residual cost category.

The second relationship stated above implies that the price charged per vehicle mile should decline with approximately the seventh power of the pavement thickness. For example, the price per mile on a heavy duty highway of 16" pavement would be much less than half the cost of the same vehicle on an 8" pavement. The actual relationship depends upon the cost of maintaining thicker pavements, but this cost goes up linearly or less with thickness.

The third relationship implies a need to restore pavement quality before it deteriorates past the level at which it can be readily rehabilitated. The optimal maintenance program is the one which provides the lowest lifetime cost per ESAL for a given pavement, traffic mix, and weather.[12] Pavement serviceability can be measured fairly well, and gives an indication of the useful life remaining.

Several practical problems arise in quantitatively estimating pavement wear costs per vehicle, for different highway segments and subsystems:

(1) The actual mix of vehicles using each segment of road is generally not known in detail, and the costs depend heavily on which vehicles use which types of roads. Collecting these data is an initial step of high priority.

(2) The AASHO Road Test results are useful and reliable, but they do not cover all types of roads and all weather conditions. Light duty roads and extreme weather conditions can lead to high vulnerability of pavement to damage, and local data must be relied upon for calibrating these relationships.

(3) The Road Test also did not evaluate alternative maintenance, reconstruction, and rehabilitation programs, many of which have changed since the tests were conducted. Optimal pavement management programs, and their relationship to the actual mix of vehicles using the highways, are not yet well developed and have only recently been given attention. Full life cycle pavement costs are the result of a blend of construction plus maintenance costs.

(4) If an ESAL factor is assigned to a particular vehicle type, an implicit assumption is made that the vehicle always carries the same load. Although actual weight distribution by vehicle class may follow consistent patterns, simply dividing up the total cost on the basis of potential carrying capacity is significantly divorcing the price charged from the cost created.

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[12]A recent report on maintenance practices is Transportation Research Board (1979). Cost estimates should be based on actual practice even if this does not constitute the most efficient production of pavement. Maintenance practices may lag behind the best available, and funding allocations may be restricted to construction purposes (leading to high initial cost), but that is the reality. If the "best" practice is evolving rapidly, estimating future costs from historical data becomes more difficult.

Empirically, the amount of pavement damage done by heavy trucks is so many times greater than the amount done by light vehicles that pavement costs could be fully assigned to medium and heavy vehicles without significant error. This does not eliminate the problem of calculating different factors for different vehicle types -- especially at the high end of the scale, where small increases in weight lead to greatly increased damage -- but the focus can be on heavier vehicles.

Pavement quality has an impact on user costs in the form of vehicle and tire wear, driving strain, reduced speed, and other operating costs. In deciding on the level of quality to construct and maintain, user costs should be balanced against the costs of higher quality pavement. Because optimum pavement design and maintenance should minimize the sum of pavement damage plus user costs, the unit cost of an ESAL application includes both components. At one extreme, the road would be restored immediately after the passage of each vehicle, in which case the costs would consist entirely of pavement restoration. At the other extreme, the road might never be restored, in which case the costs would consist entirely of reduced user benefits and increased user costs. With periodic rehabilitation of the pavement, the difference in user costs between the original pavement quality and that at later stages in the restoration cycle form part of the total cost of pavement wear.

Ideally, the cost per ESAL for each type of road and weather conditions would be estimated from laboratory tests and field observations, and the actual VMT by road type and actual loading would be recorded for each vehicle using the highways. This information is more than simply nice to have, it is essential; the total bill for each vehicle cannot be determined without knowing the unit price and the quantity consumed. If the data are not obtained, they must be guessed at.

An example may serve to illustrate the problems and the possibilities. Fuel consumption is a function of actual weight and actual VMT, so that a fuel excise tax will rise with both variables. Suppose that a fuel tax rate were set so as to raise revenues approximately equal to total pavement damage, and the two curves were superimposed as in figure 3. The exact shapes depend on many unknowns and are averages anyway, but there is little doubt that the fuel tax will overcharge light vehicles by a modest amount and undercharge heavy vehicles by a large amount. To correct this, an annual fee might be levied that credited or taxed each vehicle based on its type, the salient feature of vehicle type being average annual ESALs. The loss in efficiency from collecting part of a variable cost by means of an access charge would depend, as shown in figure 4, on the vehicle's price elasticity of travel with respect to the variable charge.

3.2 Vehicle Interference

Any unit costs that are affected by the presence of more than one user on the same facility can be regarded as interference costs. The major ones are congestion, accidents, fuel consumption, and wear and tear. Time costs go up for each vehicle as more vehicles enter a given traffic stream, resulting in

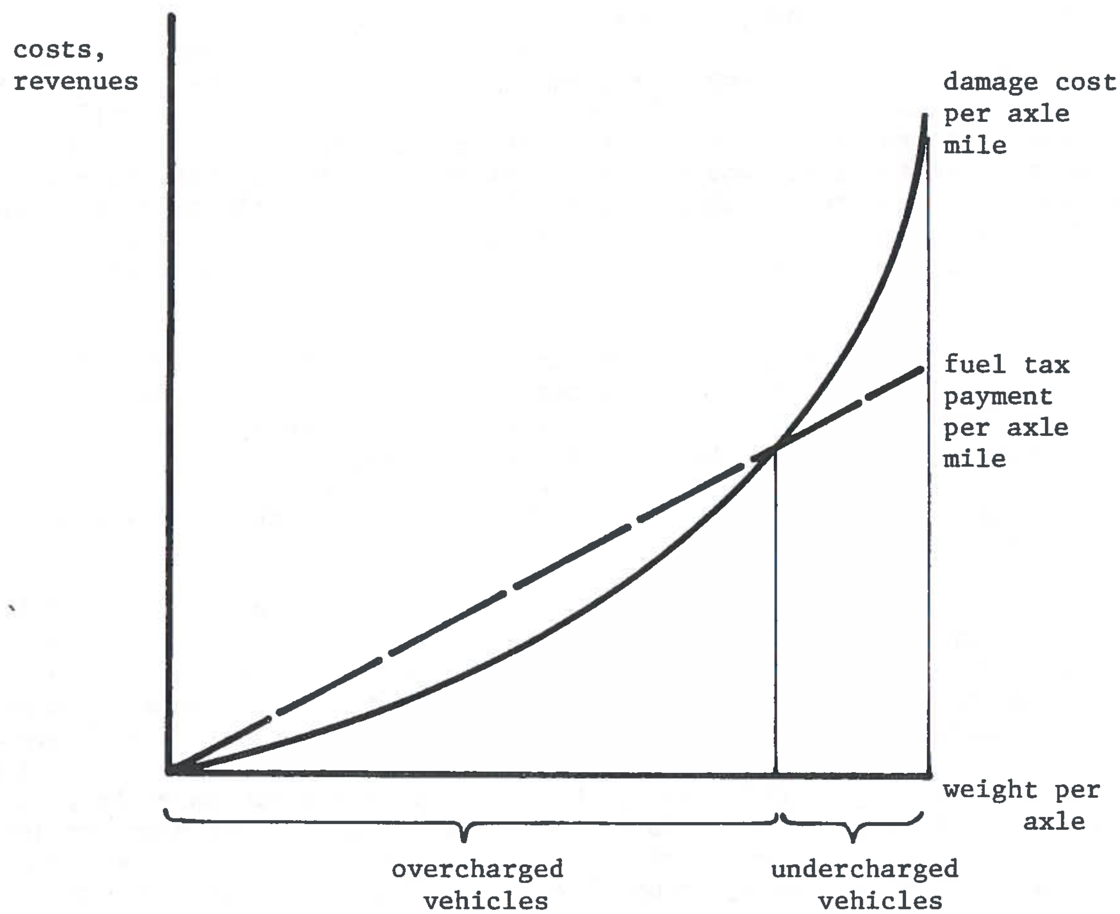

Figure 3. Actual damage to pavement versus fuel tax payments.

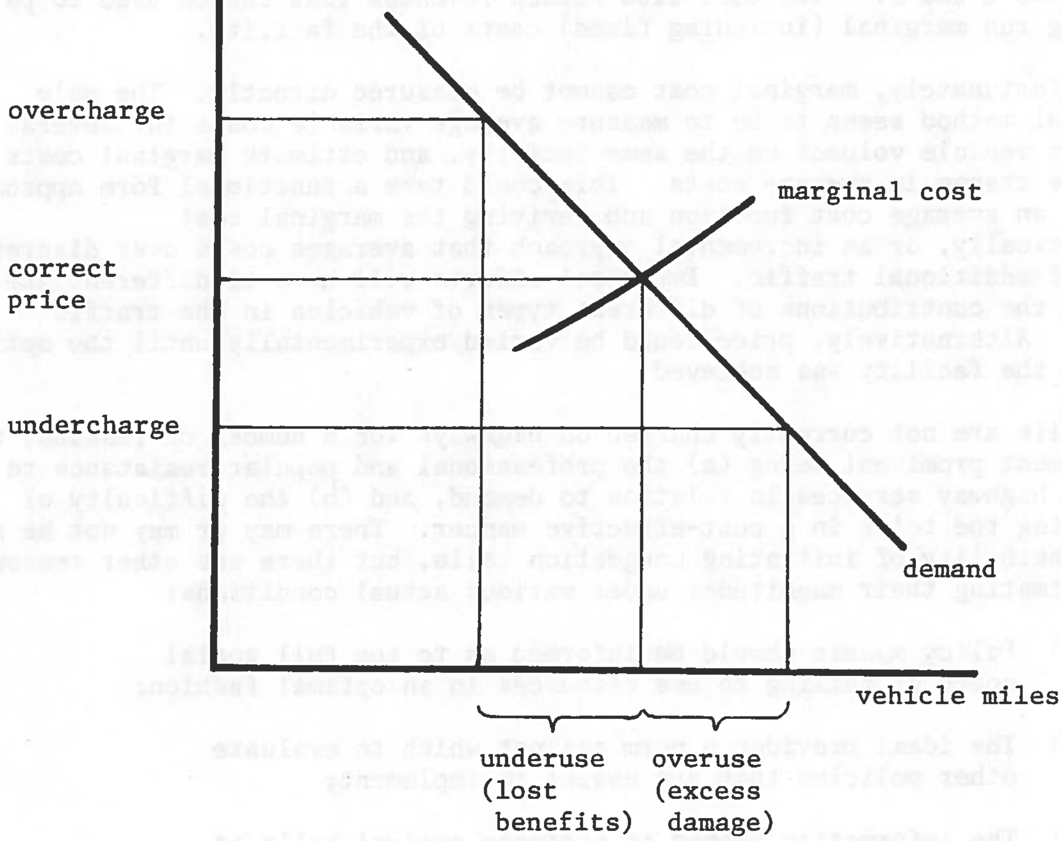

Figure 4. Effects of errors in setting user charges.

delay relative to free flow conditions. Increasing the number of vehicles in close proximity to each other increases the risk of accident, resulting in greater injury and property damage. As the volume-to-capacity ratio increases, so does the amount of braking, speed changes, lane changes, and other characteristics that cause greater fuel consumption, brake and tire wear, air and noise pollution, engine wear, and driver strain, per vehicle mile of travel. With minor exceptions (fuel mileage may improve with reductions from free flow speeds), these costs are lowest at low traffic volumes and increase with the V/C ratio. Some sample calculations are shown in table 3.

Under these conditions, efficiency requires that each vehicle be charged a toll, or price correction, equal to the difference between marginal cost and average variable cost. A properly calibrated and administrated congestion toll serves as a means for rationing the scarce capacity of the facility, preventing traffic jams of the sort described by traffic engineers as levels of service E and F.[13] The toll also raises revenues that can be used to pay the long run marginal (including fixed) costs of the facility.

Unfortunately, marginal cost cannot be measured directly. The only practical method seems to be to measure average variable costs for several relevant vehicle volumes on the same facility, and estimate marginal costs from the change in average costs. This could take a functional form approach, fitting an average cost function and deriving the marginal cost mathematically, or an incremental approach that averages costs over discrete lumps of additional traffic. Empirical efforts will have to differentiate between the contributions of different types of vehicles in the traffic stream. Alternatively, price could be varied experimentally until the optimum flow on the facility was achieved.

Tolls are not currently charged on highways for a number of reasons, two of the most prominent being (a) the professional and popular resistance to pricing highway services in relation to demand, and (b) the difficulty of collecting the tolls in a cost-effective manner. There may or may not be any real possibility of initiating congestion tolls, but there are other reasons for estimating their magnitudes under various actual conditions:

(1) Policy makers should be informed as to the full social costs of failing to use resources in an optimal fashion;

(2) The ideal provides a norm against which to evaluate other policies that are easier to implement;

(3) The information needed to estimate optimal tolls is also essential for management of the highway system and for decisions about investment in new facilities.

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[13]Highway Research Board (1965).

Table 3. INCREMENT IN VEHICLE OPERATING COSTS DUE TO CONGESTION-RELATED SPEED CHANGES

ADT/C****	Passenger Cars and Light Trucks Fuel*	Non-Fuel**	Multi-Unit Trucks Fuel*	Non-Fuel**	Travel time***
1	.23	.17	1.08	1.67	.1
2	.50	.37	2.37	3.66	.2
3	.76	.57	3.61	5.59	.3
4	1.08	.82	5.18	8.03	.5
5	1.31	.99	6.26	9.69	.7
6	1.56	1.18	7.46	11.56	1.0
7	1.82	1.38	8.71	13.49	1.4
8	2.07	1.56	9.87	15.28	2.1
9	2.34	1.77	11.18	17.32	3.0
10	3.01	2.27	17.08	26.45	5.7
11	3.70	2.79	21.24	32.91	9.3
12	4.05	3.05	23.50	36.41	11.2
13	4.43	3.34	26.28	36.41	13.6
14	5.06	3.80	30.72	47.61	16.8
15	5.60	4.21	34.81	53.94	19.7
16	6.34	4.76	40.43	62.64	24.9
17	6.70	5.03	42.77	66.27	31.1

* Fuel consumption in gallons/1,000 vehicle miles

** Non-fuel operating cost in dollars/1,000 vehicle miles

*** Increment in travel time due to congestion (hours/1,000 vehicle miles)

**** Average daily traffic per unit of capacity

Source: Ernest J. Mosbaek and Harry S. Cohen, "Methodology for Estimating the Impacts of Changes in Highway Performance," prepared for US DOT/FHWA, Jack Faucett Associates and System Design Concepts, Washington,D.C., August 1977.

Several approaches have been taken to measuring the effects of traffic volume on speed and delay, including the fitting of speed-volume curves and traffic flow simulations. Speed and delay studies collect data on travel speed for various network links, paired with the ratio of the actual volume to the design capacity of the link. It is possible to estimate marginal cost from the fitted curves, but there are several problems. One is that the measured unit of output is not constant because the quality of the service declines as volume increases, meaning that only a portion of the costs are being observed. Another problem is that the data do not appear to have been collected that would allow the independent effects of different vehicle classes to be identified. Such studies would, however, be fruitful.

3.2.1 Delay. In the same way that ESALs represent the standard unit of pavement consumption, passenger car equivalents (PCEs) measure the consumption of road space or vehicle capacity of a facility.[14] The empirical task is to estimate the PCE contribution of each vehicle type under various road type, terrain, vehicle volume, weather, and other conditions, and to place some numerical dollar value on that contribution.

There may be traffic simulation models that can be used to obtain some of this information, but the models have generally not been constructed for the purpose of estimating marginal cost contributions of different vehicle types under various conditions. These models may be able to test some very basic questions, such as the extent to which congestion is a significant effect at low and moderate traffic volumes, and the range of conditions that are most sensitive to congestion effects.

3.2.2 Accidents. Because accidents are a risk phenomenon, a large statistical base is needed to be able to estimate the expected value of accidents under various conditions. Insurance companies have built up fairly detailed actuarial tables, but they do not necessarily imply causal relationships (there may be a strong correlation between the age of the driver and the accident rate, but age does not cause accidents) and they reflect the legal responsibility for costs rather than the sources of the costs.

The primary cost components are personal injury, property damage, administration of the insurance system, public costs in the form of police, fire, hospital, court, and regulatory activities, and external costs in the form of uncompensated suffering, reduced employment opportunities, and other burdens. Private insurance rates discriminate only crudely between different classes of users and different operating environments, and most of the public and external costs are uncounted. On a vehicle mile basis, these costs are not large in magnitude, but they are certainly important in the aggregate.

An awkward issue in the safety area is the increasing divergence between the average size and weight of the passenger car and those of the heavy truck. These two vehicle types are becoming less and less compatible on the same facilities, to the point where separate facilities may sometimes be justified.

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[14]Highway Research Board (1965).

Because many accidents involve more than one vehicle, congestion tolls should include a component that assesses each vehicle for the accident costs imposed on other vehicles.[15]

3.2.3 Fuel and other operating costs. Considerable documentation exists for the effect of speed, congestion, geometry, weather, and other factors on the consumption of fuel. Even if the vehicle operator is aware of these differences, they are not properly reflected in the price to the user when the costs are increasing due to congestion. Although the costs are not large in magnitude, at least conceptually a price correction is needed to obtain short run efficiency. Such a correction might be implicitly or explicitly built into a congestion toll.

3.3 Negative Externalities

The important characteristic of an externality is the lack of a market for valuing and allocating it; an individual or a firm suffers a negative effect as the result of someone else's production or consumption decision, but the producer of the negative effect has not had to consider the economic consequences of the action on others. Externalities are treated as "free" by the persons generating them, although the impacts may constitute real costs to the recipients. A misallocation occurs because some resource is not valued in private markets as highly as it is valued by society.[16]

Examples of negative externalities abound in transportation: the noise from vehicle engines, drive trains, and wheels, toxic pollutants such as lead from gasoline, carcinogens such as asbestos dust from brake linings, disamenities such as smoke and fumes, dust from movement and tire wear, air pollution from exhaust emissions, water pollution from petroleum products and other residuals, physical danger to non-users, neighborhood disruption from barriers to movement and social interaction, caretaking burdens on relatives of maimed accident victims, litter dropped by transportation users, blight resulting from visual intrusion or incompatibility, destruction of vegetation and wildlife from road salts, haze and breathing impairments from smog, and so forth. All of these are created by the consumption of transportation, and non-users as well as users suffer economic injury for which no price is paid.

Negative externalities create problems of both efficiency and equity. With producers (of externalities) treating them as free, external costs result in overproduction (or over-consumption) of the good or service with which they are associated, and real income may be transferred from those suffering the externality to those creating it. The solution to this problem is some device which establishes a market for the external costs, thereby "internalizing" them. A user charge or tax equal to the value of the externality will have

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[15]According to Vickrey (1969), each vehicle should be charged the full expected marginal cost of any accidents in which it is involved. This means that efficient insurance premiums might recover two or three times the actual cost of accidents.

[16]Baumol and Oates (1975).

this effect. Without the tax, users operate along their own private supply curve rather than the true social cost curve.

Much work needs to be done to measure the impacts of significant externalities, to place values on the impacts for pricing purposes, and to relate the impacts to the vehicle mixes and volumes that give rise to the externalities. Both the impacts and the valuation of them depend upon the characteristics of the location in which the highway is found; e.g., noise costs imposed on urban residential neighborhoods are much greater than on rural agriculture. Despite the fact that most external costs generated by highways rarely appear explicitly (and seldom implicitly) in road expenditure budgets, the rationale for pricing external costs is strong, and the most suitable instrument is a user charge. Several problems hinder the implementation of such charges: negative externalities are hard to place dollar values on because they arise from market failure; the amount of actual and/or potential damage varies greatly from place to place and with the type of external cost; and variable charges that depend upon actual damage are hard to administer.

Table 4 lists examples of negative externalities produced by highway usage. Effects that can be regarded as vehicle emissions are identified, and the expected location of the externality with respect to urban and rural settings is noted. Several approaches can be used in conjunction with each other to control or price the effects, listed below in descending order of preference:

(1) Each vehicle can be charged according to its emissions characteristics and the annual mileage driven. As with other variable charges, annual fees based on class average rather than actual travel lack the basic characteristic of an efficient price, namely, that it vary with use.

(2) Localities can be permitted and encouraged to estimate and apply externality charges according to local conditions. Suggested rates and guidelines could be issued by Federal agencies.

(3) Externalities could be regulated to acceptable levels by means of emissions standards, design standards, prohibition of selected vehicle types from impacted locations, discouragement of traffic from particular areas, and effective enforcement of these measures.

Mandatory standards are inherently less efficient than pricing because (a) the same emissions level is imposed on all while total emissions might be reduced at less cost by holding some polluters to higher standards and others to lower standards, and (b) negative impacts remaining after efficient control measures are taken are still unpriced, leading to overuse. Thus care must be taken to ensure that the regulations are neither inefficiently lax nor overly restrictive.

Table 4. Typical highway negative externalities[a]

type	emission controls feasible?	urban/rural
noise	yes	mostly urban
air pollution	yes	mostly urban
water pollution	yes	widespread
danger, insecurity to non-users		urban
visual intrusion, glare		urban
barriers to movement and communication		urban
litter		widespread
wildlife and vegetation destruction		widespread

3.4 The Federal Share

The calculation of correct user charges does not depend upon what agency of the government or the private sector makes the expenditures to create and maintain the facilities. What constitutes a Federal responsibility is something to be determined by mutual agreement. Theory and analysis can be used to provide guidance as to what might be reasonable assignments of responsibility, but there is no strong normative basis for delineating the particular set of costs that inherently belong to the Federal government.

Several alternative strategies for delineating governmental roles and intergovernmental relationships can be described, but they are not much more than illustrations of the range of possibilities that exists.

(1) De facto expenditure shares: If 90% of the expenditures on the Interstate system are paid by the Federal government, then 90% of the correct prices would be collected by the Federal government from users of the Interstate system. For other systems, the Federal share would be lower. Each vehicle's travel by system would need to be known, and non-Federal governments would need to impose the remaining portions of the user charges.

(2) Uniform base charges: Federal user charges would be the highest set of fees that could be imposed consistently across the nation without overcharging some classes of vehicles in some circumstances. States and localities would then have to impose the additional fees that would bring the base fees up to the correct levels of user charges. Congestion and externality charges would be the focus of local user charges.

(3) Share of travel by purpose: Vehicles engaged in interstate travel would pay Federal fees, intrastate travel would be subject to state user charges, and local travel would be subject to local user fees. Because the same facility and the same vehicle may be used for several purposes, each level of government would need to know the share of each vehicle used for each purpose on each type of facility, in addition to being able to calculate the best user charge.

(4) Sole responsibility for functional systems: The Federal government would be entirely responsible for the Interstate system, deciding when and where to invest and how much to charge each vehicle for use of Interstate highways. States would have a monopoly on their own primary systems, and cities and counties would be responsible for secondary systems and local streets. Each vehicle would be charged separately for the use of each system, but there would be no ambiguity or coordination requirements for setting fees on any given system. At the Federal level, some sort of national highway authority might be formed.

(5) User charge separate from functional responsibility: User fees would be imposed by a single governmental entity on each functional system, but the construction, maintenance, and fiscal federalism that now occur could continue. Users of the Interstate system would pay Federal user charges only, but states could carry out the design, construction, and operation of the system with the aid of intergovernmental transfers. User charges would still need to be separated by system, for each vehicle.

None of these alternatives sounds very simple, from the standpoint of either information requirements or ease of implementation. The reason is that the present arrangements, whereby several governments can set fees independently of each other for use of the same facility (through fuel taxes and registration fees), generate enormous obstacles to the implementation of efficient user charges. If efficiency is an objective of charging vehicles in accordance with the costs they create, management of the highway system as a whole will probably need to change in profound ways.

4.0 RESIDUAL COSTS

For any of several reasons, user charges based on variable costs may fall short of recovering full costs. The remaining costs may be recovered from users via access charges such as registration fees, or obtained from general revenues.

4.1 Conditions Resulting in Residual Costs

Ideal user charges would set price equal to marginal cost, as shown in figure 5. If variable costs, including congestion, are included in the price, p_1, and marginal cost is increasing, correct pricing will result in a surplus over variable costs indicated as tolls/rents in the diagram. The actual surplus may be less than total fixed costs for any of the following reasons:

(1) A price is charged for congestion, but it is less than marginal cost because of underpricing on competing modes of transportation; price will be between p_1 and p_2.

(2) Full marginal cost prices are charged, but the capacity of the system is too large; this occurs at a price of p_1, and an output q_1. In the ideal long run equilibrium, capacity is adjusted until marginal cost prices recover long run marginal cost.

(3) Prices and the capacity of the system are correctly set, but the system is subject to long run scale economies; the price-output combination of p_1 and q_1 can also represent this situation.

The possibility exists for two other situations: correctly set prices based on variable costs may recover more than full long run cost, or marginal cost might be below average variable cost and thus recover less than variable costs. In the former situation the road authority would enjoy a net surplus which it could distribute in some way or invest, and in the latter situation the residual costs would be more than the total of fixed costs.

Which set of circumstances applies is an empirical question, but enough is known about variable cost functions to indicate that they are either constant or increase with higher vehicle volumes. Thus correct prices will at least recover all variable costs. Because congestion tolls have never been systematically imposed, it is hard to guess what they would be and how much revenue they would produce. Overcapacity and increasing returns, however, probably do pertain to the highway system, so there is likely to be a net residual of costs after subtracting revenues based on variable costs from total long run costs.

4.2 Variable/Fixed and Operating/Capital Cost Distinctions

The distinction between variable and fixed costs is based on whether the cost can be avoided in the short run by not running another vehicle over the facility. The distinction between capital and operating costs depends upon the lifetime of the input factor, with lifetimes greater than one year being

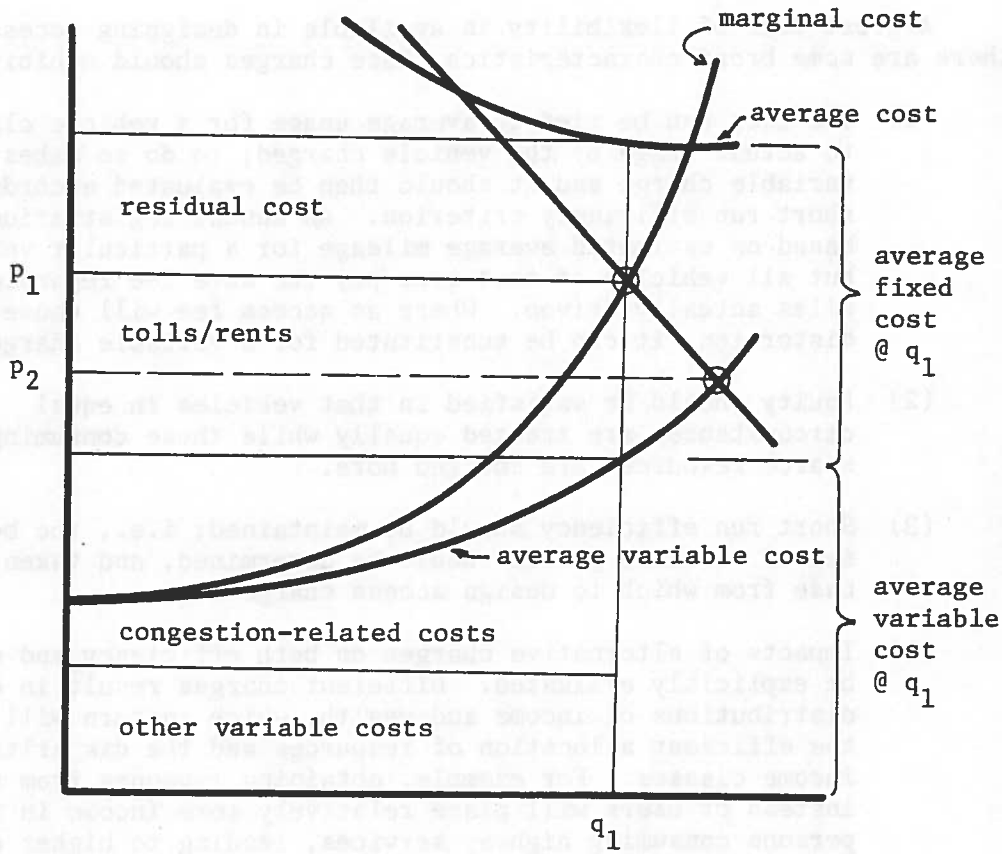

Figure 5. Residual versus fixed costs.

the characteristic of capital cost components. These two distinctions can be combined to generate the four-way categorization shown in figure 6. Examples illustrate that all combinations of the two dichotomies are possible, but the general pattern is for operating costs to be variable and capital costs to be fixed.

For highway cost allocation, the distinction between variable and fixed costs is the most appropriate one for designing user charges, while the capital-operating distinction is useful for accounting purposes. A list of fixed costs is provided in table 5.

4.3 General Requirements for Access Charges

A great deal of flexibility is available in designing access charges, but there are some broad characteristics these charges should exhibit:

(1) The fees can be tied to average usage for a vehicle class, but not to actual usage by the vehicle charged; to do so makes the fee a variable charge and it should then be evaluated according to the short run efficiency criterion. An annual registration fee might be based on estimated average mileage for a particular vehicle type, but all vehicles of that type pay the same fee regardless of the miles actually driven. Where an access fee will cause less distortion, it can be substituted for a variable charge.

(2) Equity should be satisfied in that vehicles in equal circumstances are treated equally while those consuming more of scarce resources are charged more.

(3) Short run efficiency should be maintained; i.e., the best feasible set of variable prices should be determined, and taken as a given base from which to design access charges.

(4) Impacts of alternative charges on both efficiency and equity should be explicitly evaluated. Different charges result in different distributions of income and wealth, which in turn will affect both the efficient allocation of resources and the disparities between income classes. For example, obtaining revenues from non-users instead of users will place relatively more income in the hands of persons consuming highway services, leading to higher consumption of highway services and at higher prices than will be the case if the revenues are raised from users.

(5) Access charges can be used to ensure that the full costs of transportation are borne directly by those consuming the transportation, and that each transportation mode is fully self-supporting. This is a social goal that may or may not be adopted, along with other social goals such as energy conservation and income redistribution.

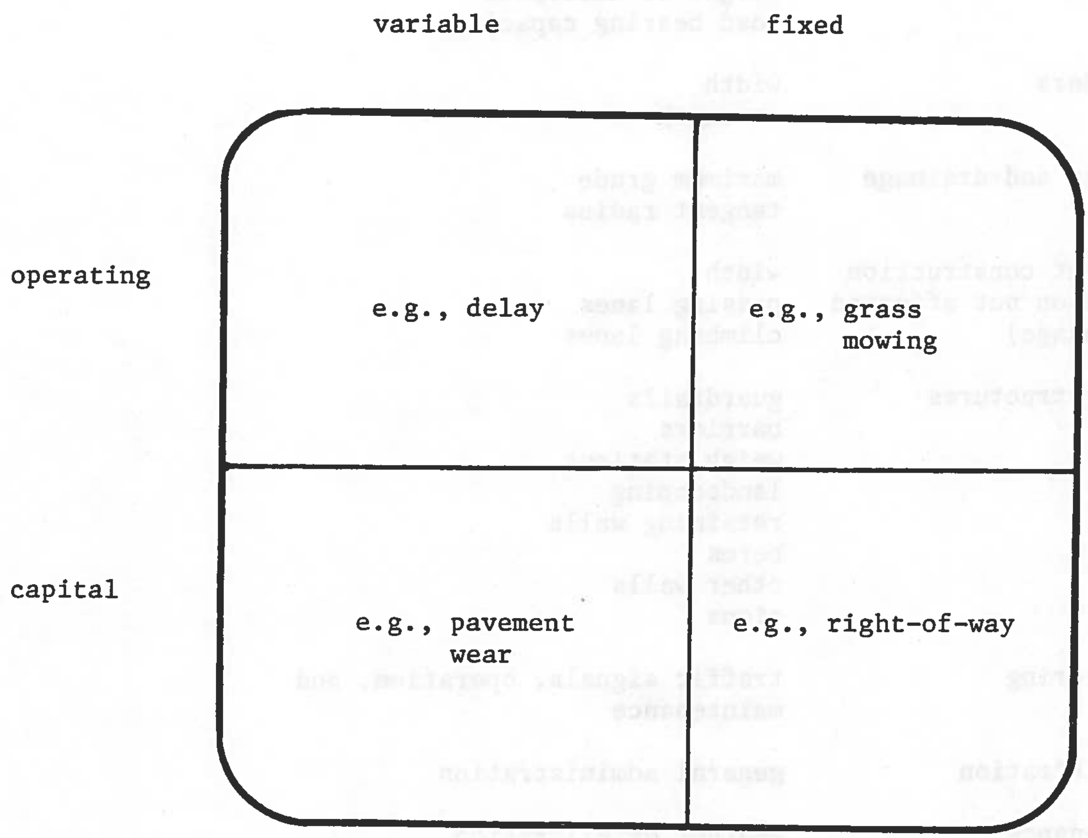

Figure 6. Examples of fixed/variable costs versus operating/capital costs.

Table 5. Fixed cost components

components	possible dimensions for disaggregation
right of way	width median
bridges	height of underpass load bearing capacity
shoulders	width strength
grading and drainage	maximum grade tangent radius
pavement construction (portion not affected by usage)	width passing lanes climbing lanes
other structures	guardrails barriers weigh stations landscaping retaining walls berms other walls signs
engineering	traffic signals, operation, and maintenance
administration	general administration
maintenance	weather deterioration snow removal
opportunity cost of capital stock	capital components

4.4 Steps in the Allocation of Residual Costs

When correct variable cost prices fail to recover enough revenues, any algorithm used for tapping users and taxpayers has an inherent degree of arbitrariness.[17] Accepting the ambiguity this creates, cost allocation strategies that produce a range of simple alternatives will be preferrable to misguided attempts at spurious precision. Direct assignments of costs to users may be feasible in a few instances, but the process will generally cover the following steps:

(1) Estimate full long run costs of the system as a whole and its major components (interstate, primary, secondary, urban, etc.);

(2) Derive residual costs by subtracting the revenues obtained by means of user charges based on variable costs;

(3) Assign cost responsibilities to levels of government;

(4) Separate residual costs into user and general taxpayer responsibilities;

(5) Allocate user cost responsibilities to categories by vehicle class;

(6) Allocate costs for a given class to members of the class.

The items below are organized in rough accordance with these steps.

4.5 Establishing the Total Budget

Long run costs include a number of categories that can be labelled opportunity costs, in that they do not appear in public budgets. Despite the fact that government agencies may not be required to finance these costs, the full economic costs of the highway system should be considered in designing a system of user charges.[18] The costs that tend to be missed are actual depreciation, opportunity costs of capital expenditures, and public overhead services.

4.5.1 Expenditures and needs. Cost information for highway cost allocation has been derived from estimates of future capital and maintenance expenditures, typically embodied in "needs" studies. In an economic sense, expenditures are not necessarily the same as cost, although they may be related. Cost is a concept, referring to the value of resources given up by society in order to produce a given output, and the empirical estimation of the concept usually draws upon some sort of price information obtained from economic market places. With highways, for example, the full social cost includes the actual wearing out of the pavement (depreciation) and the

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[17] The theoretical ideal for this purpose is a lump sum transfer that does not affect production or consumption in any way.
[18] Methods for full cost accounting are illustrated in Lee (1980).

opportunity (market) value of the land if it were used for something else; the second of these costs is not accounted for in a table of future expenditures, and the first only indirectly. Expenditures, however, may be satisfactorily used for some cost estimation purposes if costs not represented in highway expenditures are explicitly covered.

(1) Future expenditure estimates (uninflated) are usually transformed into base year dollars by discounting, and historical expenditures should be transformed into constant dollars before using them to estimate future costs;

(2) A sufficiently long time horizon should be used so as to incorporate a full lifetime of costs;

(3) Estimates of future needs should be explicitly based on policies about the future development of the highway system; e.g., maintain and replace the existing system, gradually eliminate low volume segments, expand the freeway system, etc.

4.5.2 Opportunity cost of the capital stock. As long as some portion of the highway system retains a value that is carried over from one time period to the next, the full cost of the system includes an opportunity cost that is not reflected in annual expenditures. The presence of this cost is felt when highway construction is financed through bonds, but the interest rate paid is below the true social opportunity cost because the interest paid to the bondholder is tax exempt. Federal expenditures are not financed from borrowing because the Trust Fund currently contains a surplus, but the opportunity cost of expenditures from the Fund is revealed by the interest that is foregone when the money is removed from the Trust Fund.

Even if expenditures, actual depreciation, and user charge revenues (e.g., for pavement) are all equal in a given year, the capital (e.g., concrete) used to create the value not used up by the end of the year could have been earning a rate of return in some other purpose. To society, this is a real cost of investing in highways that should be accounted for in making expenditure decisions.

An effective management information system for the highway network would track the cumulative value of the capital stock over time, adding each year's investment (pavement overlays and new construction) and subtracting actual depreciation (loss of pavement serviceability). As well as allowing opportunity cost to be readily calculated, the data would show whether the system was wearing out faster than it was being built up, by system and subsystem. Actual pavement depreciation can be estimated from actual vehicle travel, or by measuring servicability. Deterioration of structures, signs, etc., can be estimated as a function of time or by direct inspection. A shortcut method for estimating long run costs is to look at replacement cost rather than projected expenditures. The procedure is to break the entire road system into subsystems by road type (number of lanes, design standards, urban/rural, etc.) and derive estimates for the replacement cost of each type, in base year dollars. Such cost estimates per mile of road can be obtained from highway engineers familiar with the area, and multiplied by the mileage of road in each type, to obtain a total replacement cost figure. Depreciating this total will yield an estimate of the present worth of the capital stock, from which an opportunity cost can be calculated.

4.5.3 General public overhead services. When resources are diverted from the private sector into the construction and maintenance of highways, the taxes those resources would have generated are foregone. These taxes are an indicator of the value of general government and other public overhead services that support the economy as a whole. If the productivity of expenditures on the highway system is to be compared to the productivity of expenditures in the private sector, an allowance for taxes foregone should be included on the public sector side. Although this principle has never been followed in previous highway cost allocation studies, failure to recognize the foregone tax contribution creates a bias in favor of public sector investment versus private, and a corresponding bias toward publicly-operated transportation (highways and inland waterways) versus private modes such as railroads. Even though there may be little chance of collecting fees from highway users in lieu of tax payments, it is important that highway cost studies recognize the economic distortion created by the failure to collect property and other general tax equivalents.

4.5.4 The Federal share. If it can be assumed that the functional and financial responsibilities already worked out through the political process are correct, then the present statutory shares carried by the Federal government are those that determine future financial burdens. This assumption may be expedient, but it provides no basis for determining whether or not the present pattern of financing will or should change in the future. With shifts occurring in the types of expenditures eligible for Federal funding, there is good reason to review the rationales for intergovernmental cost sharing.

4.6 Full Cost Recovery from Users

In previous cost allocation analyses, arguments about property owner benefits and general economic benefits have been used to justify the expenditure of property tax revenues for highway purposes. The logic of these arguments, while not totally incorrect, lacks focus because it refers to nothing that is unique or specific to highways. Any beneficial activity generates an economic surplus and any two interrelated activities create a joint surplus.

The transfer from property and general taxpayers occurs primarily at the local level (city and county), and is the consequence of higher levels of government effectively preempting all the user charge instruments but not all the cost obligations. Local governments are left with a residual of costs and few potential user charges. Nor are local governments particularly predisposed toward limiting highway expenditures to user charge sources. Because the Federal government has a major influence on highway expenditure and finance policy, it should take a holistic view that includes within its purview the effects of local practices on efficient utilization and investment in the highway system.

While there has been no popular objection to the notion that users should pay for highways, there is considerable disagreement about whether users are actually paying the full cost, whether users <u>should</u> pay the full cost, and how to account for the full cost. Statistics for the U.S. show that total expenditures exceed total user revenues,[19] and many studies suggest that some user classes underpay by more than others. The purpose of this section is to review the arguments offered in support of why users should or should not be required to pay the full costs.

4.6.1 <u>Arguments in support of full cost pricing</u>. For all practical purposes, the question of whether users should pay the full costs of the provision of highway services has never been addressed, let alone resolved. Each level of government involved establishes its highway budget by largely informal and political means, and sets out to generate sufficient revenues to cover the budget. Decisions by one government affect the budgets of other governments, such as through matching grants and formula allocations of user charge revenues. Only expenditures are regarded as real costs, and the dominant consideration is the adequacy of the revenues -- whatever the source -- in relation to the particular budget.

The decision of whether to require user charges to cover full long run costs (including general government services and a rate of return on investment) is ultimately a political one, and there is no ironclad technical rationale that insists on such a standard. There are, however, quite a few arguments in favor of economicly self-supporting highways.

(1) The benefits of highway services are fully captured by users, and indirect benefits are passed on through normal market processes. There are no external (non-market) benefits, so there is no reason to ask nonusers to help pay the costs. Nonusers who reap windfall gains through market processes can be taxed for general purposes.[20]

(2) The market discipline of having to meet full long run costs forces highway authorities to allocate resources in a productive manner and recover costs from those receiving the benefits. This "bottom line" test encourages the entire enterprise to make only efficient investments.

(3) Although the pure theory says that residual costs can be recovered from general taxpayers, and efficient investment in capacity is based on net benefits rather than user charge revenues, forcing users to pay the full costs ensures that these total benefits really exist. Access charges can be used to test willingness-to-pay without great distortions in efficient highway usage.

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[19]FHWA (1978)
[20]See Milton Kafoglis (1963)