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Allocating Motor-Vehicle-Tax Responsibility By the Incremental Method

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Allocating Motor-Vehicle-Tax Responsibility By the Incremental Method

A Symposium

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Introductory Remarks

HUGO C. DUZAN, Secretary,
HRB Committee on Incremental Method of Motor-Vehicle-Tax Allocation

● THE incremental method of motor-vehicle tax allocation, also called the method of differential costs, is based on the undeniable fact that highway designs and costs are affected by the size and weight of the vehicles that are expected to use the roads and structures. The appellation "incremental" arises from the circumstance that most design requirements can be looked upon as being built up from a basic design and accompanying cost appropriate for the smallest vehicles to which successive increments are added to meet the requirements of progressively heavier vehicles. The cost of the basic increment, since it is necessary for all vehicles, is shared in by the entire vehicle population. The cost of each successive increment is borne by the vehicles requiring it.

The incremental concept may conveniently be illustrated by means of the variation of required pavement thickness with vehicle weight or axle load. A thickness considered adequate for the basic or passenger-car type of vehicle is selected, and all vehicles are charged with the cost of pavements of that thickness. The cost of the second increment of thickness, i.e., that required by the vehicles of the first weight group above the basic, is charged to all vehicles above the basic weight group. The cost of each successive increment of pavement thickness is charged to the vehicles requiring it or additional increments. Thus, the vehicles in the heaviest weight group are charged with the entire cost of the last increment of pavement thickness and also their prorata share of each lesser increment, including the basic increment. Other elements of highway cost are subjected to similar analysis.

Although the incremental concept is simple, its application is difficult. Roads and streets must be grouped in such a way that all roads and streets within a class are similar in traffic characteristics, design standards, and costs. Vehicles must be classified in such a way that all vehicles within a group have similar effects on highway costs, and the amount and distribution of travel of each group must be determined. The full resources of experience and judgement are required to appraise the effect of the various vehicle classes on design standards and costs.

The committee on Highway Taxation and Finance of the Highway Research Board believes that the incremental analysis offers the promise of a scientific approach to the problem of equitably allocating the motor-vehicle users' share of highway costs among the various types of vehicles that are operated over the highways. In order to give practical effect to its interest in the subject, the committee created, in 1951, a subcommittee which had the single assignment of studying the theories and procedures involved in the incremental analysis and their application. That subcommittee is now known as the Committee on Incremental Method of Motor-Vehicle-Tax Allocation.

One of the recent activities of the subcommittee was the sponsorship, during the Thirty-Fourth Annual Meeting of the Highway Research Board, of a panel discussion of incremental studies and related projects that had recently been conducted or were then in progress in individual states. A member of the subcommittee, D. F. Pancoast, of the Ohio Department of Highways, was selected to act as moderator. He was particularly well fitted for this assignment, since he was in charge of the incremental study made in Ohio in 1952.

All of those who presented papers on the program were eminently qualified to do so. Bauer had been in charge of a study recently completed in Minnesota by the Public Administration Service which involved an incremental analysis. Hennes is chairman of the Washington State Council for Highway Research, which is undertaking an incremental study as part of its current research program. Martin, a member of the Committee on Highway Taxation and Finance, is director of the Bureau of Business Research of the University of Kentucky. That bureau is now undertaking a broad highway-finance study for Kentucky, including an incremental analysis. Ross, of Louisiana State University, conducted an incremental analysis in connection with a highway-finance study for Louisiana.

Kiley, director of research for the American Trucking Associations, has a different relationship to and interest in the incremental analysis than do the others, since the membership of the Trucking Associations is composed of large-scale consumers of highways services. Working directly or through local affiliates, they have undertaken or sponsored several so-called cost-function analyses of the responsibility of various classes of motor-vehicle users for the financial support of highway programs. They have also been involved in at least one incremental type of study, that made in Virginia in 1953 by an affiliated organization, the Virginia Highway Users Association.

There was a considerable amount of discussion from the floor following the presentation of the papers, and some questions were directed at the individual panel members. Since this discussion was not recorded, those who had comments or questions were invited to submit their remarks in writing for publication with the papers. Those received are also included in this bulletin.

The authors of these comments are all technically qualified in the field of highway research: Burch is engineer of statistics and planning for the North Carolina State Highway and Public Works Commission. Lindman, a member of the Committee on Highway Taxation and Finance, has made highway finance and cost studies in the States of Washington and California. Moore is assistant professor of civil engineering at Pennsylvania State University. Rothrock, now on the staff of the Ohio Department of Highways,. was formerly highway planning engineer for West Virginia.

After the written commentaries on the papers were received, they were submitted to the individual speakers for their consideration. Bauer submitted a written answer to the comments, and his closing discussion is included following the comments.

Incremental Method of Allocating Highway Costs

WILLIAM D. ROSS, Professor of Economics,
Louisiana State University

● THE foundation of the incremental method is the fact that vehicles of different dimensions and weights differ in their requirements for highway facilities. The approach involves an attempt to differentiate the costs attributable to vehicle weight and size and to assign these costs to vehicles in graduated weight-and-size-increment groups. There is no one set of procedures which can now be considered essential to a legitimate incremental-cost solution. The time may come when one solution may be generally accepted as more accurate and more valid than others, but much experimentation will be required to determine the choice.

The incremental method has been used in efforts to appraise the soundness of past road expenditures and tax structures, current expenditures and motor-vehicle tax structures, and as a basis for adjusting the structure of taxes for future road support. Appraisals of past and current motor-vehicle taxes serve to indicate the soundness and consequences of past practices. They may serve as a guide to future policy but only in a general way. Future patterns of expenditure may bear little resemblance to past patterns.

Only by applying the incremental method to anticipated expenditures can it serve most effectively as a guide to public policy. The method has been so applied in a comprehensive study of highway finance now nearing completion under the author's direction in Louisiana. There have been two other similar studies made recently to which brief reference may be made here.

The first of these was made in Ohio by D. F. Pancoast for the Ohio Department of Highways; it was published in December 1953.[1] The other study was made by the Public Administration Service of Chicago for the State of Minnesota and was released in mimeographed form in August 1954.[2]

The Minnesota study is an exact replica of the statistical computations used in the Ohio study, without explanation of procedures and with few references to sources of data. The text of the Ohio study is more complete. As the trail blazer in a difficult terrain, it deserves high praise; without its guidance, my own task would have been immeasurably more difficult. However, the Ohio study also fails to give a complete explanation of the derivation of some of its data and of the exact nature of some of its procedures.

Only by an unrelenting critique of data and procedures used can more-appropriate and more-accurate data be provided and the method be improved. The remainder of this paper consists of a reexamination of the method as employed in the Louisiana study.

At one stage in our work, my assistant, L. J. Melton, now at the University of Florida, commented half seriously that he had arrived at one definite conclusion: "You can't make an incremental analysis." The numerous assumptions and tremendous amount of statistical detail which are required in applying the method, even when the data available are reasonably complete, do threaten at every turn to overwhelm one who undertakes the solution.

The first problem to be confronted is that of apportioning total road costs between highway users and other taxpayers. The problem is fundamental to the incremental solution and, one might add, to any other method (such as the straight ton-mile solution) which may be used as a guide to motor-vehicle tax policy.

A decision is required as to which road costs are chargeable directly to the highway user or motor-vehicle owner and which are chargeable to the general public. Some attempt to measure relative use in terms of the proportions of the different types of traffic served by the different highways, roads, and streets is basic to any apportionment which

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[1] D. F. Pancoast, Allocation of Highway Costs in Ohio by the Incremental Method, Columbus, December, 1953, 78pp.

[2] An Incremental Cost Analysis Based upon the Ten-Year ASF Proposed Highway Program, Public Administration Service Chicago, August 16, 1954 (Mimeographed).

is determined. The costs assignable to the motor-vehicle owner will be greater on those facilities which carry a high volume of through traffic. The portion of costs assignable to the motor-vehicle owner on local roads and residential streets serving primarily access and community service purposes will be small. The use of roads by public vehicles must also be taken into consideration.

The apportionment used in the Louisiana incremental analysis involves a feature originated by Melton. The objective is to separate those highway costs chargeable to the highway user from those which should not be charged to the highway user. The incremental approach holds that there are certain highway costs which are clearly attributable to the existence on the highways of larger and heavier commercial vehicles. These costs must be separated for use in the incremental solution to the problem of apportioning costs between vehicle types. It seems quite logical to isolate these costs as a partial solution to the apportionment of total highway costs between highway users and non-users. The remaining costs, which are assignable in part to all highway users and in part to the general public, still had to be assigned on a relative-use basis, but the magnitude of the task was reduced. Although some question was raised by Bureau of Public Roads personnel as to the validity of this procedure, perhaps because the process had not been tried before, it is believed that the accuracy of the result was increased (see Table 1).

TABLE 1

RATIOS OF COSTS ATTRIBUTABLE TO VEHICLES IN EACH AXLE-WEIGHT INCREMENT WHICH WERE ASSIGNED TO THE HIGHWAY USER

Axle-Weight Increment	Surface Type				
	High	Medium	Low	Gravel	Total
lb.	%	%	%	%	%
14,001 - 18,000	100				100
10,001 - 14,000	100	100			100
6,001 - 10,000	100	100	100		100
0 - 6,000	90	60	40	20	68

The resulting distribution of highway-user costs by weight increment was then employed in the incremental apportionment of highway-user costs between vehicle types and axle-weight groups. The share of costs assigned to the general public was thus deducted entirely from the cost of providing roads for vehicles in the basic axle-weight increment (0 to 6,000 lb.). This appeared to be the only procedure consistent with the objective of matching price and marginal cost of providing the more-elaborate facilities required by commercial vehicles and facilitating an economic allocation of resources among transport media. It is also true that most publicly owned vehicles fall into the basic axle-weight increment and land access and community service traffic will involve largely the low-weight vehicles. This too is a procedural innovation believed to have merit.

The Louisiana Highway Finance Study has been conducted in conjunction with a comprehensive engineering study of highway needs within the state. Thus complete and up-to-date data with respect to anticipated highway costs in Louisiana were available. Furthermore, the engineering study data are on IBM cards; machine tabulations were used to correlate traffic, cost, and other relevant data in the form needed for use in the financial analysis.

Louisiana is the only state in the nation which registers trucks and trailers by load-carrying axle weight. An axle-weight breakdown of commercial vehicles is essential to the incremental solution; in Louisiana alone such a breakdown exists in ready-made form. It was not necessary to attempt the difficult and uncertain task of adjusting from gross-weight registration data to axle-weight data on the basis of loadometer samples, which seldom indicate the incidence of over-weight vehicles among those registered for less than the maximum legal weight.

No adjustment was made in registered axle-weight groupings for loaded and empty travel of commercial vehicles. Highways are constructed and commercial vehicles are licensed to carry maximum axle or gross weights. It does not seem unreasonable to expect such vehicles to pay their appropriate share of the total cost of constructing such highways to meet their maximum requirements, whether all travel is with maximum legal load or not. Using loadometer data to develop axle-weight groupings, the Ohio and Minnesota studies produced data which presumably were adjusted for loaded and unloaded travel.

The Louisiana study, like the other two studies, distributes weight-related costs between vehicles falling into the various weight increments on an axle-mile basis. The Ohio and Minnesota studies distribute nonweight costs, other than the costs of state highway police administration and vehicle registration and drivers license administration, on a vehicle-mile basis. The Louisiana study distributes nonweight costs on an axle-mile basis. The choice of axle-miles rather than vehicle-miles was dictated by the judgment that axle-miles give a fairer distribution of costs between passenger cars and multi-axle commercial vehicles than vehicle-miles. The choice also eliminated the necessity of determining whether combinations of vehicles should be considered as one vehicle or more and, if the latter, how many. The costs of state highway-police administration and vehicle registration and drivers-license administration are distributed on a per-vehicle basis in all three studies.

The Ohio and Minnesota studies used average road inventory figures (the miles of road of each surface type in the entire road system of the state at the beginning of the improvement program plus the miles of each type proposed for the entire system at the end of the improvement program divided by two) in distributing costs and traffic in their solutions. In these states, where the change in surface types on each system from the beginning of the program period to the end will not be significant, the choice of average inventory figures for use in the solution was a logical step and probably the most-valid procedure.

In Louisiana, where many miles of road will be up-graded from gravel and low-type bituminous surfaces to medium and high-type paved surfaces, the problem of selecting the most-valid inventory figures for the solution was an extremely difficult one. Average inventory figures are clearly more valid for the allocation of maintenance costs. On the other hand, ultimate inventories (the miles of road of each surface type expected to exist at the end of the improvement program) are more valid for use in allocating construction costs; this is true because the motor-vehicle owners who use those highways which will ultimately be constructed to higher standards should be the highway users who pay for the improvements.

The use of either set of figures for the distribution of both maintenance and construction costs involves some distortion. However, careful consideration of the alternatives produced the conclusion that the magnitude of the distortion would be far greater if average inventory data were employed. In fact, examination of the Louisiana data showed that, since the larger maintenance costs are involved on the lower type surfaces on which few heavy vehicles travel, the distortion in the allocation of maintenance costs resulting from the use of ultimate inventory figures was reduced to insignificance. Thus the decision was made to employ ultimate inventory figures in the Louisiana solution.

In most recent studies in which the incremental method is discussed, particularly in those studies which have been sponsored by the various states to be used as a guide to public policy, the task of developing the engineering cost increments for each vehicle weight and size group has been cited as the most-perplexing problem of the solution; it is the obstacle cited most often as dictating a decision against use of the method. The experience in Louisiana has been that the engineering-design sections of state highway departments are engaged daily in making cost estimates for constructing highways or sections of highways designed to specific standards. In Louisiana, the development of cost increments was accepted by the highway department as quite plausible, even for the hypothetical roads designed for lower vehicle weight groups in the case of the higher types of surfaces. Some assistance was received from Hugo Duzan, of the Bureau of

Public Roads, in developing the increments for the Louisiana Study.[3] However, complete cooperation was given by the engineers of the Louisiana Department of Highways; a thorough job was done; and considerable confidence was evidenced in the results obtained.

The next problem confronted in the solution, one which is critical, was the problem of distributing total traffic by road-surface type and by vehicle-use type and weight group. The task proved a difficult one, despite the availability of perhaps the most-complete statistical data for the purpose in existence anywhere in the nation. The distribution of total traffic by proposed surface type was accomplished automatically by IBM tabulation of traffic count data for each section or portion of the road system. This known distribution of current traffic was assumed to hold generally valid for the improvement program period, and the traffic projection to the midpoint of the program period for use in the solution was made on the basis of this distribution pattern.

In Louisiana, the classification of trucks and trailers for registration purpose is more elaborate and apparently more complete than in most other states. There are five use types: private use, common and contract carrier, forest product, city use only, and farm. Trailers are registered independently; in each of the above use categories there are five vehicle types, regular trucks with a single load-carrying axle, regular semitrailers, tandem trucks, tandem semitrailers, and full trailers. Registration is by maximum load-carrying axle weight; the weight increments are 0 to 3,5000 lb., 3,501 to 6,000 lb., and increments of 2,000 lb. each from 6,001 to 18,000 lb., the latter being the maximum legal load limit. The registration fees are graduated upward for each vehicle-use type from the lowest to the heaviest weight increments; but within each vehicle-use type, the fee per load-carrying axle is the same for each weight increment, regardless of the vehicle type involved. The complexity that this system of classification introduces into the problem of distributing truck traffic by use type, vehicle type, and weight increment is obvious.

Recent visual counts of vehicles, by type of vehicle (autos, regular trucks, etc.), in traffic on the state system were available. Adjustments had to be made to make these data applicable to the parish road system and to the municipal street system, but the data served as the basis for the distribution of traffic by vehicle type on the various systems.[4] The registered axle weight and use type of sample vehicles had been recorded in making a recent loadometer study in Louisiana. These data were tabulated and provided the statistical basis for distribution of traffic by use type and registered axle-weight increment on the state system. Again, adjustments had to be made to make these data applicable to the parish and the municipal systems.

Because both the visual-classification-count data and the loadometer data were assembled with objectives other than use in an incremental solution, obvious incongruities were found in some use and vehicle classifications. Most of these discrepancies, however, were subject to logical interpretation and the direction of the adjustment required was easy to determine. Despite the fact that much more complete traffic data by system, use type, vehicle type, and by weight increment would have been desirable, the data which were available and which have been made the foundation of the traffic distribution in the Louisiana study would seem to demonstrate beyond question the desirability of the traffic survey approach to the traffic distribution problem in the incremental solution.

A reference in the Ohio study to the need for more adequate information for dealing with this problem suggests that "commercial vehicle operators are probably in the best position to gather the necessary data."[5] It is true that a final check on the reliability of a distribution of commercial vehicle traffic for use in an incremental solution is the aver-

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[3] Acknowledgement is also made of the advice and assistance received from C. A. Steele and G. P. St. Clair, likewise of the Financial and Administrative Research Branch of the Bureau of Public Roads, during the development of the incremental analysis in Louisiana. Full responsibility for the choice of procedures employed, nevertheless, rests with the writer.

[4] The Louisiana Motor-Vehicle Use Study and Origin-and-destination studies for a number of Louisiana cities served as the basis for the adjustments.

[5] Pancoast, op. cit., p. 29.

age annual travel figures which it produces for the various commercial vehicle types. The more complete the information available as to the average annual mileage of the various vehicle types, the more adequate will be the check on the traffic distribution produced by statistical methods from traffic survey data.

The average annual mileage data will also serve as a guide to adjustments where incongruities do appear in the results obtained from the statistical approach; average annual mileage data available for commercial vehicles in Louisiana served this purpose in the Louisiana study. On the other hand, the implication of the Ohio study is that the entire problem of traffic distribution for the incremental solution should be approached from the standpoint of average annual travel data for commercial vehicles. The Louisiana experience would seem to suggest that the problem should be approached from both ends.

State highway departments should design and conduct their traffic surveys so as to provide the statistical data needed for the incremental solution. Commercial truckers, who should be interested in finding the most-accurate answer possible to the problem of highway finance and taxation, would also make a useful contribution to progress in this area by undertaking to assemble more-reliable information with respect to the average annual travel of the various types of commercial vehicles.

The comparisons that have been made between the Louisiana study and the Ohio and Minnesota incremental solutions indicate that there are many similarities but, also, many variations between the former and the latter two studies. The possibilities of further variations and refinements in the method are numerous. The claim which the Louisiana solution may have to greater reliability and precision than the other two rests largely upon the fact that the basic data available in the state were more directly adaptable to the incremental solution and were more complete.

Initial Problems Confronted in the Kentucky Incremental-Cost Study

JAMES W. MARTIN[1], Director, Bureau of Business Research,
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EVEN though the investigation of the highway-finance background in Kentucky, looking toward economical distribution of expenditures, sound methods of taxation, and wise choice between current revenues and borrowing as initial financing measures, is well under way, the problems of the distribution of the highway-user tax load among various classes of vehicles on the basis of an incremental-cost study are as yet confronted only in the planning stage. Thus, the following discussion of Kentucky thinking on the definitions of "basic road" and "basic vehicle," the classification of highways for incremental-cost study, and the treatment of maintenance expenditures in the light of Kentucky policies and methods must be regarded as distinctly preliminary. One fundamental purpose of the explanation is to invite criticism looking toward possible revision of the staff's outlook.

Although the point is only incidentally important to the problems mentioned, perhaps one should recognize that the Kentucky incremental analysis will be wholly in terms of projections to 1964-65. This fiscal period is accepted as representing a typical year within the program time span envisaged by the Automotive Safety Foundation.

DEFINITION OF "BASIC ROAD" AND "BASIC VEHICLE"

In Kentucky, as in other states which have attempted an incremental analysis, the decision regarding what is the "basic vehicle" and the "basic road" is of paramont importance and of considerable difficulty. In the Kentucky study, a basic vehicle is arrived at by the process of calculating backward from the basic road, that is, the definition of the basic road simultaneously determines the basic vehicle.

Members of the staff of the state highway department who collaborated on defining the basic road believed that it is determined by weather conditions. The state experiences a severe winter one year in four or five. It is not economical to design surfaced roads that will withstand, in excellent condition, this occasional frost; rather, the department designs the road to a lower standard and then bears the higher maintenance costs which ensue. But the road must be good enough to remain in operation and not be damaged irreparably by severe frost. Design standards established by these considerations determine, for any traffic-volume system, the basic road for that traffic-volume system. Working backward from the basic road, it is possible to determine the axle loads that a road designed to these standards would bear, and thus to arrive at the basic vehicle. To put it more specifically, the basic vehicle is one having axle loads no greater than those the basic road can withstand when used in keeping with the traffic volume normal to the particular system.

This treatment of the problem seems to be more realistic than the usual method of defining a basic vehicle in terms of a given axle load and then defining the basic road on each volume system in terms of that basic vehicle. Fundamentally, it means that the increments in cost on each density system are based on the cost of a road of minimum design standards in the sense that the Kentucky Department of Highways would not build a road of less-rigid specifications under any circumstances. In all probability this method of determining the basic vehicle will mean that the first axle-load class will extend to a weight considerably greater than is usual in studies of this type.

CLASSIFICATION OF ROADS FOR INCREMENTAL STUDY

In an incremental-cost study, it is essential that increments in pavement design standards be based on both axle loads and traffic volume. The Automotive Safety Foundation needs study, now nearing completion in Kentucky, has defined the standards for grade, curvature, and structure on each of three administrative systems of rural highways:

[1] The author's colleague, Virgil Christian, and W. B. Drake, of the Kentucky Department of Highways, have aided in the preparation of this paper.

state trunk-line, county arterial, and country feeder roads. Within each of these systems, design standards were established on the basis of traffic volume. These standards for each section of road were determined by two considerations: the administrative system to which it belonged and the volume of traffic on it.

The method of classification, when followed in Kentucky, led to 14 basic design standards for rural roads. To make matters worse, from the viewpoint of an incremental analysis, various modifications in trunk-line and county-arterial standards were necessitated by the wide differences in terrain throughout the state. Also, street design involved some departure from rural standards, especially in geometrics. When these modifications were counted, a grand total of 34 clearly identified standards resulted.

It is impossible to obtain traffic data in the detail that would be required to make an incremental analysis on such a vast scale. If such figures were at hand, the amount of calculation required would be prohibitive. It was decided, therefore, that highways with the same design standards would be combined, regardless of the administrative system in which they fell. This occasioned no serious difficulty, as the design standards did not vary greatly among administrative systems for given traffic volumes.

The traffic groupings in vehicles per day that most nearly satisfied the combined standards with a minimum number of categories are: 0 to 99; 100 to 399; 400 to 999; 1,000 to 1,999; 2,000 to 2,999; and above 3,000.

MAINTENANCE-COST PROBLEM

The determination of maintenance costs and the construction of maintenance-cost indexes present many problems of extreme practical difficulty. For example, if the calculation to be made is in terms of maintenance costs per mile for a given traffic-volume system, what can be done about the fact that the state's roads in that system have varying widths of pavement, of shoulder, and of right of way? A reduction factor is not feasible, because maintenance costs, as studies made by the Bureau of Public Roads indicate, do not vary functionally with road width. Yet it is hardly plausible that road width has no bearing at all.

Several alternative courses of action seem possible:

1. One can classify the sample of maintenance-expenditure data from each system by road widths, prepare estimates for maintenance cost per mile by road width, and then test for significant difference by comparison of averages and of dispersion or by analysis of variance techniques. If there is no significant difference, this implies that road width is of negligible importance relative to other factors for that traffic-volume system and can be ignored. If the difference is significant, it will be essential to prepare separate estimates for the different road widths and combine these in the final estimate by weighting each in proportion to the number of miles of that width in the system. This approach appears promising. But as the department has not yet completed maintenance record tabulations for the selected subsections of road, one cannot be sure that the conditions for the analysis of variance study are met.

2. If road width varies only slightly within lower traffic-volume systems, one can ignore it. On higher-volume systems, separate estimates must be made, at least, for two- and four-lane roads. Variations in width on these highways, however, can be ignored.

3. Separate estimates for pavement maintenance and for other maintenance expenditures would be essential. Within a given traffic volume system it is probable that expenditures for pavement maintenance would vary directly with road width, but those for shoulders would vary inversely. Should these two variations approximately offset each other, then ignoring road width would seem feasible; if not, then the separate estimates would be combined to arrive at a final average estimate applicable to the entire traffic-volume system.

4. Highway engineers by examination of maintenance expenditures might develop "judgment" maintenance-cost indexes independent of statistical analysis.

A second problem in connection with the construction of maintenance cost indexes is that of reconciling road age as it affects these costs with road age as recorded on the state's maintenance records. The department classifies a road as new after reconstruction, and reconstruction may mean 0.75 inches or more of resurfacing without alteration in subgrade and other cost factors having vital importance in road life and in other ways bearing on the expenditures required.

Even the third task of translating a definition of maintenance cost into usable terms is quite difficult. A theoretical definition, as "the cost... of preserving, within practical limits, the carrying capacity of existing roads" would include costs which differ appreciably from those shown on state maintenance records. Indeed, there would be heavy maintenance costs, as thus defined, on many sections of road on which only minor sums were spent during a given year and the reverse. To elide this aspect of the problem, maintenance expenditures for an average of 4.5 years, rather than maintenance costs, can be employed. This means essentially an attempt to assign responsibility for funds actually spent on maintenance.

A fourth problem as to maintenance expenditures has two distinct aspects: (1) What proportion of total maintenance expenditures are weight function expenditures? (2) What proportion of the weight function expenditures should be allocated to vehicles of each different weight and type? To get a preliminary basis for answers to these questions, a probability sample was taken from the maintenance records of the state highway department. Statistically, each section of road was put into one of the six traffic-volume systems. The six universes were then sampled at random, the size of the sample from each being determined by the usual statistical consideration.[2]

An ideal solution would involve expressing maintenance expenditure per mile as a function of age of the road and the number of axle miles of each axle-load increment to be used in the study. This would yield a multiple regression equation with expenditures per mile as the dependent variable and age of road and axle miles of each different axle-load increment as independent variables. Unfortunately, in this particular equation the independent variables, except age of road, would themselves be highly correlated; so the results of the analysis would consequently be quite unreliable. Specifically, if the number of axle-miles of the basic axle load is highly correlated with the number of axle-miles in the other axle-load increments (and that is most assuredly the case), then there is little basis for measuring the separate influence of each on maintenance expenditures. This limitation, incidentally, seems to preclude the use of a multiple regression equation to develop maintenance-cost indexes, not only in Kentucky but in any state, since it is inconceivable that the number of axle-miles of any given axle load would not be correlated with total traffic and thus with axle-miles of other axle loads.

This does not mean, however, that the expenditure records taken in the sample cannot be used to provide valuable information. A regression analysis involving maintenance expenditures as the dependent variable and total vehicle-miles of travel as the independent variable should provide a basis for making the decision as to what proportion of maintenance expenditures is a function of highway use. Perhaps a more useful approach would be to treat age of road and total vehicle-miles of travel as independent variables, with maintenance expenditures as the dependent variables, and then, using partial correlation analysis, find the effect of vehicle-miles on maintenance expenditures "net" of road-age influences.

It would be well to emphasize, however, that one cannot depend exclusively on the results of any contemplated statistical analysis. In the first place, the maintenance records as kept by the state highway department are admittedly not absolutely correct, and the maintenance expenditures upon which the analyses will be based will therefore be more or less incorrect.

Secondly, there is the possibility of error in the traffic estimates which will be used as one of the variables in the regression equation. This is in nowise a criticism of Kentucky's traffic data. As indicated by Hugo Duzan, of the Bureau of Public Roads, these data are much better than those in the average state. Even so, the statistics fall far short of an actual count on all the roads and streets of the state.

Thirdly, there is the difficulty, already mentioned, of determining accurately the age of a road.

Fourthly, there is possible sampling error. The sample was designed in such man-

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[2] Specifically, standard deviation and measures of skewness and kurtosis.

ner that the chances are nineteen to one that the error in the estimates will not be more than 10 percent of the estimates themselves, and it will in all probability be less; but we cannot ignore entirely that one chance in twenty. Actually, the sample from each traffic-volume system is large enough that the sampling error should be negligible compared with the likely errors in estimating road age and traffic.

Concepts of Cost Function and Incremental Solutions of Vehicle-Tax-Allocation Problem

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American Trucking Associations, Inc.

● A DISCUSSION of the incremental solution of the motor-vehicle-tax-allocation problem begins in the favorable atmosphere of its being generally recognized as the soundest approach to the problem.

This recognition of the theoretical soundness of the incremental approach stems from its inherent acknowledgment of the fundamental fact that highway-user taxes levied on individual vehicles, or groups of vehicles, should bear as close a relationship as possible to the actual costs these vehicles bring into existence.

Proper application of this principle must, of course, be preceded by acceptance of the collateral principle that the purpose of highway-user taxation is to recover from the highway users their fairly assigned share of highway costs.

In states where highway-tax and highway-cost studies have been undertaken, it has been readily admitted that the incremental method represents the soundest approach. However, statements to this effect are often qualified by the comment that the incremental solution requires the accumulation of a great deal of material that is not available, with the time factor cited as an insurmountable obstacle.

These may be valid reasons for the inability to apply the incremental solution. Being the more complex of suggested approaches, it represents considerably more work and extensive research.

It is somewhat ironical, however, that these acknowledgments of the soundness and desirability of the incremental approach are then followed by the application of a method that is completely opposed to the incremental, both in principle and in purpose.

In many states where gross ton-mile analyses have been made, it has been only after a frank admission that the incremental is the soundest and the best and should be applied if at all feasible. Thus, they begin their studies by contradicting in principle the method they attempt to apply and persist in making ton-mile analyses and, on the basis of their findings, recommend severe adjustments in the level of truck taxes.

The ton-mile approach contains the basic fallacy of ignoring completely the fundamental characteristics of highway costs. There are many different elements affecting the cost of building and maintaining roads and streets. Modern highway construction and maintainance is a complex undertaking. There are many different things to be considered, and each has an important effect on the ultimate costs of highways.

For example, such important elements as rain, snow, and excessive temperatures all have harmful effects on highway surfaces, unless built to withstand their destructive action. In addition, many costs of maintainance and administration are influenced solely by the volume of vehicular traffic, irrespective of vehicle size or weight.

Vehicle weight is a factor in determining the level of highway costs, but it is only one factor out of many. To use one measure of use, such as ton-miles, is to ignore the other factors and, therefore, to exaggerate beyond equitable proportion the proper responsibility of some vehicle groups.

Nevertheless, this invalid procedure was followed in the ton-mile analyses that were made. The sound principles behind the incremental method were completely and rudely discarded. The true relationship between highway-tax responsibility and highway costs was distorted beyond reason.

The error of the ton-mile approach becomes readily apparent when highway costs are analyzed on a more-scientific basis. Such a basis is provided in the incremental method; but the ton-mile studies were being made in those states where the incremental method was not considered, because of the extensive research that would be required.

Failure to consider the incremental approach because of technical and research difficulties was understandable. However, the abandonment of accepted principles is inexcusable.

The trucking industry found itself facing the brunt of the assult from the ton-mile analyses. Inevitably, they resulted in charges that truck taxes were too low and recommended severe adjustments, including the imposition of third-structure taxes.

In the face of this assult, and to bring the highway cost-tax relationship into proper focus, the industry developed and applied what has been called the cost-function method of highway-tax analysis.

The cost-function method analyzes all elements of highway construction, maintainance, and administration and segregates them into groups according to the factors that are predominant in bringing the costs into existence.

The first group of costs contains those items which are not affected by either miles of travel or weight of vehicles, such as beautification, landscaping, and similar roadway improvements. In the states in which studies have been made, these costs have been found to range from 10 percent to 14 percent of the total cost.

The second group of costs are those which are affected by mileage, or volume of traffic, but not by variation in vehicle size or weight. To a large extent these are basic highway costs and cover such items as traffic control, right-of-way expense, clearing, grading, etc. These costs, classified as nonweight-use costs, are assigned to the various vehicle groups on the basis of miles operated and have been found to comprise from 35 percent to 43 percent of total costs.

The third group, called weight-use costs, contains those items affected both by mileage operated and weight of vehicles. They are the major construction as well as surface-maintenance costs. They have been considered to be allocable to the various vehicle groups on the basis of ton-miles operated and have been found to comprise 45 to 50 percent of total costs.

The use of ton-miles, even to allocate those costs where vehicle weight may be admitted as a factor, still tends to overstate the responsibility of the larger vehicles. One reason for this is the use of gross weight in determining responsibility for highway-surface costs, whereas accepted engineering principles, as set forth in the incremental approach, tell us that axle wieght, rather than gross weight, is the controlling element in determining pavement stresses generated by larger and heavier vehicles. Gross vehicle weight may be a factor in determining the bearing stress of structures, but it gives way to axle weight as a factor in pavement design.

In those states where the cost-function analysis has been used, it has clearly shown gross inequities in the ton-mile method. The mere fact that the ton-mile method automatically assumes that gross weight is a factor in all elements of highway costs, whereas analysis develops that fewer than 50 percent of highway costs may conceivably fall in the weight category, is sufficient to condemn the ton-mile approach as a dangerous expedient.

An additional element that tends to overstate the responsibility of the heavier vehicles is the fact that contained in the weight-use category is the entire cost of surface construction. This means that a great many of the truly basic road costs are still assigned on the basis of vehicle weight, although a significant portion of them would remain even in the absence of the larger vehicles.

Despite these deficiencies, the cost-function approach has earned deserved recognition as a valid approach to the tax-allocation problem. This has come about not only because of its exposé of the weaknesses in the ton-mile method but because it seeks to inject the element of scientific analysis in the highway-tax field. It accomplishes this through detailed investigation and segregation of highway costs and an effort to bring into focus the important relationship between highway costs and the vehicles that use our roads and bring these costs into existence.

It is in this important respect that the cost-function approach tends in the direction of the incremental method. The latter is much preferred and should be used in those states where there is a sufficient resevoir of data and adequate background of acceptable information that makes a complete incremental study possible.

Actually, the cost-function method is also dependent upon extensive information on all elements of highway cost. It requires detailed segregations of all items of construction, maintainance, and administration. As data on these expenditures, where available, must be taken from the records that reflect different methods of accounting, the same segregation of items is not found in every state. However, despite these differences, the variation in the assignment of items among the three classes has not shown unusual variation in the states where studies have been made.

The cost-function study that was completed in Virginia in 1952 was coupled with an incremental study that was part of the same report. This report was submitted to a study commission on behalf of the Virginia Highway Users' Conference. An incremental study was possible in Virginia, because of the method used by the state in planning and constructing its road system. The state has in effect two road systems, which, for the sake of brevity, may accurately be referred to as its truck-road system and its non truck-road system. The latter is designed, and accordingly paid for, as a road system to carry normal, basic vehicular traffic. Truck traffic is not considered a factor in the design of these roads.

The remaining roads in the state's system are its truck, or general-purpose, roads, and these are designed with truck traffic in mind. Sufficient data on the design and costs of both road systems were available to enable an incremental study to be made. The difference between the cost of the nontruck road was considered to be the increment, or additional cost, to be assigned to truck traffic. The remaining costs were considered the basic costs, to be distributed to all vehicles on the basis of mileage operated.

It is not necessary to go into detail as to the findings in the Virginia study. However, it is significant to note that the findings as to tax responsibility in the incremental study and in the cost-function study were remarkably similar in many respects. Both found that the prevailing tax system was generally fair and equitable.

The Virginia incremental study did not depend upon the acceptance of engineering principles or procedures nor upon agreement as to what constituted the basic road and what its costs might be. By actual practice the state was incurring actual expenditures for roads that were being built. The incremental costs lay in the cost records of the state and not in seeking general agreement as to what might or might not be built if there were no heavy vehicles on the road.

In contrast to the type of incremental study that was possible in Virginia are studies that must look for their validity in the acceptance of certain suppositions and hypotheses. In these cases there is no background of experience as to what constitutes the increments of costs as proven bv practice. The study must set forth its assumptions and draw its conclusions based on these assumptions.

An illustration of such as assumption and its extreme importance is the basic road concept that is inherent in the incremental approach. The basic highway is the type of road that would be built if all motor vehicles were passenger cars and light trucks. These vehicles are classified as the basic vehicles.

Such a situation would mean that highways would not have to be built to carry the traffic of heavier vehicles, and engineers would not have to design weight-carrying capacities in the road system.

However, such a road would have to be designed to carry safely and expeditiously the large volume of passenger-car traffic, as well as the greatly increased volume of light truck traffic that would be required to take the place of the larger vehicles.

In addition, the basic road would have to be designed to overcome the destructive action of the elements, as mentioned earlier in the discussion of the ton-mile method. Engineers long have recognized that a good road's greatest enemy is the weather. Thus, although engineers may not have to design weight-carrying capacities in the basic road, they must continue to engineer for the elements.

Admittedly, the determination of the characteristics of the basic highway, and the resultant costs, is the most-difficult step in applying the incremental method. There is a tendency in some areas to treat the basic highway concept in a completely academic fashion and to forget that it must be a road that actually would be built in the absence of certain classes of traffic under prevailing conditions and not a road that might be built or possibly could be built.

The importance of the basic highway concept can be illustrated through reference to an incremental study recently completed in Minnesota. The Minnesota study selected the lowest type of highway design in each road system as the basic road, the one that would be built if there were no heavy vehicles.

All increments of cost were computed from this basic highway. Thus, the acceptability of the study's findings must rest primarily on the validity of the assumption that the state would design all roads in accordance with the standards of the 4,000-lb. -axle-load section, regardless of the volume of traffic the road would be called upon to carry. Such an assumption ignores the many important factors other than weight which influence highway design and highway costs.

In its publication "A Policy on Highway Types" (Geometric Design) the American Association of State Highway Officials states:

> Highways may be grouped in various types, the highways in each group differing from those of other groups in broad physical characteristics and in facilities for accomodating traffic. The phase of traffic which has the greatest effect on general highway design is density of traffic.
>
> The type of any highway should be related to the following factors: (A) traffic density; (B) character of traffic; (C) assumed design speed; (D) weight of traffic.
>
> These factors are indicated by the approved classification in the Policy of Highway Classification, except that weight carrying capacity is indicated only indirectly.
>
> The choice of the general type of highway is influenced more by traffic density than by any other factor . . . .

Although these remakrs relate to the geometric design of highways, (width of lanes, number of lanes, degree of curvature and gradient, etc.) it is also true that vehicle weight is not the sole factor in the determination of structural design. Structrual design is in reference to such items as pavement or surface thickness, bridges and structures, and preparation of subgrade.

It is true that vehicle weight is more of a factor in structural design than geometric design, but the extent to which it is a factor in structural design is also a matter of considerable conjecture. There are other equally important factors which must be considered in designing pavement thickness and subgrade characteristics. Among these are: traffic density, climatic conditions, soil types, and frequency of heavy axle loads.

It is interesting to note the appearance of traffic density as an important factor in both design standards. It is also interesting to reflect on the fact that, while we have been conducting studies and attempting to reach conclusions as to the effect of climate, subsoil, and axle loadings on highway surfaces, there seems to be little available on the precise effect of traffic density on pavement thickness.

The importance of climatic conditions on highway design was emphasized by Thomas H. MacDonald, then commissioner of the U. S. Bureau of Public Roads, in his testimony several years ago before the Interstate Commerce Commission in Docket 23,400. Commissioner MacDonald stated:

> We would not build roads much less than 7 inches at the edge and 6 inches in the center, no matter what kind of loads we were going to carry.
>
> If we built thinner surfaces they would curl up like tissue paper in the rays of the sun. They would warp; the frost heave would destroy them.
>
> So we have a certain minimum thickness of roads that is necessary to build if there were nothing heavier than ordinary passenger cars and farm trucks to use the road, and the whole question of the heavier buses and heavier trucks therefore begins with a certain minimum thickness of road which is necessary regardless of whether they exist or not .

The importance of the basic road design cannot be overemphasized. In the Ohio incremental study the basic road was stated to be the equivalent of a 4-inch cement-concrete surface. This is an interesting specification. It is interesting not only from the standpoint of Commissioner MacDonald's statement but because, in the City of Columbus, a sidewalk must be 5 inches thick; where a driveway crosses the sidewalk, it must be at least 6 inches thick.

Recently at Metropolitan Beach, Macomb County, Michigan, bids were sought for the construction of a roller-skating rink. In the public advertisement setting forth the construction standards for the skating rink, it was specified that the surface would consist of a 6-inch concrete slab. This requirement, together with the sidewalk requirement in Columbus, supports the concept that there is a minimum pavement thickness that must be designed, regardless of the load that may be imposed.

It is not suggested that sidewalk or skating-rink specifications be used as positive criteria for the design of highway surfaces. However, the existence of these specifications does illustrate the large area of controversy that surrounds the basic highway concept and its translation into actual costs.

The importance of traffic density as a factor in highway design seems to be submerged in some incremental studies that have been made. There seems to be considerable confusion in evaluating the dual effect of traffic density and the frequency of heavy axle loads.

Certainly we need to know a great deal more about the importance of axle load frequencies, but at the same time, we should know more about the effect of traffic density as a factor in itself. We know from actual traffic-volume studies that the high frequency of heavy axle loads is almost always found on roads of the highest traffic density. Despite this important fact, there is a tendency in some quarters to assign the additional highway costs solely to the axle-load frequencies; ignoring completely the important effect of traffic density. On many of these roads the elemination of the heavier axle loads would have no appreciable effect on road design. The presence of a high density of traffic would demand a facility of equal cost.

In addition to the selection of the basic highway and the determination of its costs, proper application of the incremental analysis calls for the assignment of certain highway costs to each vehicle group on the basis of miles operated. The costs to be assigned on this basis are the nonweight costs—the costs that are not affected by differences in vehicle size and weight.

Ordinarily this would seem to present no problem. However, in the case of vehicle combinations (tractor semitrailers and truck trailers) it has been advanced by some that separate mileage responsibilities should be computed for each unit. Such a procedure was followed in Ohio and Minnesota. Under this procedure, a tractor-semitrailer combination traveling 40,000 miles per year is given a mileage responsibility of 80,000 miles; 40,000 for power unit and 40,000 for the semitrailer. This means that a tractor-semitrailer combination with a total of three axles is charged with twice as much mileage responsibility as a three-axle truck of the same gross weight.

This is a procedure that is contrary to all principles of highway-tax analysis. The semitrailer, or cargo unit, it not a revenue-producing vehicle. It has no motive power and is incapable of producing mileage without the power unit, with which it forms an integral unit and becomes one vehicle. A double assessment of tax responsibility against these vehicles represents a penalty on vehicle combinations and places a premium on the efficiency that is gained through the use of articulated units.

The question of vehicle-combination mileage is one of the controversies surrounding the techniques involved in application of the incremental. There are others, including the use of axle mileage as a common denominator for the division of costs, that are not within the weight category.

However, the basic road—its structural and geometric design standards, its actual costs, and the type of traffic it could actually carry—remains the critical point in the incremental approach. It is in this area that the greatest amount of exploration is needed.

Comments on Tax-Allocation by Incremental Method Based on Application of the Method in Minnesota, 1953-54

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● THIS paper is based on two applications of the incremental method conducted by Public Administration Service as part of a highway finance study in Minnesota in 1953-54. Those applications were in turn based upon publications about other applications of the incremental method, and related subjects. This paper will attempt to establish the philosophical framework within which the incremental method has been developed, to outline the Minnesota study procedure and indicate how certain classes of vehicles were treated as the result of the use of that procedure, and to suggest ways of performing future incremental method solutions of the problem of allocating highway user taxes.

SOME PHILOSOPHICAL CONSIDERATIONS

Government activities may be characterized as proprietary activities or general activities according to the way they are financed. For the purposes of this discussion, proprietary governmental activities are defined as those services for which users pay on the basis of the cost of providing the service, such as the supply of water or the delivery of mail. General government activities are defined as those which provide a service that is paid for out of government revenue raised without regard for the use to which it will be put, and include such activities as police protection or the coinage of money.

The line between the two is not hard and fast, and occasionally an activity will be shifted, in whole or in part, from one basis to another. Apparently general activities are changed to a proprietary classification when a segment of the people or the legislative body becomes dissatisfied with the share of general revenue that has been expended for an activity and convinces the majority that a special group of beneficiaries can be isolated and taxed to obtain the desired revenue to carry on the activity at higher level of expenditure. Contrariwise, a proprietary activity reverts to a general basis when the majority wishes to regain flexibility in the use of all revenue available.

The activity of providing highways and byways to move people and products and to provide access to and egress from property has been supported through both approaches at various times. On the one hand, the completely proprietary toll highways have kept reappearing in the tapestry of history. On the other hand, the free use of paths turned into traces and tracks by the road building action of the users who cleared away this obstacle or filled in that hole has been the pioneering phase of public highway activity since man began walking. In Minnesota, the state government started with a completely general approach that ignored the question of who used the roads or how much anyone used them. Road work in the young state was paid for by a tax on all property supplemented by a tax of two days time to be put in on the roads by each able man. The coming of self propelled vehicles introduced a new type of thinking into Minnesota and culminated in a constitutional amendment in the early 1920's. As a part of this amendment, the people of Minnesota approved a change in highway finance philosophy. The meeting of this panel on the incremental method is one of the by products of this change in philosophy in Minnesota and other states.

Minnesota was in the van of a movement to dedicate certain revenue for exclusive use on highways. Since the action of dedicating highway revenue implies that portions of the revenue had been "diverted" to other activities, the logical conclusion of dedication is for all highways to be supported by the dedicated revenue alone. However, the conclusion actually reached through practical politics, as exemplified in Minnesota, is that the dedicated revenue should pay for only a certain part of the highway program; other parts of the program, largely those parts carried on by the local governments, should be supported by general revenue.

Thus, Minnesota highways can not be considered as a completely proprietary activity, nor are they an activity readily synchronized with general government activities. Each other lines which represented the relative maintenance costs on two highway sections which were alike in geographical location, width, materials, and construction standards, that is, everything but traffic volume. For instance, if costs on one section carrying 900 vehicles per day were 120 percent of the costs on its companion section which carried 500 vehicles per day, then a line was drawn between the point where the trial line crossed the 500 vehicle per day ordinate to a point on the 900 vehicle per day ordinate which was 120 percent of the first point. The slope of these test lines indicated whether the slope of the trial line should be changed. The lines finally determined gave a higher responsibility for maintenance costs to the forces of nature than did the Ohio study, a difference possibly due to the more severe Minnesota climate, or perhaps to the use in Ohio of a multiple correlation process to develop the curve, the controlled variables being total traffic and a general class of "heavy vehicles."

The increments finally used are presented in Appendix A.

Item 4. Tabulating the number of vehicles in each class according to registered weight is largely a mechanical task. The only problem facing the Minnesota study was to isolate tandem axle equipment from single axle. This was done by checking model numbers and by a survey of automotive chassis shops to determine the number of single axle vehicles converted to tandem axles. Tabulating vehicles by axle arrangement deviated from the Ohio study procedure, but in Minnesota tandem-axle equipment has different highway use characteristics than single axle equipment of similar capacity. The tabulations were for the first six months of 1953, rather than estimates for mid year of the program as in Ohio. (Registration fees in Minnesota go down one-twelfth each month after the first of the year, thus six months of vehicle registrations were used to get a normal registration fee.) The registration tabulation, as finally used, limited the number of weight brackets in each vehicle class according to the pattern of registrations and the load distribution characteristics of the vehicle type. The use of brackets larger than those used in the Ohio study reduces the computation work involved, but left enough points to plot a curve to obtain the graduated tax schedule.

Item 5. The tabulation of vehicle miles according to vehicle class and axle loading was made by the Traffic Section of the Highway Planning Survey. The accumulation of data from studies at loadometer stations, origin and destination surveys, traffic volume and classification counts, speedometer checks and reports of regulatory bodies provided the background of information necessary. These tabulations were on a current basis rather than estimates for midyear of the program as in Ohio.

Item 6. The arithmetical procedure used to distribute the appropriate share of the highway program in accordance with the above factors is expressed in the formula in Appendix B. This formula does not significantly deviate from the Ohio procedure, although one difference in computation that was introduced involved the smoothing of the license fee allocation left after the gas tax credit is applied to the vehicle tax allocations. The Ohio study developed a least squares curve to establish the license fees for each vehicle class. Feeling that distortion in the tax allocation to the class of vehicles might result from a least squares curve, the Minnesota study adjusted the rates visually to make a neat curve while keeping potential tax income at the proper level. Thus if a rate were raised $5 and it affected 500 vehicles, some other rate or rates would have to be reduced for enough other vehicles to eliminate the added $2,500.

ASSUMPTIONS THAT MAY HAVE AFFECTED ALLOCATIONS TO CERTAIN VEHICLE CLASSES

If action waited upon complete knowledge of all the pertinent factors, there would be no action. Knowing this to be true, the Minnesota study consciously included certain assumptions, with at least partial knowledge as to their effect. For example:

1. It was assumed that each vehicle affected lane capacity equally, hence, no responsibility was assigned to any class of vehicles for disproportionately reducing lane capacity. However, certain studies have shown one commercial vehicle to be equivalent to four passenger vehicles in reducing lane capacity on normal rolling terrain. Undoubtedly, this is responsible for adding additional lanes to various highways with attendant higher costs of right of way, construction, and maintenance.

Recognition of this greater reduction in capacity would have been reasonable.

2. It was assumed that loads over the legal limit have no extra effect upon highway costs, hence, no attempt was made to penalize the classes of vehicles that have frequent axle loads over the legal limit. Naturally, these loads beyond the designed capacity of the roadway hasten the day of replacement and add to the costs of maintenance up to the day of replacement.

3. Average annual mileages as used in the report for certain commercial vehicles may be both high and low in some instances, as judged from early returns of a speedometer check being made too late for inclusion in the study. While this is true, no serious inequities would result in the taxes paid since a pay as you go tax structure was recommended for the classes of vehicles with the higher mileages.

4. Lane widths for the design sections in the two highest capacity systems were the same for all axle loads. The Ohio study, backed up by research, did have a narrower lane width for the lightest class of vehicles. The Minnesota procedure gave an advantage to heavy vehicles.

5. Whereas the incremental method formally ends with an allocation of total tax responsibility against the several types of vehicles analyzed, practically, the gas tax paid by each vehicle is subtracted from the total tax allocation for that vehicle in order to determine the amount of license fee and weight tax to be paid. The rate of topographical rise and fall of Minnesota highways is less than that established in gas consumption curves in Research Report 9-A of the Highway Research Board. This means that actual rate of gas consumption in Minnesota is less than that plotted in the lowest gas consumption curve. However, the lowest gas consumption curve was assumed, providing a differential of allocated but unchanged tax that becomes significant for heavier vehicles.

In spite of giving the heavier vehicles the benefit of every doubt, the tax allocation developed for them was much higher than their present tax payments.

FUTURE USE OF INCREMENTAL METHOD

Some objective means of allocating a share of highway program costs to each highway user must be used as long as there is pressure to treat highways as a proprietary rather than a general function of government. The general procedure of the incremental method is the only one upon which interested parties have reached substantial agreement, indicating that this method probably will continue to be used in the future.

Suggested Changes in Technique

It would be folly to think the zenith will be reached tomorrow in this type of engineering-economic analytical problem. Research keeps pressing forward into the vague areas of the unknown and no one can say where the boundaries of ascertainable knowledge about this field are. But based on two applications of this procedure and having available the excellent exposition of the Ohio study, it would seem that techniques can be improved in at least five ways.

First, the costs of the highway program in all its aspects should be allocated with sureness to the proper incremental study systems. Present needs study techniques develop and present certain portions of highway cost information quite capably. But to conduct the incremental method, program costs must be by the traffic characteristic systems selected for study. Further costs should include all costs occasioned by modern vehicles, that is, enforcement of vehicle registration, load limit regulation, traffic police, street lighting, traffic control devices, and a proportionate share of street cleaning and storm drainage; these are all a part of highway costs and should not be avoided simply because they are controversial. Naturally some of this will require a special investigation not being done in current needs studies.

Second, the costs must be broken between the share to be treated as a proprietary responsibility and the share to be treated as a general government responsibility. This split between cost to the highway user and cost to the general public requires some additional work, since available solutions to the problem have proceeded from shaky philosophical bases.

Third, it may well be that in future solutions, costs should be distributed upon wheel load rather than axle load. This suggestion leads directly into another question as to whether load per square inch of tire-pavement contact area is not the proper way of grouping vehicles, at least for obtaining construction cost increments. Tied into this general question is the problem of whether tandem wheels should be considered as a single unit acting upon the highway, or as two individual loads, or as partly one and partly the other. At any rate, just as axle load is a better measure for distributing highway costs than total load, so may wheel load or load per unit of contact area be a better measure than axle load.

Fourth, there should be separate solutions for rural and urban highways. The characteristics of vehicle travel, the increments of cost and the emphasis of program is quite liable to be different in each case. The lumping of urban and rural highways into one solution probably distorts the answers obtained through the incremental or any other method of vehicle tax allocation.

Fifth, there should be a way developed to penalize each class of vehicles according to the regularity of axle loads over the legal limit. If our highway designs are correct, overloads are probably a heavier contribution to highway costs than any other one thing, and as such, it would seem desirable to realize additional revenue from the classes of vehicles that carry overloads regularly. Unless enforcement procedures are intensified, this may be the only (though undesirable) way of penalizing weight violations.

Availability of Data

The Minnesota Highway Department was in a position to provide much of the basic data needed for the incremental method, although it must be recognized that not every state is in that position. However, even in a state like Minnesota some data must be estimated on the basis of circumstantial evidence, and, unfortunately, the need for other data must be ignored or treated expediently.

Travel Data. In particular, better data are needed on urban travel. The nature of most state highway planning surveys has restricted the scope of survey operations within cities and this has left a void in knowing what vehicles are in the urban traffic stream, where they travel, how often, and with what loads. Generally speaking, more accurate data is needed on the annual average mileage of the various vehicle weight groups within each class of vehicle.

Maintenance Cost Data. Better data are needed on the relative effect of each type of vehicle upon costs of maintenance of condition. For instance, do multiple axle vehicles cause a disproportionate part of the maintenance, either more or less? Is the share attributable to vehicles of each weight and type constant from rural highways to urban streets, or high structural strength roads to low strength roads?

Data on Cost of Auxiliary Facilities Caused by Highways. A more accurate accounting is needed of the expenditures, particularly by local governments, which are auxiliary to highways; such things as traffic police and traffic technicians, traffic control devices, bigger drainage facilities occasioned by rapid runoff from increasing areas of impervious pavement, and the costs of storing vehicles are all things which should be considered in a proprietary treatment of highway use.

ESSENCE

This paper has reviewed the philosophical base which creates a need for some such device as the incremental method. If the pressure for dedicating highway user tax revenue were removed, the need for this type of approach would be lessened. It appears, however, that the necessity of developing a tax structure based on a buyer-seller relationship must be faced; the incremental method presents a rational approach. The basic information is generally available and the gaps represent data which can and should be developed for better highway construction and operation and for purposes of tax analysis. The extent of agreement as to the suitability of the incremental method indicates that the results should provide a reliable base for legislative action in states requiring the dedication of highway user revenue.

Appendix A

INCREMENTS OF COST DETERMINED IN THE MINNESOTA STUDY

Axle Load in Kips	System A	System B	System C	System D
		Roadway Costs		
0- 4	52	64	75	100
4-10	13	18	25	
10-14	13	18		
Over 14	22			
		Structure Costs		
0- 4	73	76	88	100
4-10	11	12	12	
10-14	11	12		
Over 14	5			
		Maintenance of Condition Costs		
0- 4	64	84	87	100
4-10	2	5	13	
10-14	6	11		
Over 14	28			

Appendix B

INCREMENTAL METHOD OF ALLOCATING VEHICLE TAXES EXPRESSED ALGEBRAICALLY

Primary Equation

Tax Allocation to One Vehicle of a Certain Type=

$$AMA_{0-4} \times WCA_{0-4} + AMB_{0-4} \times WCB_{0-4} + AMC_{0-4} \times WCC_{0-4} + AMD \times WCD + AMA_{4-10} \times WCA_{4-10} + AMB_{4-10} \times WCB_{4-10} + AMC_{over\ 4} \times WCC_{over\ 4} + AMA_{10-14} \times WCA_{10-14} + AMB_{over\ 10} \times WCB_{over\ 10} + AMA_{over\ 14} \times WCA_{over\ 14} + VMA \times TCA + VMB \times TCB + VMC \times TCC + VMD \times TCD + FC$$

Secondary Equations

Elements of Weight Costs

$$WCA_{0-4} = \frac{RIA_{0-4} \times RPA + SIA_{0-4} \times SPA + MIA_{0-4} \times MCPA}{CAMA_{over\ 0}}$$

$$WCA_{4-10} = \frac{RIA_{4-10} \times RPA + SIA_{4-10} \times SPA + MIA_{4-10} \times MCPA + WCA_{0-4}}{CAMA_{over\ 4}}$$

$$WCA_{10-14} = \frac{RIA_{10-14} \times RPA + SIA_{10-14} \times SPA + MIA_{10-14} \times MCPA + WCA_{4-10}}{CAMA_{over\ 10}}$$

$$WCA_{over\ 14} = \frac{RIA_{over\ 14} \times RPA + SIA_{over\ 14} \times SPA + MIA_{over\ 14} \times MCPA + WCA_{10-14}}{CAMA_{over\ 14}}$$

$$WCB_{0-4} = \frac{RIB_{0-4} \times RPB + SIB_{0-4} \times SPB + MIB_{0-4} \times MCPB}{CAMB_{over\ 0}}$$

$$WCB_{4-10} = \frac{RIB_{4-10} \times RPB + SIB_{4-10} \times SPB + MIB_{4-10} \times MCPB + WCB_{0-4}}{CAMB_{over\ 4}}$$

$$WCB_{over\ 10} = \frac{RIB_{over\ 10} \times RPB + SIB_{over\ 10} \times SPB + MIB_{over\ 10} \times MCPB + WCB_{4-1}}{CAMB_{over\ 10}}$$

$$WCC_{0-4} = \frac{RIC_{0-4} \times RPC + SIC_{0-4} \times SPC + MIC_{0-4} \times MCPC}{CAMC_{over\ 0}}$$

$$WCC_{over\ 4} = \frac{RIC_{over\ 4} \times RPC + SIC_{over\ 4} \times SPC + MIC_{over\ 4} \times MCPC + WCB_{0-4}}{CAMC_{over\ 4}}$$

$$WCD = \frac{RPD + SPD + MCPD}{CAMD}$$

Elements of Travel Costs

$$TCA = \frac{RWA + MOPA}{CVMA}$$

$$TCB = \frac{RWB + MOPB}{CVMB}$$

$$TCC = \frac{RWC + MOPC}{CVMC}$$

$$TCD = \frac{RWD + MOPD}{CVMD}$$

Elements of Nontravel, Nonweight Costs

$$FC = \frac{\text{Motor Vehicle Bureau + Petroleum Division}}{\text{Total Vehicle Registration}}$$

Definitions of Vehicle Allocation Factors Which Would Be the Same For All Vehicle Types

Costs Which Are Attributable to Weight

WCA_{0-4} = cumulative cost per axle mile of 0-4 kip load travel on A
WCA_{4-10} = cumulative cost per axle mile of 4-10 kip load travel on A
WCA_{10-14} = Cumulative cost per axle mile of 10-14 kip load travel on A
$WCA_{over\ 14}$ = cumulative cost per axle mile of over 14 kip load travel on A

WCB_{0-4} = cumulative cost per axle mile of over 0-4 kip load travel on B
WCB_{4-10} = cumulative cost per axle mile of 4-10 kip load travel on B
$WCB_{over\ 10}$ = cumulative cost per axle mile of over 10 kip load travel on B

WCC_{0-4} = cumulative cost per axle mile of 0-4 kip load travel on C
$WCC_{over\ 4}$ = cumulative cost per axle mile of over 4 kip load travel on C

WCD = cumulative cost per axle mile of all kip load travel on D

Costs Which Are Attributable to Travel

TCA = the share of the cost of right of way and maintenance of operation on A allocated to each vehicle mile of travel on A
TCB = the share of the cost of right of way and maintenance of operation B allocated to each vehicle mile of travel on B
TCC = the share of the cost of right of way and maintenance of operation on C allocated to each vehicle mile of travel on C
TCD = the share of the cost of right of way and maintenance of operation on D allocated to each vehicle mile of travel on D

Costs Not Attributable to Travel or Weight

FC = fixed cost per vehicle

Elements of Weight Costs

RIA_{0-4} = increment of A roadway costs chargeable to 0-4 kip axle loads
RIA_{4-10} = increment of A roadway costs chargeable to 4-10 kip axle loads
RIA_{10-14} = increment of A roadway costs chargeable to 10-14 kip axle loads
$RIA_{over\ 14}$ = increment of A roadway costs chargeable to over 14 kip axle loads

RIB_{0-4} = increment of B roadway costs chargeable to 0-4 kip axle loads
RIB_{4-10} = increment of B roadway costs chargeable to 4-10 kip axle loads
$RIB_{over\ 10}$ = increment of B roadway costs chargeable to over 10 kip axle loads

RIC_{0-4} = increment of C roadway costs chargeable to 0-4 kip axle loads
$RIC_{over\ 4}$ = increment of C roadway costs chargeable to 4-10 kip axle loads

There are similar series for structure costs (SI), and maintenance costs (MI).

RPA = roadway program costs for A
RPB = roadway program costs for B
RPC = roadway program costs for C
RPD = roadway program costs for D

There are similar series for structure costs (SP), and maintenance of condition costs (MCP).

$CAMA_{over\ 0}$ = cumulative axle miles of travel on A for all axle loads
$CAMA_{over\ 4}$ = cumulative axle miles of travel on A for over 4 kip axle loads
$CAMA_{over\ 10}$ = cumulative axle miles of travel on A for over 10 kip axle loads
$CAMA_{over\ 14}$ = cumulative axle miles of travel on A for over 14 kip axle loads
$CAMB_{over\ 0}$ = cumulative axle miles of travel on B for all axle loads
$CAMB_{over\ 4}$ = cumulative axle miles of travel on B for over 4 kip axle loads
$CAMB_{over\ 10}$ = cumulative axle miles of travel on B for over 10 kip axle loads
$CAMC_{over\ 0}$ = cumulative axle miles of travel on C for all axle loads
$CAMC_{over\ 4}$ = cumulative axle miles of travel on C for over 4 kip axle loads

CAMD = cumulative axle miles of travel on D for all axle loads

Elements of Travel Costs

RWA = right of way costs for A
RWB = right of way costs for B
RWC = right of way costs for C
RWD = right of way costs for D

MOPA = maintenance of operation program costs for A
MOPB = maintenance of operation program costs for B
MOPC = maintenance of operation program costs for C
MOPD = maintenance of operation program costs for D

CUMA = cumulative vehicle miles for A
CUMB = cumulative vehicle miles for B
CUMC = cumulative vehicle miles for C
CUMD = cumulative vehicle miles for D

Definitions of Vehicle Allocation Factors Which Would Change For Each Vehicle Type

Axle Miles

AMA_{0-4} = axle miles traveled per vehicle on A while carrying a 0-4 axle load
AMA_{4-10} = axle miles traveled per vehicle on A while carrying a 4-10 axle load
AMA_{10-14} = axle miles traveled per vehicle on A while carrying a 10-14 axle load
$AMA_{over\ 14}$ = axle miles traveled per vehicle on A while carrying an over 14 axle load

AMB_{0-4} = axle miles traveled per vehicle on B while carrying a 0-4 axle load
AMB_{4-10} = axle miles traveled per vehicle on B while carrying a 4-10 axle load
$AMB_{over\ 10}$ = axle miles traveled per vehicle on B while carrying an over 10 axle load
AMC_{0-4} = axle miles traveled per vehicle on C while carrying a 0-4 axle load
$AMC_{over\ 4}$ = axle miles traveled per vehicle on C while carrying an over 4 axle load
AMD = axle miles traveled per vehicle on D while carrying any axle load

Vehicle Miles

VMA = mileage per vehicle on A
VMB = mileage per vehicle on B
VMC = mileage per vehicle on C
VMD = mileage per vehicle on D

On the Incremental Analysis of Highway-Cost Responsibility

R. G. HENNES, Professor of Civil Engineering, University of Washington; Chairman, Washington State Council for Highway Research

● THE first problem inherent in the incremental theory is suggested by the term itself. The word "incremental" implies the existence of a base to which increments are to be added. After some basic road standard has been assumed, it becomes possible to determine rationally the additional costs involved in the higher design standards, which are necessary to extend the usefulness of the road for heavier vehicles. This is not to discount the grave problems of data and of professional judgment which still remain; nor to deny the possibility of arbitrary decisions on controversial details.

The selection of a basic road will always be subject to criticism and disagreement. Consequently, the decision should be reached with the objectives of the study clearly in mind, and with full recognition of the practical implications of all assumptions.

THE MATTER OF OBJECTIVES

Any highway tax study is motivated either by the need for more money, or by a desire for greater equity in the distribution of the existing tax burden, or by some combination of both motives. Rather commonly, an important consideration in authorizing the study is a feeling that some particular class of vehicle (for example, heavy trucks) is paying more or less than its share of highway costs. Under such circumstances it is natural to choose for the basic road a facility designed exclusively for passenger car traffic. This assumption is right and proper, if the scope of the problem has been correctly gauged, if our concern is whether at the current rate of highway expenditure each vehicle group bears its fair share of the bill.

However, the attainment of complete tax equity between automobiles and trucks would not in itself assure adequate support for an adequate system of public roads and streets. Highway economists would be at fault if they failed to recognize the popular mandate for road facilities far superior to those which existing revenues are able to provide. No matter how these superior facilities are to be financed, the cost will ultimately be repaid from revenues, necessarily based upon higher rates.

Thus the problem is not really to determine the equity of the allocation of today's road costs. It is to find an equitable plan for meeting the expense of tomorrow's program.

A STABLE BASIC ROAD

Even though changing traffic creates constantly changing road standards, it is possible and helpful to conceive of a basic standard that does not change. Any base should represent stability rather than flux. A basic road chosen to accomodate automobile traffic means one thing today and another tomorrow. To find a basic road which will have permanent meaning we must go back 50 years to the period immediately before the influence of the automobile became a factor. The highway treatises of that period describe road standards applicable to the type roads found in each of our modern administrative systems; county, city and state. Such basic roads provided land access and permitted the exercise of governmental functions at all levels of government. Modern road improvements are incremental to those bases. Except for the tremendous expansion of road use which followed the development of the internal combustion engine, the expense of modern highway development would have been avoided, nor would there be justification for the user taxes which have paid most of the bills.

THE SHIFT IN HIGHWAY EXPENDITURES

Another consideration which argues for a comprehensive sort of tax theory is the radical change which is taking place in the pattern of highway expenditures. The urban expressway does not fit neatly into any of the traditional road systems which had been evolved for administrative and financial reasons; and the compromises which have permitted expressway construction have varied expediently with circumstances and with geographical location.

Because the expensive expressways are functionally intermediate between city streets and intercity state highways, a satisfactory tax theory must embrace both systems. Here it is relevant to recall that the one system has been built, largely, with property taxes, and the other largely with user taxes. The problem of meeting expressway costs transcends the division of cost responsibility between car and truck, or it will forfeit the traditional property tax support for city streets by default, rather than by a conscious act based upon rational judgment. Even if the conclusion is correct it should be reached through deliberation, not by oversight.

If the pre-automobile road is taken to be the basic road, the first increment should be the cost of improving that road to accomodate automobile traffic, and succeeding increments should correspond to appropriate types of commercial vehicle. These increments must recognize both the effect of wheel loads on structural design, and the effect on geometric design made by vehicle size, speed and power.

ROAD CLASSIFICATION

Because road design will vary with the use to which the road is to be put, a comprehensive incremental cost study should deal, in turn, with each of several road types selected on a functional basis. For practical reasons the number of road types must be kept to a minimum: say, rural land service, roads, county arterials, intercity highways, residential city streets, city arterials, and expressways. Normally, each of these road types will depend to a different degree upon user taxes. Consequently, the division of responsibility between car and truck is only a partial solution, and if my earlier remarks tended to over-emphasize the importance of the basic road concept, the excuse is to be found, here, in the importance of property tax support for some road types.

The selection of road types on a functional basis permits a reasonable estimate of the user's cost responsibility before applying the incremental procedure, and also facilitates tax scheduling at the various levels of government, because, in a general way, the classification of roads and streets into administrative systems has a functional basis.

TRUCK FEES

The application of incremental cost theory may end with the assignment of cost responsibility to each of the several vehicle types. However, the philosophy of incremental cost may properly be extended to influence the choice of methods for the collection of the incremental cost assignments. For example, if it is found that trucks of 10,000 to 20,000 lb. GVW should pay, as a class, $500,000 per year, the question of collection still remains. Should each such truck pay the same annual fee, or should a mileage charge be assessed? It seems in line with the concept of incremental cost that those cost items which represent readiness to serve should be collected by equal annual assessments against each unit of the vehicle group, while those elements of cost which are proportional to frequency of load repetition or to density of traffic should be charged on a mileage basis. The fuel tax is the simplest device for this purpose, but more complicated procedures may be found necessary. Sometimes theory can be compromised to obtain a practical solution without any significant sacrifice of equity.

A mileage tax based upon those incremental cost items which are proportional to traffic density is quite different from a mileage tax based upon the ton-mile theory. The one is a charge for using-up the road, while the other is a charge for road use. The former charge is a joint-owner's share in the cost of construction or replacement, while the latter is a tenant's payment of rent. It is a major attraction of the incremental-cost theory that it recognizes each user to be responsible for his fair share of the cost of the road which, as a citizen, he owns in part. Alternative theories consider the user as a customer of the government, with fees based upon service rendered. Because costs are not necessarily proportional to service, only the incremental cost theory is aimed at what should be our ultimate objective - providing facilities that permit transportation of people and of goods at minimum total cost. Road use will be influenced by road costs only to the extent that user fees reflect cost responsibility rather than some other unit of service.

An important quality of incremental cost theory is that it recognizes the unique character of highway transportation, and faces up to the problem directly rather than by some analogy. Analogies are useful in explanation but dangerous in agrumentation. Thus, some say that operating a highway system is like running a business, and that since a businessman may prefer to borrow rather than to sell stock there is justification for a permanent highway debt. Such reasoning would overlook the fact that the highway user is a part-owner of the facility which he uses; and that buiness debt, in contrast, results from a decision to pay interest rather than to share profits by issuing more stock.

To say that a highway is like some competing privately-owned transportation agency and hence should be financed by a similar method of rate-making is again to miss the distinction between types of ownership. When highway user-owners each pay their fair share of the cost of the road, the standard of road improvement becomes subject to economic control; and the rates of competing agencies, in response to this competition, also become more closely geared to the cost of the service. Only through incremental cost can we automatically approach transportation at minimum total cost.

THE HIGHWAY COST ALLOCATION PROJECT IN WASHINGTON STATE

The current study of highway taxation in the state of Washington, under the auspices of the Washington State Council for Highway Research, includes the incremental approach, as well as several other theories, for the use of the State Legislature in its establishment of policy. The study was authorized by the 1953 Legislature, which directed that a study be made of "motor vehicle taxation, including the assignment of total highway costs among property owners, general taxpayers and highway users." The prospectus for the investigation was finally approved in December 1953, and work has been in progress throughout 1954. The final report will be available to the 1957 Legislature.

In planning this investigation, major reliance was placed on forthcoming data from current research by other agencies. These other projects include the WASHO test road at Malad, the Road Life Study, the Operating Cost Study, the Vehicle Use Study, and the Highway Needs Study. Most of the effort expended during 1954 has been in the collection of data not otherwise available in Washington State.

Bayard O. Wheeler, professor of general business, University of Washington, has been supervising analysis of the effect of limited access highways on suburban property values, based upon several thousand records of real estate sales before, during and after construction of the improved facility.

Stanley H. Brewer, associate professor of marketing and transportation, University of Washington, has under way an extensive study of intra-state commodity movements and competitive freight rates. Such information is needed for the estimation of the value of user benefits.

William L. Garrison, assistant professor of geography, University of Washington, is in charge of an analysis of highway benefits to rural property.

Martin I. Eksey, associate professor of civil engineering, University of Washington, has been organizing the incremental cost phase of the project.

Earl C. Hald, associate professor of economics, University of Washington, has been conducting an inquiry into the feasibility of bond financing for highway improvement.

Joseph W. McGuire, assistant professor of general business, University of Washington, has under way the collection and analysis of data needed for the ton-mile approach. At the present time questionnaires on car mileage and fuel consumption are being returned with car, truck and bus license renewals.

G. A. Riedesel, research engineer, State College of Washington, is currently conducting a classification of county roads and city streets, to supplement the classification of state highways which was completed in 1952.

Prior to the inception of the project, advice on the formulation of the prospectus was obtained from a board of consultants, composed of M. Earl Campbell, Harmer E. Davis and Bertram H. Lindman. The Board will also be invited to review the findings and recommendations resulting from the study.

The chairman of the legislature's Interim Highway Committee also has appointed an advisory committee, composed of representatives of groups within the state having an economic interest in the construction and financing of highways; to guard against overlooking any relevant factor in the investigation, and to promote public understanding of the final report.

General Discussion

● JAMES S. BURCH, North Carolina State Highway and Public Works Commission — I do not know of any current question in the field of highway research more important than the motor vehicle allocation tax problem.

We have the peculiar situation of a public-owned and operated facility being used as basic plant by commercial operators, and by the general public. In many respects, the size of the plant, its design, its capital cost and upkeep, are dictated more by the commercial users than by the general public users. The charges, in the form of tax rates, made by the public agencies to these users, rarely rests upon anything more basic than opinion or controversy. The result is a hodgepodge of pricing systems, few of which appear to involve much logic, sound reason or factual approach.

It is readily granted that the problem is quite complex. There is, at once, both a lack of general interest, and a very intense controversial attitude in some specific segments. The result has become a complete lack of understanding and cooperation between the owners of the plant and the users. Perhaps it could be said that this has many "landlord-tenant" aspects. Both argue periodically over rental rates, but neither is able to prove his arguments or justify his position. It would appear timely to make exhaustive cost-use-depreciation studies on a factual basis.

It is realized that some progress has been made, and that the incremental solution appears to offer the most equitable and practical approach. However, I feel that this work should be expedited, and should not be permitted to drag out for many years. I see no reason why some of the $1\frac{1}{2}$ percent Federal Aid funds could not be originally earmarked for such a study, to be handled by the Highway Research Board, and done as a special project on a National basis.

BERTRAM H. LINDMAN, Operations Research Office, Johns Hopkins University — One important area of controversy in the incremental cost solution to the highway cost problem is that of the proper depth or thickness of pavement for a basic highway. My recollection is that in the study by the Federal Coordinator of Transportation a Portland cement concrete thickness of 2.6 inches was calculated to be theoretically adequate but a thickness of 4 inches was adopted as the minimum likely to be built. In the study by the California Division of Highways a relatively thick pavement (I cannot recall the exact thickness) strong enough to support highway maintenance trucks producing 8,000-pound axle loads was assumed. I have come to the view that the pavement for the basic highway should be of sufficient thickness to withstand weather effects.

But differences with respect to the assumed thickness of pavement do not affect the cost allocation as much as might be expected. If a thin pavement is selected for the basic highway, both the increments of added cost caused by the heavier vehicles and the number of vehicles sharing this cost are greater, thereby reducing the share assignable to each. On the other hand, if a relatively thick pavement is selected, both the increments of added cost assignable to the heavier vehicles and the number of heavy vehicles to share this cost are less, thereby reducing less than might be expected the share assignable to each.

It would appear desirable to have studies made to determine if differences in the assumed thickness of pavements for the basic highway do have any major effect on the resulting cost allocations.

JOSEPH H. MOORE, Assistant Professor of Civil Engineering, The Pennsylvania State University — In recent years there has been an increased interest in the high costs involved in building and maintaining adequate highways. The public has at last been incited to action and is demanding that costs be properly distributed among those who benefit directly from the use of these highways. The incremental weight method is the most practical solution to this distressing problem.

In 1952 the Joint State Government Commission of the Commonwealth of Pennsylvania engaged the firm of Haller, Raymond, and Brown of State College to conduct a study on highway use and highway costs.[1] The writer, a structural engineer, was concerned with many phases of the study but wishes to limit this discussion to only one item—the design of rigid pavements.

This single item was chosen simply to illustrate the thesis that one of the major stumbling blocks in any incremental weight study is the absolute fact that we may not know how to determine the proper thickness to build pavements to support various loads applied in the way in which wheel loads are applied to pavements. While it is true that the surface of the road represents only a small proportion of the total cost of a section of highway, we must remember that it is chiefly the surface and subgrade which directly reflect the effects of heavy wheel loads. A method of correlating subgrade bearing capacity, pavement depth, wheel load, and pavement life is therefore needed.

The writer has recently written an article [2] outlining the method of determining pavement depth and pavement life which was used in the Pennsylvania study. One of the points of interest was that a concrete pavement depth of eight or nine inches was found to be the proper depth to give the longest possible pavement life regardless of the type of traffic. Pavement life for a given pattern of traffic (note that a practical pattern of traffic loads was used rather than single loads) however, could be considerably increased by improving the bearing capacity of the subgrade. Various patterns of traffic from very heavy (a large percentage of heavy wheel loads) to very light were analyzed, and of course this reflected the effect of heavy wheel loads on pavement life. The analysis, incidentally, was not just a theoretical treatment but was the result of tested theory and on-the-site condition and traffic surveys.

The details of the design method will not be covered in this discussion, but a few of the considerations will be mentioned. Obviously we should design a rigid pavement to resist cracking. In Pennsylvania many transverse cracks were found in the long slabs but few diagonal cracks across the corner were observed; and since the pavement slabs were more than twenty or thirty feet long the method of design suggested by the Portland Cement Association[3] was not applicable. Restrained warping stresses in slabs can be large[4], and very high stresses result when these are added to the maximum wheel load stresses that are produced when the wheels are along the free longitudinal edge of the slab. It was the frequency of this combination of stresses which was considered in the design.

Another factor considered was the lateral distribution of vehicles in the traffic lanes. This obvious item appears to have been omitted from any previous design procedure but it of course clearly introduces the well-known fact that a 12-foot pavement lane will have a much longer life than a 9-foot pavement lane.

It should therefore be noted that there are many engineering questions relative to design which must receive careful consideration if the life of a pavement under practical traffic patterns is desired. And pavement thickness is only one of the preplexing design problems which must be answered when any incremental weight cost analysis is attempted. These detail design questions must not be hastily considered lest it later be discovered that the "30-year pavement life" so quickly determined during the study becomes a 15 or 20 year pavement life in reality, and seriously effects the validity of the entire cost analysis.

C.A. ROTHROCK, <u>State Planning Engineer, State Road Commission of West Virginia</u>[5]— The just division of the costs of providing adequate highways among the various bene-

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[1] Highway Use and Highway Costs; Technical supplement to Highway Use and Highway Costs, Reports of the Joint State Government Commission to the General Assembly of the Commonwealth of Pennsylvania, Session of 1953, Harrisburg, Penn.

[2] Moore, Joseph Herbert, "Determining the Required Thickness of Concrete Pavements for Highways", Separate No. 596, Proceedings American Society of Civil Engineers, New York, N.Y., January 1955.

[3] Concrete Pavement Design, Portland Cement Association, Chicago, Ill.; 1951.

[4] "Final Report on Road Test One-MD", Special Report 4, Highway Research Board, Washington, D.C., 1952.

[5] Now engineer of preliminary location and design for the Ohio Department of Highways, Columbus, Ohio

ficiaries is one of the most complex and perplexing problems confronting today's highway administrators.

This problem is especially complicated in a state like West Virginia, which is one of the few in which the burden of constructing and maintaining all the highways is upon the state (except for some city streets but including connecting routes in cities). The difficulty is further aggravated in West Virginia by two outstanding characteristics of the state's highway systems, not generally found in other states to as great a degree and therefor not an important factor in their calculation of a just allocation, or in the collection of highway imposts.

(1) West Virginia is a so-called "corridor" state, that is, its main highways are used largely by the heavier types of property carrying vehicles in trips between the areas of the more southern and northern states, and between the areas of the middle west and the Atlantic seaboard.

(2) West Virginia's terrain is, in large part, mountainous in character, for which reason many of its main highways, having been constructed in the past before the era of the "truck problem", are on steep grades with a considerable mileage of winding alinement.

How these characteristics complicate what might otherwise be considered an equitable solution of the allocation problem is described as follows:

First: Assume that an equitable allocation of highway costs has been made between the highway users as one group, and the other beneficiaries, such as land, property, business, etc., as another group. Then suppose that the part of the burden allocable to the user has been further equitably divided among the various classes of users, such as passenger cars and the commercial vehicles of various gross weights and axle characteristics. Having done this, under the present generally accepted method of taxation, the rate of registration fee per unit is fixed upon those vehicles which are registered within the state, with due allowance being made for fuel tax payments as a part of the allocated cost.

To do this neglects the fact that a large percentage (approximately 50 percent on many highways) of the traffic by heavy combination vehicles responsible for a great part of the cost under the incremental analysis are registered in other states. They pay nothing toward the cost of the highways in West Virginia beyond the motor fuel tax, and that not necessarily in proportion to the fuel consumption.

Obviously this situation adds an inequitable burden upon the owners of vehicles of the classes affected which are registered within the State.

It would appear that the remedy would lie in a tax based upon determinable units of road usage, whereby all users of the affected classes would pay in proportion to their usage, regardless of the state of registration. Of course this method would upset the present agreements of reciprocity between states, at least for those classes of vehicles of which the above-mentioned condition exists; but it can be argued that reciprocity has been outmoded by the event which have brought about the present situation for which it offers no solution except by discrimination.

As far as the element of fuel taxes is concerned, it is unfortunate for West Virginia that the base price of gasoline structure, excluding the tax, is in most cases discriminatory against the state; so that owners of heavy vehicles, of course, naturally restrict their purchases of fuel in West Virginia to the barest minimum in order to save the cost of the differential. Our statute provides for the payment of the state's fuel tax on the gallonage used within the state even if purchased elsewhere, but collection of such a tax is extremely difficult and costly, especially on some of the main highways crossing our so-called "pan handles" where the foreign vehicle traffic is heavy but the distance short.

In these cases the foreign vehicles make practically no contribution whatever to the cost of furnishing the highways they are using; our local registration is forced to foot the bill.

Second: It is claimed by representatives of the commercial vehicle owner, probably with some justice in some cases, that many of the elements of cost should be based not progressively by increments upon classes of vehicles but evenly upon all vehicles regardless of class.

Recent studies of the capacities of our West Virginia highways, made for the purpose of determining the needs for better facilities, revealed that on many miles of our roads, because of the terrain, the presence of a truck upon the roadway reduces the practical capacity to the point that a truck is the equivalent of as many as 40 or 50 passenger cars. Should not this be taken into consideration in distributing such costs?

The claim is often made that peak periods of heavy vehicle traffic do not coincide with periods of heavy passenger vehicle traffic, and therefore conflict is avoided. Actually the extreme of peak periods of density of passenger car traffic is more than often caused by the presence of heavy vehicles in the traffic stream. If there are only two vehicles visible on the road of which the alinement and grade is bad, consisting of a passenger car behind a heavy truck, to the lone passenger car the truck may be the equivalent of a density of 40 or 50 other passenger cars.

Representatives of the trucking interest claim in such cases that costs of remedial efforts to increase the capacity, so passenger vehicles can travel the road without the restrictive effects of truck traffic, should be borne entirely by the passenger vehicle class of traffic. Their argument is that costs of such additions as climbing lanes on steep grades and extra passing lanes are solely for the expedition and benefit of the faster moving element of traffic; that the trucks are content to use the original road, as is.

As a matter of fact, the original road, as is and when constructed, was in most cases built solely for the passenger type of traffic, for which it was sufficient; trucks were rare and combinations non existent. An analogy of the situation caused by the influx and growth of this heavy type of traffic upon our highways might be that of the fable of the camel, who, after intruding his nose into his master's tent to get it warm, finally decides to move in and use up the entire space. The decision as to remedy for such a situation should be that of the master, not the camel.

It is an effort to reach such a decision that is responsible for the presently engrossing interest in the incremental analysis of the problem. The principal difficulty to the achievement of the final solution, as it appears to me, is that the problem is growing by the addition of new factors faster than they can be evaluated and integrated into the formula. As a conclusion one is forced to fall back upon the phrase which has almost become a cliche: more research is needed.

DAVID J. BAUER, Closure — I believe Rothrock of West Virginia is right in his suggestion that the automobile equivalent effect of vehicles other than passenger cars be considered. The effect of such an effect of such an equivalent should be restricted to those special categories of roads with traffic densities such that the equivalent number of cars cause the addition of traffic lanes or other features. That is, if at over 4,000 automobiles per day a 4-lane highway is required and under 4,000 only 2 lanes are required, then only for those roads where the equivalent automobile rating of trucks, etc., pushes the actual traffic count over 4,000 would the heavier vehicles be charged for additional facilities.

On Rothrock's second point, reciprocity is a dead issue if any sort of distance tax is used. Being unnecessary, it is no problem. If a transition is needed, then the fixed tax states and the distance tax states could determine a mileage credit to be provided each other's vehicles. (See the Minnesota report, PAS, October 1954).

As for the comments of Moore and Lindman, the question of incremental pavement thickness for various load and density groupings disappears if bituminous pavements are used. Whereas cement concrete pavements are apparently difficult to conceive in thin sections (in spite of actual thin slabs in service) no one can deny that bituminous pavements are serving in all thicknesses depending on the nature of the traffic carried.

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The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government designated by the President of the United States, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY-COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.