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Research on the problem of determining the relationship between highway costs and vehicle size has been in progress at The Ohio State University for more than four years under the sponsorship of four trucking firms and the Ohio Trucking Association. Most recently, a final report covered the entire cost assignment for the conditions and expenditures of the Ohio Department of Highways. The present paper discusses the problems associated with the development of cost responsibility for the studies to date.

Specifically, the paper covers the following philosophies that can be utilized in cost assignment problems:

1. Use of theoretical vs empirical relations between vehicle parameters and cost items.
2. Theoretical vs engineering solutions wherein single-valued results are obtained.
3. Direct or indirect sources of cost responsibility.
4. Distribution of indirect costs, classically designated as engineering or administration.

Several practical difficulties that must be overcome in assessing cost responsibility also are discussed, such as: (a) combining capital improvement costs with annual costs for maintenance and operations, (b) combining of cost factors controlled by weight requirements with those controlled by factors other than weight, (c) influences of traffic data on the assignment of costs to various highway user groups, and (d) extrapolation of empirical data to include vehicle sizes greater than currently authorized.

The paper concludes that the general shape of the curve for cost vs vehicle-size is available. Furthermore, based on a given annual expenditure by a highway department, reasonable estimates of differential cost can be obtained. However, theoretical answers to the cost-size problem will not be available until the establishment of more rational methods for design, particularly for highway geometrics and the related cost factors.

There is no completely rational method for developing the relationship between vehicle size and the highway costs which are required to provide a facility for a specific vehicle. Therefore, current solutions which provide such relationships are empirical and require many assumptions and arbitrary techniques. While fundamental concepts can be studied and used where applicable, large portions of highway expenditures are currently processed without direct reference to the size of the vehicle.

Two types of considerations lead to the need for vehicle size and highway cost relations; namely, (a) the establishment of cost responsibility, and (b) the obtaining of the characteristics of the optimum-sized vehicle for the transportation system. The fact that these two problems require the same data as to vehicle size and highway costs does not necessarily mean that the approaches to solution are comparable. As a result, the philosophies and techniques which are utilized will vary and will be dependent upon the principal reason for the development of the relation. Highway costs as used herein will refer to those expenditures by an industry or governmental agency which are re-
quired for the construction, maintenance, and operation of a highway system. Specifically excluded are the operating costs expended by the owner or operator of a motor vehicle.

The research which has been conducted at The Ohio State University has included efforts to delineate the difficulties associated with both cost responsibility and optimum vehicle size. The work has been in progress for more than four years and has resulted in a number of publications (1, 2, 3, 4, 5, 6). Sponsorship for the investigation has come from four individual Ohio trucking firms, which initiated the studies four years ago, and, subsequently, from the Ohio Trucking Association.

The purpose of the following paper is to delineate the various basic philosophies which can be utilized in the highway cost relationships. Furthermore, possible points of departure and orientation for those interested in pursuing such research have also been discussed. The scope is restricted to the problems concerned with the highway cost and vehicle size relationships. Specifically excluded are taxation theories and the operating costs paid directly by the highway user. Rather than to attempt to discuss all of the individual cost items, the following report restricts itself to the broader questions which are in the realm of fundamental philosophy or basic engineering methodology.

DEFINITIONS

For the sake of brevity, several expressions and concepts requiring definition will be utilized in the following report. Frequent references will be made to weight factors and non-weight factors. These two terms are used to designate vehicle parameters which affect highway costs, or portions of cost items, which are influenced by weight, and by variables other than weight, respectively. The only highway costs which are largely influenced by the weight of the vehicle are structures and pavements. As a matter of fact, since these two cost items are affected by factors other than weight, such as the width and height of the structure, only a part of the costs is completely defined by weight requirements. Weight effects, then, would include those portions of the structural and pavement costs which are influenced by the vehicle weight. The costs may also be referred to as structural effects, because of the influence of structural capacity. Specifically, the non-weight factors include the geometry of the vehicle, the performance characteristics of the vehicle, and the capability of the driver. Since the non-weight variables influence costs which are related to highway geometry, the costs are also referred to as geometric effects. Pedestrians can also be considered weight and non-weight factors insofar as sidewalks and pedestrian underpasses or overpasses are concerned. However, direct pedestrian responsibility is a negligible consideration in most problems.

The following definitions have been found quite useful for the cost assignment problem but are not necessarily valid for more general usage:

1. Construction Costs—direct expenditures related to capital improvement.
2. Maintenance Costs—direct expenditures related to preserving and maintaining facilities which are provided by capital improvement.
3. Operation Costs—direct expenditures required to expedite the flow of traffic.
4. Administration Costs—indirect expenditures incurred for construction, maintenance, or operations in the form of over-all direction and supervision of the system.
5. Engineering Costs—indirect expenditures incurred in the construction, maintenance, and operation of the highway required for technical direction, planning, supervision and execution of the work performed.

In the preceding definitions, the term direct expenditure implies that the costs are readily traced to the cost item, whereas indirect expenditure suggests that the normal accounting system would not provide data as to the proper assignment to a specific cost item.

The preceding cost delineation does not eliminate practical problems in assigning highway expenditures. For example, there is certain to be some question as to whether a cost should be classed as construction or maintenance, particularly when the maintenance expenditures are quite large. Also, certain costs could logically be classed as
either maintenance or operations, and a good example is the replacement of a guardrail. A precise delineation between groups may or may not be critical. In most instances, the method of allocating cost to vehicles is independent of the group to which a cost is assigned. The decisive consideration as to cost grouping is usually the availability of records.

Cost responsibility as used herein refers to users only and to the direct variables used to obtain the final design. This differs from the more general definition used in the highway economics field (13).

The use of benefits to allocate costs is a recognized procedure, but the benefits are not in themselves variables that affect the magnitude of highway cost items.

**VARIATIONS IN BASIC PHILOSOPHY**

In initiating a study of highway cost relationship with vehicle size there will be several choices as to the basic philosophies which will be applied to the research. Some of these constitute true alternatives, while others are related to the purposes for which the investigation is established. In the following paragraphs several of these questions are discussed.

**Theoretical Methods vs Design Techniques**

There are two theories under which cost-size relationships can be developed. The first approach might be designated as the "theoretical" in that all expressions relating cost with vehicle size would be rational. The second approach involves the establishment of the relations between cost and size on an empirical basis, namely one that is in current use as a design technique. Complete use of a theoretical approach is not a practical possibility because of the many functions which have not been established on a rational base. Even if one could assume that the weight affects can be evaluated rationally, the non-weight factors represent the complete reversal. The methods for determining roadway width, grade, curvature, structure openings, and other similar geometric factors are completely empirical and direct relations with vehicle size are normally differentiated only by extreme size variations. Even the weight effects are questioned as reflected in the AASHO tests at Ottawa, Illinois. In fact, if a theoretical answer is to be obtained, then all highway research problems are involved.

While certain adjustments between theory and practice could be tolerated in an effort to obtain as theoretical an approach as possible, there is a more fundamental distinction and philosophy involved with the choice between the two. The importance of the concept of using empirical practices goes beyond the fact that the data are based upon the best experience available. If empiricism is used, actual methods employed in the design procedures could be incorporated. Thus, the results would reflect the methods under which the funds are being expended. The fundamental question becomes, then, whether the cost relationships to be developed are intended to reflect a theoretically true condition or the actual manner in which monies are expended.

Where the problem is one of establishing the optimum vehicle size with reference to costs for all types of transportation, then the theoretical approach might be the more desirable. Where the relationships are being developed for the purpose of providing data for assigning cost responsibility, the most equitable method appears to be relationships based upon current design techniques; that is, methods under which funds are being expended.

**Degree of Accuracy**

As stated in the preceding paragraph, the absence of specific and implicit functions prevents a completely rational solution to a cost-size investigation and one must assume that any solution achieved during the next few years will require empirical techniques or some modification to a purely theoretical approach. Associated with the empiricism will be a question as to the degree of accuracy of the results. The question will be raised because of (a) the absence of a rational expression, and (b) the evaluation of many variables which require statistical considerations. Assuming that the level of
accuracy will be a function, in part, of the dollars available for the study, there is still a part of the accuracy which is controlled by the adequacy of the empiricism.

The question to be considered is whether one relationship will be obtained and referred to as the solution, or whether multiple sets of data are to be developed. Multiple relations could take the form of maximum and minimum solutions (Fig. 2) or could be statistical deviations from a single curve. The advantage of a multiple set of values over a single solution is that less argument will exist as to the competency of the extreme values. Furthermore, the influences of the questionable factors will have been estimated.

Some problems, such as one upon which cost responsibility and, ultimately, taxation is based, may require that a unique result be obtained. After obtaining multiple values, judgment may be needed in order to reduce the data to a single set.

A very difficult problem is encountered in attempting to estimate the total cost requirements, for various sized vehicles, which will be needed for a major road network. For a limited size and type of road system, such as a turnpike, the total costs for various sized vehicles can be reasonably precisely determined. The total cost of a major road system is complicated by the absence of rational methods for design, and by the wide variation in the unit costs which exist on a large geographical unit. Under the existing state of knowledge, estimates varying by 200 to 300 percent should not be surprising (Fig. 2). Furthermore, many different answers can be completely justified when conducted under the design principles of current practice. Unfortunately, a precise type of estimate should not even be considered within the realm of practicality. Total cost relationships should be developed with a firm understanding of the limits of accuracy.

Where differential cost is the principal objective of the study, the results of the investigation can be more precisely obtained than for total cost. Past studies (2, 6) have indicated that while the actual total cost to be anticipated can vary over a wide range the differential costs are predictable within much more narrow dollar values (Fig. 2).

In solving the problem of cost and size relationships, then, it is important to study the reasons for which the research is conducted. Since single-value data may be difficult to justify, the double-set of data is recommended, at least within the framework of the methodology. Of paramount importance, however, is the fact that the limitations of existing knowledge must not be overlooked, and should be evaluated if possible.

Indirect vs Direct Sources of Cost Responsibility

Consideration must be given at the start of the study as to whether direct or indirect sources of cost responsibility are to be treated as major variables. For the purposes of this report, the assumption is made that highways are solely for the purpose of the highway user and therefore direct sources must be related to the highway user. Direct sources of costs then, refer to the factors used in the design for controlling the magnitude of the structure or geometric conditions. Specifically, the sources of direct costs are the numbers, weights, and types of vehicles. Driver ability, vehicle performance, and pedestrians are direct sources, theoretically, but are rarely utilized as such in current design criteria. Indirect sources of responsibility include such things as railways, abutting property owners, and physical and natural obstacles. The railroads produce a part of the requirements for a special crossing but the magnitude of the members of the structure are controlled by the vehicles which will be utilizing the crossing.

The geology, topography, and climate of an area are typical of indirect sources of cost responsibility. They are a source of cost in that the dollars expended are affected by their characteristics, but are indirect in the sense that ultimately vehicle parameters control the design. The principal influence of indirect sources is to increase or decrease the magnitude of the cost differential. In conducting a cost-size study, a statistical evaluation of the effect of geology, topography, and climate will be required. Thus, if one part of an area is particularly mountainous and another part is essentially flat then the cost differential assignable for earthwork for the combined areas will be some value between those produced in the two extreme conditions.
Direct cost responsibility, therefore, associates all highway expenditures with the highway user. Indirect costs on the other hand, affect the magnitude of expenditures and of cost differentials, and contribute to, but do not "control," the ultimate design.

There is no inference intended that indirect sources of cost responsibility are not important to highway economic studies. For such items as geology, topography, and climate the indirect sources will become a factor in statistical evaluations for a given area of application. For other indirect sources, such as railroads, abutting property owners, and the general public the question is concerned with economics of the total society and whether the highway user should be relieved of any part of the total cost responsibility. In questions of taxation this last decision is critical and associated with broad economic questions. In attempting to determine the optimum size of vehicle the importance of the indirect sources may or may not be pertinent. In any event, in

![Figure 1. Relationship between cost responsibility and taxes paid.](image)

order to develop rational expressions of the relation between highway cost and vehicle size, indirect sources should not be confused with the direct sources which control the design of the various elements.

**Types of Cost to Include**

To a certain extent, the types of costs which should be included in the research are a function of the particular problem. In most cases, the problem will be addressed to the total expenditure required to construct, maintain, and operate a system. Attempting to include all possible costs leads to some interesting questions. For example, the officials of the state government who deal with the highway system, such as the governor, state treasurer, legislators, etc., undoubtedly should have part of the expenditures of their offices attributed to highways. For major systems these costs will be a very small part of the highway budget, and can be safely neglected. For a toll turnpike the question is a little more confused, since the relationship between the toll facility and the governmental offices may be less clearly defined. If no charges are made, then no actual costs arise, and, therefore, none need be considered.

An interesting cost is that required for conducting the business of agencies such as the public utilities commissions. In some states, the operating funds, insofar as highways are concerned, are collected directly from trucking companies in the form of taxes. The purposes of such commissions are for the regulation, and thereby, to a degree, the protection of the individual trucking companies and are not for the assistance
of highway users in general. Therefore, such expenditures would appear to be more logically "operating costs" of the user than highway costs as defined herein.

Included in many highway department lists of expenditures are certain interest charges on bonds sold for some phase of highway construction or maintenance. There is little question but that these interest costs are charges accumulated because of the highway system. Sometimes forgotten, however, is the fact that the dollars collected on a pay-as-you-go basis theoretically deprive the citizens of opportunities to invest or to reduce their own obligations. Therefore, highway programs which are based upon a pay-as-you-go program should include consideration of when money is collected with reference to when the improvements are obtained or expended. If one is to consider the total transportation picture, including railroad, airports, waterways, and pipelines, then the interest costs, both on dollars collected and on bonded indebtedness, should be included as cost. The inclusion or exclusion of interest costs will ultimately be decided by the demands of the problem. Consistency as to treatment of interest should be encouraged, particularly where interest on bonded indebtedness is obviously present, but the loss of income to the taxpayer on a pay-as-you-go plan is not so obvious.

Types of Taxes to Be Included

Cost responsibility studies will frequently lead to a comparison between costs and taxation for various highway user groups. Many such studies have led to conflicting results, particularly as efforts are made to express taxes paid on a unity basis. One of the reasons for the apparent discrepancies lies in the types of taxes which are included. For example, in a preceding paragraph the taxes collected by the public utilities commissions were suggested as logical "operating costs" and as such could not be termed taxes paid to compare with cost responsibility. Thus, a principle is suggested; namely, that the taxes to be compared with cost responsibility should be "highway user taxes" if highway users are considered as the direct source of all highway costs. As used here, "highway user taxes" are intended to designate those taxes paid by the user and which are utilized for highway purposes.

If the preceding principle is valid, then taxes paid by the highway user which are not used for highway purposes would not be included. Examples of such taxes would be Federal and State income taxes and some excise taxes. In certain states and local governments portions of the general fund are used to supplement the highway user taxes in order to have sufficient operating funds. Thus, certain portions of general taxes may be logically presumed as "highway use" taxes. In such cases, the non-highway-user sources of highway use tax should be credited as the source of part of the monies collected. Results from the Ohio State studies(6) are included in Fig. 1 and the influence of the taxes included in the investigation is shown.

Since the inclusion or exclusion of taxes paid is argumentative, data under several assumptions may be required. However, the validity of comparing cost responsibility with taxes paid, when the tax included monies which are not utilized on highways, is to be questioned. There does appear to be greater consistency if only highway use taxes are included.

PROBLEMS OF APPLICATION

In the actual development of the relationship between highway costs and vehicle size many practical problems are encountered. Some of the more critical of these questions of methodology are covered in the following paragraphs. In order to facilitate the discussion, the methods used at The Ohio State University have been used by way of illustration. There is no inference intended that the solutions constitute the only way nor the best way for general conditions.

Selecting a Single Vehicle Parameter

Most cost-size problems must ultimately be expressed as a relation between a single vehicle-parameter and a highway cost. The selection of units for cost and size
is a troublesome problem, particularly for the vehicle parameter. Perhaps the situation is best exemplified by considering pavement and earthwork costs. Pavement expenditures are obviously more related to axle load than to any other vehicle parameter, and dimensions of the vehicle are not of much importance in differential pavement cost analysis. On the other hand, earthwork expenditures are hard to relate to axle load and cannot be done on a direct, rational basis, for they are more logically associated with vehicle dimensions, performance, and the driver. While there is no established requirement that a single parameter be utilized, many problems, and particularly the taxation question, must be expressed as a single parameter or else the solution will be confused with two vehicle parameters for expressing relationships. While it is reasonable and necessary in the early stages to develop independent functions in terms of more than one vehicle parameter, one should not be surprised to find pressures or reasons to reduce the relationship so as to express the highway cost in terms of one vehicle variable.

To develop a single vehicle parameter one must return to the basic factors which influence expenditures. Assuming that only direct sources of cost responsibility are to be considered, then cost responsibility can be traced reasonably, to either (a) a vehicle weight factor, or (b) to a vehicle dimension or performance characteristic. This assumes that the very minor effect of pedestrians can be neglected. The vehicle weight factors can conveniently be reduced to axle load, if certain considerations are treated in terms of axle spacing. Similarly, the effects of vehicle dimensions and performance can be traced to the way they affect various phases of highway geometry. All items of cost which are not affected by weight will then by necessity be affected by the vehicle geometric factors. To reduce the geometric factors to a single vehicle parameter does cause some difficulties. The best solution is achieved by a statistical evaluation of the traffic using the highways. Another possible technique would be to use a common design methodology, wherein vehicle characteristics are handled solely on the basis of trucks.

Figure 2. Relationship between annual costs and the design axle load.

Figure 3. Annual costs versus design axle load for weight and non-weight factors.
and passenger cars. Utilizing the last-mentioned approach, one can set the maximum axle load for passenger cars and pick-up trucks and produce a cost differential for heavier trucks due to geometric factors.

Considering for a moment the actual influence on a given study, one can consider the three elements or groups of cost; namely, capital improvement, maintenance, and operation. For the first two, the weight and the geometric factors can be related to the actual capital improvement costs. Operations, however, are restricted to geometric considerations. For a given problem, then, cost is divided into weight and geometric requirements within the capital improvement and maintenance groupings. Having the total costs which are affected by the weight variable and the total expenditures which are influenced by geometric considerations, two cost differentials can be established. Combining the two on a basis of a single vehicle parameter is accomplished from the Ohio State studies (6) in Fig. 2. The basis for the combined cost is given in Fig. 3. It can be seen that there is a cost differential between axles smaller and larger than 2.5 tons for the geometric factors but an exponential type of curve reflects the weight influence. The curves of Fig. 2 require a statistical evaluation of the point at which the geometric differential occurs. For some problems, the single differential at 2.5 tons (or similar-type value) is all that might be required. However, for the case of establishing the optimum size of the vehicles or for predicting the effect of increasing the size of the axle load, the relationship suggested by the cost versus axle load would be useful. There is no way, based upon design practice, for estimating the effect of lengthening or widening the vehicle. Figure 3 suggests that geometric effects are independent of the vehicle geometry, but such an answer is a reflection of design methods rather than sound analysis of cost differential.

To summarize, then, attempts to relate all highway unit costs to a single vehicle parameter may produce misleading concepts. It will be desirable to indicate for highway unit costs separate relationships for geometric factors and for a weight parameter. One additional reason for developing two parameters is related to assigning cost responsibility because use must be made of axle-mile and vehicle-mile for allocating costs to various user groups.

Reducing Highway Costs to a Unit Basis

Insofar as the highway cost variable is concerned, several methods could be used for reducing all expenditures to a common highway unit cost parameter. Two commonly used factors are total cost and annual cost per mile. For certain kinds of problems, the total cost expended by a highway department or by an agency could be plotted versus vehicle size. Total cost is particularly useful for a taxation problem or for a condition where a known amount of funds is to be available. However, where the intent is to establish the optimum vehicle size it will be necessary to reduce the highway costs to a unit basis.

The handling of maintenance and operation costs is not particularly difficult. Since the expenditures are made on an annual basis and presumably can be spread over the entire mileage in the system, total maintenance and total operations costs can be divided by the number of miles. For capital improvement some reduction is necessary to obtain an annual figure to combine with maintenance and operations. The reduction of capital investment to an annual cost poses the normal question as to the proper interest rate to be utilized with a capital recovery factor. The selection of the interest rate will undoubtedly parallel the practice of a particular agency in its normal economic studies.

Reduction of expenditures for major improvements to annual cost also involves predictions or establishment of design life. There is quite a range of values commonly assigned to various items of capital improvement; for example, the design life of right-of-way may extend for 50 to 75 years whereas for pavements the period is rarely more than 20 years. Fundamental principles of engineering economics, as used in industrial practice, suggest that the life period to be utilized for a study should be based upon the longest period of some component of the cost, provided that the period is consistent with the planned use of the facility. Components with shorter lives must have
replacement values computed. Based on experiences of the past in the United States, it is somewhat difficult to envision the current right-of-way and earthwork designs being sufficiently advanced to permit a design life of 75 years. Furthermore, the problems of obtaining costs of several successive pavements 20 to 40 years in the future are obviously in the realm of conjecture. As a result, in the studies conducted at The Ohio State University, a design life of 20 years was utilized for all elements of new construction costs. This in effect assumes that within 20 years the roads being constructed at this time will have outlived their current right-of-way and earthwork design. For the average state highways, this is probably true, whereas for the interstate system it is quite likely that a longer design life would be permissible.

In order to combine annual costs of capital improvement with those for annual-type expenditures, the total mileage in the system must be considered. The rate of new construction on an existing system will rarely be great enough to rebuild the system completely within the design life. Therefore, some adjustment must be made for new construction costs to obtain costs for capital improvement per mile. If a completely new system is under study, the cost of new construction or capital improvement can be readily reduced to an annual basis and combined with anticipated maintenance and operations to obtain total cost. Such a condition exists for a toll turnpike.

One adjustment which can be made for an existing system is accomplished by assuming that the capital improvement for a specified period of time will consist of four types of activity; namely, new construction, reconstruction, resurfacing, and surface treatment. One may also have to assume that certain mileages will receive no capital improvement. By statistically evaluating and weighting the costs for the four types of capital improvement, one can get the average cost of capital improvement per mile per year. Such a procedure, in effect, reduces the cost of capital improvement from the typical value for new construction to an expenditure commensurate with the type of improvement received by the system as a whole. Including resurfacing and surface treatment as capital improvement rather than maintenance is not particularly critical. If it were included as maintenance there would merely be a higher number of miles with "no capital improvement," and the weighted average annual cost of capital improvement would be reduced.

Reducing the cost of structures to an annual expenditure per mile obviously requires special procedures. Variations in structure costs are frequently obtained for lineal feet of bridge or for square feet of bridge roadway. The conversion of such data to annual cost per mile requires a reduction of the capital investment to an annual basis as well as the determination of how many lineal feet or square feet of bridge are present on a mile of highway. The fact that the type of bridge structure will vary, thus changing the relationship between cost and size, must be handled on a statistical, weighted basis. Assuming that one can get a realistic relationship between a vehicle parameter and the average cost per lineal foot of structure, the problem is to convert to a structure cost per mile for the system.

One reasonable approach would be to obtain the total number of bridge feet in the system and by dividing this value by the number of miles, the average number of bridge-feet per mile could be obtained. By employing a factor to account for the rate of replacement, annual costs would be available.

A less complex procedure was utilized in the studies at The Ohio State University (6). The total dollars expended per year each of a six-year history were averaged in order to obtain the average dollars for structures per year. The total number of miles of new construction were also computed on an average annual basis and the total structural dollars per mile of new construction was obtained. It was then assumed that the same ratio of structure cost to new construction mileage would be followed throughout the period studied. Such an approach produces the structural dollars per mile of new highway construction and no conversion to lineal feet is involved. Since maximum and minimum solutions were obtained the accuracy of the estimate was considered to be reasonable in light of other assumptions required in the study.

Considerations of Highway Systems

In many studies involving incremental or differential costs, the highway expenditures
are separated on a basis of highway systems. Sometimes this is done on the basis of political subdivisions, such as federal, state, county, municipal, etc., and in others it is on the basis of types of highways required. For example, in Pancoast's studies in Ohio (7) a division was made on the basis of Type A, B, C, and D roads where each of the four types had typical cross sections for pavement and other cost items. The need for such a breakdown can be traced in part to auditing and accounting procedures. There are also requirements for such a delineation because of differences in design, construction, maintenance, and operation procedures. In many problems, there is no need to consider the type of roads. In fact, for theoretical considerations, the solution should be achieved using only the fundamental direct cost parameters. However, when costs are being assigned on the basis of the method utilized in design, then road-type becomes a consideration insofar as the method of design varies for the several systems.

Responsibility for certain types of highway costs should not vary appreciably with the road system, even utilizing the applied approach. For example, structure capacity is normally established for a constant type of maximum load and the frequency of loading produces minor variations. With the exception of low-traffic secondary highways, even pavements are currently designed for the heaviest axle load to be expected, but with variable numbers of applications. Unfortunately, the quantitative effect of repetitions is not well understood. The cost factors controlled by geometric considerations do not normally require a delineation into highway systems since there is some indication that the traffic volume itself indicates the cost differential (6). Thus, the basic variables of vehicle weight and geometry plus the number of repetitions should describe the variation adequately, and the use of road systems would be restricted to those cases where different political subdivisions or design philosophies produce different design standards.

One of the more difficult, fundamental decisions which is required is in the realm of the low-traveled secondary systems, particularly for the allocation of cost responsibility for the minor traveled highways with only a nominal pavement thickness. Such roads are capable of carrying some heavy axle loads, particularly during certain seasons of the year. The loads originate from private, industrial, and commercial sources. The question is, should all vehicles which use the road be responsible for the costs on a differential basis, or should the largest vehicles be treated on an equivalent basis with the largest vehicle for which the design is completely adequate? Two answers appear reasonable. One is to assume that the theories and cost assignments which are applicable to the heavy pavements can be applied proportionally to the thin ones. A second theory would be to arbitrarily assign the costs of the low-cost pavement to the axle load group which most frequently uses the highway and for whom the pavement is completely adequate. This, in effect, would give the heavier vehicles a "differential-free" ride. More precisely, they would be paying essentially the same amount per repetition as would the smaller vehicles. In effect, the second theory suggests that such roads are designed for the smaller vehicles, and a few larger loads can be tolerated in a quasi-restricted manner.

There are sound reasons for applying either of the two concepts. In the studies at The Ohio State University, such problems were handled by obtaining a minimum and a maximum relationship between pavement costs and axle load. In the cost assignment part of the studies, the pavement costs for the thinner pavements were distributed in the same manner as for the heavier pavements. In all fairness, since requirements for the heavier vehicles are not built into the road, there is some question as to whether the use of differential costs is a proper assumption.

Vehicle-Mile and Axle-Mile Allocations

The data of Figs. 2 and 3 refer to the increase in cost which is required for an increase in axle load. A second problem involves the allocation of the cost of a system to a various size vehicles or to user groups. For example, in Fig. 2 the cost to provide a highway capable of carrying 9-ton axles is suggested. However, all vehicles share a part of the responsibility for that cost, and the problem is to determine what portion of a given expenditure can be attributed to the various-sized axles.
As stated in the definitions, highway costs are a direct function of axle load, vehicle dimensions and performance (including driver ability), and the number of vehicles. Furthermore, the repetitions of these factors consistently affect all phases of design. In fact, there are practically no costs which are independent of load or vehicle repetition. Thus, there are relatively few dollars which can be allocated solely on the basis of the number of vehicles in the system insofar as direct cost responsibility is concerned.

One notable exception is the collection of part of the revenue (motor vehicle registration). In states where a third-structure tax such as axle-mile or a ton-mile is used, even a part of the revenue collection costs are affected by the mileage traveled. In the studies at The Ohio State University it was assumed that the amount of cost which was strictly related to the number of vehicles was negligible and all costs were distributed on the basis of either axle-mile or vehicle-mile.

For those costs which are related to structure capacity (structures and pavements), the distribution was on the basis of axle-miles (Fig. 3b). For those expenditures which were related to geometry or vehicle dimensions (earthwork, right-of-way, drainage, etc.) the allocation was made on the basis of vehicle-miles (Fig. 3a). While there may be justification for assigning costs on a "per vehicle" basis in some highway economic studies, there appears to be no such justification for such an assignment where the question is one of cost responsibility.

A fairly substantial portion of all highway expenditures can be classed as "uniform" costs. These values represent the expenditures which are independent of vehicle dimensions. Pavement and structure costs required for the basic vehicle are typical, as are all costs for axle loads of approximately two tons or less (Fig. 2). The compilation of uniform costs can be separated so as to indicate whether the expenditures are for structural or geometric requirements. While it might be argued that these uniform costs could be allocated on a unit vehicle basis, a fair presumption is that ownership of a vehicle does not constitute reasons for providing extensive mileages of highways; rather, usage of that vehicle. Therefore, axle-miles or vehicle-miles are considered a more reasonable bases for allocation of the uniform costs.

Influences of Traffic Data

The type of traffic data which are available affects the accuracy of cost allocation problems. Since highway costs are associated with axle-miles or vehicle-miles, the average ADT (including the number of various types of vehicles), and the average number of axles per vehicle are required for the highway system being studied. Most state highway departments have developed traffic volumes for the various roads in the system. Furthermore, periodic checks have established a reasonable basis for assumption as to the numbers and sizes of vehicles. It is probably that the degree of accuracy of the traffic data is commensurate with the accuracy of the other phases of a cost-size investigation.

The contribution of foreign vehicles travelling in the state and the amount of travel of domestic vehicles out of the state is a source of question. Such a problem arises in the application of average miles travelled per year to the numbers of vehicles in order to get axle-miles or vehicle-miles. While a state bureau of motor vehicles can normally give the number and types of registered vehicles, the amount of travel per year which is driven in or out of the state is quite a different matter. It is also difficult to determine the number and average mileage of foreign vehicles. Studies designed to obtain such data are in progress in some states but no reliable data are yet available. For the studies at The Ohio State University a simplifying assumption was made; namely, that the amount of out of state travel by domestic vehicles was equal and identical in terms of types of vehicle to the amount of in state travel by foreign vehicles.

While traffic data has a pronounced influence on the allocation of cost responsibility, there is also a significant effect on the crediting of taxes paid to various highway user groups. In attempting to determine how much tax was paid by a given type of user, the total revenue obtained is frequently utilized. Thereafter, average miles per vehicle, average gasoline consumption per mile, and average number of vehicles are used to
account for the taxes paid. In the case of third-structure taxes, gross weight, axle-load, or number of axles may also be needed. Having achieved the allocation of taxes to various groups, one may wish to compare the cost responsibility for the same groups. To do so, the same assumptions must be utilized for numbers of vehicle-miles and axle-miles.

In reviewing cost-tax studies, a point of discussion frequently arises with reference to the assumptions that lead to the vehicle-mile and axle-mile values. Smaller or larger mileages are debated in order to improve relationships. A greater number of vehicle-miles assigned to a group will indicate a higher percent of the total taxes paid. On the other hand, a greater number of vehicle-miles increases the percent of cost responsibility. Special studies were conducted at Ohio State in June, 1958, by Robert Chieruzzi, research associate, to learn more of the rate of change of taxes and cost responsibility with changes in the ratio of vehicle-mile and axle-mile data between the several highway-user groups. Contained in the following paragraphs is a summary of the results of that study.

The vehicle miles used in obtaining cost allocation (6) were obtained for the year 1953 in an earlier investigation (1) by multiplying the number of registered units in each vehicle category by the average annual mileage for the particular vehicle group. The six user-groups selected were passenger cars, panel and pickup trucks, other single-unit trucks, multi-unit trucks, farm trucks, and buses. The registered numbers of units for the passenger car, farm truck, and bus groups were initially obtained directly from the registration records of the Ohio Bureau of Motor Vehicles. Panel and pickup trucks were considered as all registered single-unit trucks with empty weights of 4,000 lb or less. As estimating procedure was necessary to obtain the numbers

<table>
<thead>
<tr>
<th>Vehicle Group</th>
<th>Registered Units (Adjusted)</th>
<th>Average Annual Mileage*</th>
<th>Vehicle-Miles</th>
<th>Per Cent of Total</th>
<th>Number of Axles</th>
<th>Axle-Miles</th>
<th>Per Cent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Passenger Cars</td>
<td>2,772,063</td>
<td>9,235</td>
<td>25,600,001,805</td>
<td>81.1</td>
<td>2</td>
<td>51,200,003,610</td>
<td>76.2</td>
</tr>
<tr>
<td>2. Panel and Pickup Truck</td>
<td>140,721</td>
<td>10,127</td>
<td>1,425,061,567</td>
<td>4.5</td>
<td>2</td>
<td>2,850,163,134</td>
<td>4.2</td>
</tr>
<tr>
<td>3. Other Single Unit Trucks</td>
<td>121,644</td>
<td>17,582</td>
<td>2,138,744,808</td>
<td>6.8</td>
<td>2.064</td>
<td>4,614,000,000</td>
<td>6.6</td>
</tr>
<tr>
<td>4. Multi-Unit Truck</td>
<td>38,354</td>
<td>42,188</td>
<td>1,618,978,552</td>
<td>5.1</td>
<td>4.46</td>
<td>7,220,000,000</td>
<td>10.8</td>
</tr>
<tr>
<td>5. Farm</td>
<td>72,691</td>
<td>8,044</td>
<td>584,728,404</td>
<td>1.8</td>
<td>2</td>
<td>1,169,452,800</td>
<td>1.7</td>
</tr>
<tr>
<td>6. Bus</td>
<td>3,475</td>
<td>47,750</td>
<td>165,931,250</td>
<td>0.7</td>
<td>2</td>
<td>331,862,500</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>3,148,948</td>
<td>31,532,564,386</td>
<td>100.0</td>
<td></td>
<td></td>
<td>67,188,482,044</td>
<td></td>
</tr>
</tbody>
</table>

* Assumes that the travel out-of-state by local vehicles is equal and similar to travel in-the-state by foreign vehicles.
A direct method for obtaining the axle-miles was employed. Essentially, it consisted of multiplying the assigned vehicle-miles by the average number of axles per vehicle for each group. A total of two axles each was arbitrarily assigned to the passenger car, panel and pickup truck, farm truck, and bus groups. Considerably greater difficulty was encountered in computing the number of axles per vehicle for the other two groups. An estimate was obtained for the single-unit trucks with empty weight greater than 4,000 lb from the data on the study by Pancoast (7). From the estimated vehicle-miles for two and three axle units, a weighted average number of axles of 2.064 was obtained. The calculations are shown below.

<table>
<thead>
<tr>
<th>Two Axles</th>
<th>Three Axles</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle-miles</td>
<td>1,816,501</td>
<td>123,690</td>
</tr>
<tr>
<td>Axle-miles</td>
<td>3,633,102</td>
<td>371,070</td>
</tr>
</tbody>
</table>

Average number of axles = \( \frac{4,004,172}{1,940,191} = 2.064 \)

The steps which were required to obtain the axle-estimate for the multi-unit groups were as follows:

1. The average number of axles for semi-trailers was obtained from data in the study by Pancoast (7) as follows:
<table>
<thead>
<tr>
<th>One Axle</th>
<th>Two Axles</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle miles</td>
<td>25,479</td>
<td>171,916</td>
</tr>
<tr>
<td>Axle miles</td>
<td>25,479</td>
<td>343,832</td>
</tr>
</tbody>
</table>

Average number of axles = \( \frac{369,311}{197,395} = 1.871 \)

2. Average number of axles for trailers with empty weights greater than 4,000 lb was assumed as equal to two.

3. The bases for combining power units with trailers were the following statements of Pancoast (7) who traced the data to results obtained from a study in 1950: (a) 45 ⅜ percent of trailer-miles was pulled by a commercial truck (single-unit greater than 4,000 lb); (b) 54 ⅝ percent of trailer-miles was pulled by a tractor-semi-trailer combination.

Accordingly, the following calculations were made with the use of data from the tax study (1):

<table>
<thead>
<tr>
<th>Vehicle-Miles</th>
<th>Number of Axles</th>
<th>Axle-Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Trailers greater than 3,000 lb</td>
<td>498,287,600</td>
<td></td>
</tr>
<tr>
<td>2. Trailers pulled by commercial trucks (45 ⅜ percent of Step 1)</td>
<td>225,800,000</td>
<td>4.00</td>
</tr>
<tr>
<td>3. Trailers pulled by tractor-semi-trailer (Step 1 - Step 2)</td>
<td>272,500,000</td>
<td>5.87</td>
</tr>
<tr>
<td>4. Semi-trailers, total (from tax study)</td>
<td>746,444,160</td>
<td></td>
</tr>
<tr>
<td>5. Semi-trailer combination only (Step 4 - Step 3)</td>
<td>473,944,160</td>
<td>3.87</td>
</tr>
<tr>
<td>6. Total</td>
<td>972,244,160</td>
<td></td>
</tr>
</tbody>
</table>

Average number of axles = \( \frac{4,337,363,000}{972,244,160} = 4.46 \)

The axle-mile data are summarized in Table 1.

The results of traffic variations can be expressed as percentages of either vehicle-miles or axle-miles, so that the variation can be in any one of the independent variables of (a) registered units, (b) average annual mileage, and (c) number of axles. For instance, axle-miles \( (A_m) \) are obtained by the following equation:

\[
A_m = R \cdot M_a \cdot a
\]
TABLE 2
CHANGES IN COST RESPONSIBILITY WITH TRAFFIC VARIATIONS

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td></td>
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<tr>
<td>P</td>
<td>+10P</td>
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<td>82.6</td>
<td>77.9</td>
<td>44.4</td>
<td>47.4</td>
<td>42.8</td>
<td>13.0</td>
<td>22.7</td>
<td>15.6</td>
<td>10.8</td>
<td>20.4</td>
<td>10.8</td>
<td></td>
<td></td>
<td></td>
<td>(-0.1)</td>
</tr>
<tr>
<td>P</td>
<td>-10P</td>
<td></td>
<td>79.6</td>
<td>74.2</td>
<td>42.8</td>
<td>45.6</td>
<td>12.7</td>
<td>22.1</td>
<td>15.5</td>
<td>14.7</td>
<td>10.0</td>
<td>20.6</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td>(-1.2)</td>
</tr>
<tr>
<td>P</td>
<td>+20P</td>
<td></td>
<td>84.3</td>
<td>79.4</td>
<td>45.1</td>
<td>48.1</td>
<td>13.0</td>
<td>22.7</td>
<td>15.6</td>
<td>14.8</td>
<td>10.0</td>
<td>22.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td>(-2.1)</td>
</tr>
<tr>
<td>P</td>
<td>-20P</td>
<td></td>
<td>71.6</td>
<td>67.9</td>
<td>41.7</td>
<td>44.5</td>
<td>12.3</td>
<td>21.5</td>
<td>14.8</td>
<td>14.1</td>
<td>10.9</td>
<td>21.9</td>
<td>10.9</td>
<td></td>
<td></td>
<td></td>
<td>(-3.3)</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td></td>
<td>81.1</td>
<td>76.2</td>
<td>43.6</td>
<td>46.6</td>
<td>15.0</td>
<td>22.7</td>
<td>15.6</td>
<td>14.8</td>
<td>10.0</td>
<td>22.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td>(-14.1)</td>
</tr>
<tr>
<td>C</td>
<td>6.8</td>
<td></td>
<td>8.6</td>
<td>6.6</td>
<td>5.1</td>
<td>8.8</td>
<td>5.6</td>
<td>9.8</td>
<td>10.6</td>
<td>16.4</td>
<td>9.0</td>
<td>16.4</td>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
<td>(-0.2)</td>
</tr>
<tr>
<td>B</td>
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<td></td>
<td>8.8</td>
<td>10.8</td>
<td>3.8</td>
<td>5.1</td>
<td>9.5</td>
<td>15.6</td>
<td>13.4</td>
<td>20.8</td>
<td>9.0</td>
<td>20.8</td>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
<td>(-0.0)</td>
</tr>
<tr>
<td>P</td>
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</tr>
<tr>
<td>B</td>
<td>5.1</td>
<td></td>
<td>5.1</td>
<td>8.8</td>
<td>3.8</td>
<td>5.1</td>
<td>9.5</td>
<td>15.6</td>
<td>13.4</td>
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<td>9.0</td>
<td>20.8</td>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
<td>(-0.0)</td>
</tr>
</tbody>
</table>

where:

R = number of registered units

M_a = average annual mileage per unit

n = number of axles per unit

A ten percent change in axle-miles can be obtained by a ten percent change in any one of the three independent variables or as the aggregate of individual changes in all three variables.

For the special study, variations in traffic data were expressed as percentage changes in the vehicle-mile and axle-mile quantities of three vehicle groups, (a) passenger cars, (b) other single-unit trucks, and (c) multi-unit trucks, and were limited to plus and minus ten and twenty percent. Interpolation and extrapolation are possible for other values. The scheme produced a total of twelve separate variations. The panels and pickups, bus and farm truck groups have a total influence of less than ten percent of total taxes and cost responsibility, and therefore were combined into a single group.

For each of the twelve variations considered, there are corresponding changes in both the vehicle-mile and axle-mile distributions, which produce proportionate changes.
TABLE 3
OHIO TAX DATA FOR 1953*

1. Registration Fees

<table>
<thead>
<tr>
<th>Vehicle Group</th>
<th>Registered Units</th>
<th>Registration Fees</th>
<th>Fees per Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars</td>
<td>2,772,063</td>
<td>26,576,913</td>
<td>9.58741</td>
</tr>
<tr>
<td>Single Unit Trucks</td>
<td>121,644</td>
<td>13,511,092</td>
<td>111.07076</td>
</tr>
<tr>
<td>Multi-Unit Trucks</td>
<td>79,592</td>
<td>11,991,923</td>
<td>150.66744</td>
</tr>
</tbody>
</table>

2. Gas Tax

<table>
<thead>
<tr>
<th>Vehicle Group</th>
<th>Vehicle Miles</th>
<th>Amount Collected (dollars)</th>
<th>Unit Tax (dollars per vehicle mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars</td>
<td>25,600,001,805</td>
<td>79,258,191</td>
<td>0.0003096</td>
</tr>
<tr>
<td>Single Unit Trucks</td>
<td>2,138,744,908</td>
<td>12,514,276</td>
<td>0.005851</td>
</tr>
<tr>
<td>Multi-Unit Trucks</td>
<td>1,618,078,552</td>
<td>18,330,204</td>
<td>0.011328</td>
</tr>
</tbody>
</table>

3. Highway Use Tax

<table>
<thead>
<tr>
<th>Vehicle Group</th>
<th>Axle-Miles</th>
<th>Amount Collected (dollars)</th>
<th>Unit Tax (dollars per axle mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Unit Trucks</td>
<td>4,414,000,000</td>
<td>229,000</td>
<td>0.00005188</td>
</tr>
<tr>
<td>Multi-Unit Trucks</td>
<td>7,220,000,000</td>
<td>14,501,000</td>
<td>0.0020084</td>
</tr>
</tbody>
</table>

* From tax studies (1)

in the assignment of cost responsibility. Shown in Table 2 are the results thus obtained.

For each of the twelve variations in the vehicle-mile and axle-mile quantities, the changes produced in the distribution of tax credit were also computed. Of the various sources of taxes, only the three major sources were considered in the special study—(a) registration, (b) gas, and (c) highway use. Pertinent tax data, shown in Table 3 were obtained from the tax study (1). The changes in the three taxes which are associated with the traffic variations are summarized in Table 4.

TABLE 4
SUMMARY OF DATA FOR TRAFFIC VARIATIONS

<table>
<thead>
<tr>
<th>Vehicle Group Involved</th>
<th>Variation (%)</th>
<th>Registration Fee (dollars)</th>
<th>Gas Tax (dollars)</th>
<th>Highway Use Tax (dollars)</th>
<th>Total Taxes (dollars)</th>
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<tbody>
<tr>
<td>Passenger Car</td>
<td>10P</td>
<td>2,657,688</td>
<td>7,925,816</td>
<td>-</td>
<td>10,583,504</td>
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<tr>
<td></td>
<td>20P</td>
<td>5,315,375</td>
<td>15,851,633</td>
<td>-</td>
<td>21,167,008</td>
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<tr>
<td>Single Unit Trucks</td>
<td>10C</td>
<td>12,164</td>
<td>1,297,678</td>
<td>24</td>
<td>1,309,866</td>
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<tr>
<td>(Type C)</td>
<td>20C</td>
<td>24,328</td>
<td>2,595,356</td>
<td>48</td>
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<td>Multi-Unit Trucks</td>
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<td>3,835</td>
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<td>(Type B)</td>
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<td>7,670</td>
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<td>Variation (%)</td>
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<td>Tax Scheme (1)</td>
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By introducing the proper changes in the tax credits for each of the traffic variations, corresponding tax credit distributions were obtained. As stated previously, a significant factor in the comparisons of cost responsibility with taxes paid is the taxes which are included in the analysis. Each of the following four tax schemes was considered in the special study:

**TABLE 6**

**EFFECT UPON TAXES PAID-COST RESPONSIBILITY RELATIONSHIPS**

<table>
<thead>
<tr>
<th>Vehicle Group</th>
<th>More Favorable*</th>
<th>Negligible Effect</th>
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<tr>
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<td>Increase</td>
<td>Decrease</td>
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<td>Passenger Cars (P)</td>
<td>P1</td>
<td>P2, P3, P4</td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td>C2, C3, C4</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>B2, B3, B4</td>
</tr>
<tr>
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<td>P1, P2, P3, P4</td>
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<td>C3</td>
</tr>
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<td></td>
<td>B3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td></td>
</tr>
<tr>
<td>Multi-Unit Trucks (B)</td>
<td>P1</td>
<td>P2, P3, P4</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>B3</td>
<td>B4</td>
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</table>

* Numbers used with letters refer to the four tax assumptions. The column indicates the tax assumptions that produce more favorable cost-size relations, and whether the traffic variation for a given vehicle group must be increased or decreased to obtain the better relation.
1. All taxes were included except the general public's portion.
2. All taxes were included except state sales, federal excise and the general public portion.
3. All taxes were included except non-highway use taxes.
4. All taxes were included except state sales and federal excise taxes.

Non-highway use taxes were those obtained from highway users but not expended on Ohio highways, while the general public's portion came from the general funds of the state and local governments; that is, not highway user taxes. The results are somewhat misleading in that the federal tax laws of 1953 and 1954 are considered. Several types of taxes which were not utilized on highways at that time must now be incorporated into the highway budget. The various tax credit distributions are tabulated in Table 5.

The influences of the traffic variations were expressed on the basis of the variations produced more or less favorable taxes paid-cost responsibility relationships for each

Figure 4. Effect of traffic variation on taxes paid and on cost responsibility passenger cars.
of the vehicle groups considered. Summarized in Table 6 and in the following are the trends indicated in the plots of the data shown in Figs. 4, 5, and 6.

Passenger Cars.—(a) Under the Tax Schemes 2, 3, and 4 the effects of variations in both C and B Type traffic data (Table 3) are negligible. (b) Under Tax Scheme 1 an

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Figure 5. Effect of traffic variation on taxes paid and on cost responsibility—type "C" vehicles.

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Figure 6. Effect of traffic variation on taxes paid and on cost responsibility—type "B" vehicles.
increase in both C and B traffic and a decrease in P vehicle-miles will produce favorable effects.

**Type C Trucks.**—(a) Variation in the passenger car vehicle-miles will have negligible effect, regardless of tax schemes. (b) Favorable effects are produced by a decrease in the C Type vehicle-miles under Tax Schemes 1, 3, and 4 and an increase in B Type vehicle-miles under Tax Schemes 1. (c) Under Tax Scheme 2 an increase in the C Type vehicle-miles will produce non-favorable effects.

**B Type Trucks.**—(a) Favorable effects will be produced by an increase in C Type vehicle-miles and a decrease in both P and B Type vehicle-miles under all Tax Schemes except one which has negligible effect, namely a passenger car variation under Tax Scheme 1.

The analyses for the special study were not complete and represent the results produced by the consideration of only three of the tax sources: (a) registration fees, (b) fuel tax, and (c) highway use. Furthermore, the tax and traffic data were obtained from the tax study and highway cost study and variations were made therefrom. However, the following significant statements are considered reasonable interpretations of the results.

There are two major variations which improve the taxes paid-cost responsibility relationship for the B and C Type vehicles. One condition is produced by a decrease in their respective vehicle and axle miles. This infers that although the tax credits increase with increased vehicle and axle mileage, the cost responsibility increases at a faster rate. Conversely, the cost responsibility diminishes at a faster rate than taxes paid. The other favorable variation is an increase in vehicle and axle mileage in the other group; that is, an increase in B Type vehicle and axle mileage will produce improved relationships for the C Type group and vice versa. Again, the reason for this situation stems from different rates at which the taxes paid and cost responsibility are affected.

An increase in passenger car vehicle-miles produces favorable effects for all tax schemes except the one which includes most of the taxes which are paid by highway users but are not used on Ohio highways. This indicates that the taxes paid increase at a greater rate than cost responsibility except for the one instance.

**Considerations in Establishing a Basic Vehicle**

The basic vehicle can be defined as that vehicle which can satisfactorily operate on highways without adding to the minimum highway costs required for the safety and convenience of the smallest vehicle. The establishment of the basic size of vehicles is critically necessary for problems where differential costs between vehicles is the basis or where allocation of cost responsibility is concerned. On the other hand, if one is attempting to establish the optimal design, considerations of the basic vehicle may not be pertinent. The last statement assumes that the size of the basic vehicles is at least as great as a passenger car. In developing a relationship between highway costs and vehicle size, one can originate with, or extrapolate to, the lowest sized vehicles. At some point near the lowest limit of vehicle size, climatic and non-highway user requirements start controlling. It is at this point that the size of the basic vehicle is defined. Figure 2 illustrates the point by use of the Ohio studies. As can be seen, if the optimum-sized vehicle has an axle load larger than 2.5 tons, the size of the basic vehicle is not a factor.

On the other hand, assignment of cost responsibility requires an estimate of the size of the basic vehicle, since all vehicles share, on some equivalent basis, the costs required for the basic vehicle. The indirect source of cost which affects the size of the basic vehicles more than any other is climate. Another contribution however, is the minimum construction cost which is feasible. To a certain extent, the topography is also a factor in the geometrics due to the performance characteristics of the vehicle. Since climate, topography, and construction costs are factors, the size of the basic vehicles will vary from one locale to another; that is, the basic vehicle for the State of Maine will be different than that for New Mexico. For area-wide studies, then, the basic vehicle is based upon a statistical evaluation of the conditions in the area.
In starting an investigation of the relationship between highway costs and vehicle size it will be important to know whether the establishment of a basic vehicle is required in the problem. Secondly, it should be understood that the size of the basic vehicle is a function of the region and the area under study must be utilized as a basis rather than the adoption of a value derived for different conditions.

Reconstruction, Resurfacing, and Surface Treatment

Allocating cost responsibility for reconstruction, resurfacing, and surface treatment includes certain unique considerations. While the following discussion is limited to pavement costs, the principles would be applicable to other costs which are normally included in reconstruction.

An interesting question, pertaining primarily to reconstruction and resurfacing, can be stated as follows: to what size vehicle should costs be assigned for those pavement expenditures which attempt to extend the design life? In the strictest sense, there is no problem because the heaviest axle loads which are utilizing the pavement undoubtedly produce the greatest stress per repetition. The confusing element is the fact that climate has contributed to the reduction in structural capacity of the pavement. Unfortunately, the effect the smaller vehicles would have on the pavement cannot be rationally determined. Furthermore, climate alone may start producing damage which will require maintenance. It has been argued that since the pavement has gone beyond the design life, all vehicles should share on an equivalent basis for its rehabilitation. For the studies at The Ohio State University, however, the direct responsibility for the pavement disintegration was considered as resting with the heavy trucks. It was also recognized that this assumption produced extreme relationships since the climatic deterioration of the structure and the activity of the lighter-weight vehicles undoubtedly contribute. Therefore, the method finally adopted was to compute maximum cost differential by assigning the entire reconstruction and resurfacing pavement costs to the heavy vehicle. For the minimum cost differential it was assumed that vehicles shared responsibility on the same basis as they would for new construction.

The uncertainties associated with surface treatment are somewhat different. The definitions for surface treatment vary with organizations, but for the following discussion it will be assumed that surface treatments are those additions to the pavement which add no structural capacity. It is also assumed that no serious surface irregularities could be levelled by surface treatment, and one can conclude, therefore, that the surface treatment is principally placed for control of climatic influences.

On newly-constructed secondary highways the inclusion of surface treatment may furnish the completion of a long-range, new-construction project. In such cases, surface treatment should be considered as new construction and prorated in accordance with the accepted pavement design techniques. The procedure followed for The Ohio State studies consisted of applying the principles of pavement cost allocations for new construction in order to obtain the maximum cost differential. Whereas for a minimum cost differential, the costs were distributed uniformly on a usage basis. In no case were the costs of surface treatment assigned directly to the truck as was done for reconstruction and resurfacing.

From the foregoing it will be noted that an engineering decision was made with reference to the assignment of the costs. By more rigorous study of the cost data, it might be possible to assign the expenditure on a more rational basis. However, it will be quite an unusual situation where the available cost and design records are sufficient to permit a detailed analysis of the type and extent of reconstruction, resurfacing, and surface treatment.

Engineering and Administration

The cost responsibility for engineering and administration has been generally allocated on one of two basic concepts. One philosophy states that engineering and administration is a function of the dollar size of the program and should, therefore, be divided proportionally among the various cost items for which the engineering and administration has been required. Under this theory the dollars for engineering and ad-
administration would be allocated on the same basis as the individual cost items to which they are assigned; that is, dollars of engineering and administration added to the cost of pavements would be allocated on the same basis as the actual pavement costs.

A second theory for considering engineering and administration deals with the assumption that such costs are a function of the numbers of vehicles and miles of highways in the system and not a function of the size of the vehicle; that is, engineering and administration would be approximately the same even if passenger cars were the largest vehicles using the highway. From a viewpoint of plan preparation or design engineering, one is inclined to accept the second theory. For actual construction, however, the increased quantities required for the heavier vehicles undoubtedly add to the cost for field engineering and administration. The fact that engineering fees are based upon a percentage of the contract costs is used as an argument in favor of the first theory. However, actual costs of plan preparation and construction supervision would not vary significantly with the sizes of the vehicle for which the design is accomplished without varying the level of effort to achieve the design.

From a practical point of view, it seems certain that the actual relationship lies somewhere between the two extremes suggested in the two aforementioned theories. In application, the first theory leads to the allocation of costs on the same basis as other highway costs which would place a higher cost differential on the larger vehicles. Under the second theory, the engineering and administration would be considered a function of the number of vehicle-miles or of axle-miles, but on a uniform basis, rather than an added increment assigned to the larger vehicles.

**Estimating Differential Costs**

The extensive work required for developing cost-size relations, and the dependency upon design methods for current results discourages many agencies from undertaking detailed analyses. Most of the research at Ohio State was devoted to the basic methodology of obtaining cost-size relationships for the individual cost items. Since the studies were for Ohio highway conditions only, the results are not directly applicable to other areas or agencies. However, in lieu of other information, the data are considered to be approximately equivalent, at least qualitatively. Where comparable design criteria are utilized, the shape of the cost-size curve shown in Fig. 2 is considered as representative of results using comparable assumptions. Further enlightenment may be provided by Table 7 which summarizes the equations which lead to the combined data.

Assuming that the relations expressed in Fig. 2 are acceptable, particularly as to the shape of the curves, differential costs can be estimated directly from total annual cost (or total cost per mile) and the legal load (or design load). The following is the mathematical expression for total costs:

\[ C_{\text{max}} = 9.7W_1^{0.1412} \]  
(2)

in which:

- \( C_{\text{max}} \) = Maximum total annual cost per mile in thousands of dollars.
- \( W_1 \) = Weight of axle load in tons.

\[ C_{\text{min}} = 4.5W_1^{0.1302} \]  
(3)

in which:

- \( C_{\text{min}} \) = Minimum total annual cost per mile in thousands of dollars.

The equations hold for a range of \( W \) of 5 to 20 tons, and for the single value of 2 tons. However, there is an implication that the axle load weights of 10 to 20 tons will (a) not involve a change in vehicle dimensions, or (b) not affect the geometric requirements.

For the general solution:

\[ C = C_a W^S \]  
(4)
in which:

\[ C = \text{annual cost per mile for the axle load, } W. \]

\[ C_a = \text{annual cost per mile for the unit axle load.} \]

\[ s = \text{constant (equal to the slope of the logarithmic relation).} \]

The unit axle load is defined as the axle load for which \( C_a \) is known. If no data are available as to cost for a specific axle load, Equation 4 will not be helpful. However, for an existing system, the legal (or design) load can be used in conjunction with the actual expenditures and a solution achieved. Values of \( s \) are a function of the design techniques, which for Ohio were defined by:

\[ s = 0.00163C_{9.5} + 0.1210 \]  \hspace{1cm} (5)

in which:

\[ C_{9.5} = \text{Total annual cost per mile in thousands of dollars for a design axle load of 9.5 tons.} \]

The equation is considered applicable for \( C_{9.5} \) values between $6,000 and $13,200. Where the differential costs between two axles is desired:

\[ D = C_1 - C_2 = C_a W_1^s \]  \hspace{1cm} (6)

in which:

\[ D = \text{Differential costs between requirements for axle loads of } W_1 \text{ and } W_2. \]

TABLE 7

EQUATIONS USED IN DEVELOPING COST-SIZE RELATIONS

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Equation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavements (P)</td>
<td>( C_p = C_{9.5} W^s )</td>
<td>New construction, two-lane full depth</td>
</tr>
<tr>
<td>Structures (S)</td>
<td>( C_{9.5} \max = 410 \log W + 90 )</td>
<td>Weighted combination for six structural types and seven vehicle types</td>
</tr>
<tr>
<td></td>
<td>( C_{9.5} \min = 115 \log W + 155 )</td>
<td></td>
</tr>
<tr>
<td>Earthwork (E)</td>
<td>( C_{EN} = 32.8 \log T - 63.6 )</td>
<td>Rural new construction</td>
</tr>
<tr>
<td></td>
<td>( C_{ER} = 0.001 \log T + 12.1 )</td>
<td>Rural reconstruction</td>
</tr>
<tr>
<td>Right-of-Way (A)</td>
<td>( C_{AN} = 4.0 T + 6.4 )</td>
<td>Rural new construction</td>
</tr>
<tr>
<td></td>
<td>( C_{AR} = 0.003 T + 3.8 )</td>
<td>Rural reconstruction</td>
</tr>
<tr>
<td>Roadside Development (Q)</td>
<td>( C_{QN} = 0.000065 T + 5.5 )</td>
<td>Rural new construction</td>
</tr>
<tr>
<td></td>
<td>( C_{QR} = 0.0001 T + 3.7 )</td>
<td>Rural reconstruction</td>
</tr>
<tr>
<td>Drainage (D)</td>
<td>( C_{UN} = 0.007 T + 3.8 )</td>
<td>Rural new construction no relation found for reconstruction</td>
</tr>
<tr>
<td>Maintenance (M)</td>
<td>( C_{M} = 4.5119 + 0.206 T_H )</td>
<td>Roadbed and surface maintenance and repair - excludes resurfacing, surface treatment, etc.</td>
</tr>
<tr>
<td>Total</td>
<td>( C_{\max} = 5.7 W^{0.1412} )</td>
<td>Discontinuous over the range 2 to 5 ton axle loads. Assumes no increase in geometric dimensions of vehicles for 10 to 20 tons. Unit axle load is one ton.</td>
</tr>
<tr>
<td></td>
<td>( C_{\min} = 4.5 W^{0.1302} )</td>
<td></td>
</tr>
</tbody>
</table>

C - Annual cost per mile in thousands of dollars.
N - New construction
R - Reconstruction
S - Constant
W - Axle load in tons.
T - Adjusted ADT - number of heavy vehicles increased by topographic factor.
H - Heavy vehicle - (Type B & C trucks).
If costs are to be compared to the legal axle load or to the unit axle load, then:

$$D_u = C_u (W^s - 1)$$

(7)

Figure 7. Rate of increase of annual cost with increase in axle load.
in which:

\[ D = \text{Differential annual cost per mile in thousands of dollars between the unit axle load and } W. \]

\[ C_t = \text{Annual cost per mile in thousands of dollars for the unit axle load.} \]

\[ W = \text{Axle load in tons for which differential costs are desired.} \]

Values for \( s \) are determined as discussed in the preceding and in Equation 5.

Another interesting consideration is the rate of increase of highway costs with axle load. Based upon Equation 4:

\[ dC = C_a s W^{s-1} \, dW \tag{8} \]

and:

\[ r = C_a s W^{s-1} \tag{9} \]

in which:

\( r = \text{rate of increase of total annual cost responsibility in thousands of dollars per mile per ton (axle load).} \)

A typical plot of Equation 9 is shown in Fig. 7 for Ohio conditions. The implication of Fig. 7 is that for higher axle loads, the rate of cost increase is reduced, particularly for weights in excess of 6-8 tons.

**SUMMARY**

In considering the differential cost studies to date, the problems of developing the relationship between highway-cost and vehicle-size leads to certain conclusions. The complexities of rationally expressing the relations which are needed prevent too many general statements.

For a truly rational and theoretically sound development of the relation of highway costs to vehicle size a great deal of research is still required. Since so many phases of highway engineering are still empirical and since the elements of highway costs which are rational represent such a small part of the total cost, the values derived from the cost-size investigations are certain to be questioned. On the other hand, studies based upon the methods currently used for design will at least reflect present practice and expenditures. Insofar as this type of an answer is suitable, reasonably reliable estimates can be made.

From a research viewpoint, the studies which are most needed for cost-size investigations are related to the geometric factors. While it is true that a rational solution to structural elements such as pavements is not available, the empiricism utilized in pavement design is more effectively related to vehicle size than is the design for geometric factors.

The shape of the curve of highway costs versus vehicle size appears to be reasonably well established at this time, at least for current design procedures. There is little question but that the curve is basically of the exponential form Fig. 2 rather than the reverse curve frequently used as a qualitative description of the relationship. There is greater question as to the validity of the geometric capacities than for the structural elements.

Considering the complexities of achieving values for cost-size relations, a suggested procedure for estimating differential costs may be quite adequate for many problems. The method proposed involves knowing the dollars per mile which are available for a given highway system. Using the legal load as the axle load for which the system is designed, one point on the cost-size curve is available. Equations for projecting the curve above and below this given point have been suggested (6).

One of the major problems for which little direct research is currently under-way is involved with the problem of solving for the optimum sized vehicle to be used on an existing road network. There are a great many miles of highways in this country, and until it is possible to evaluate the load-carrying characteristics of these pavements, it will be illogical to extrapolate current expenses for reconstruction and resurfacing.


The same is true for maintenance costs which are associated with vehicle weight (structural capacity). There is also some question as to the validity of extrapolating the geometric capacity requirements beyond the current values. According to the standard design practice today, the vehicle dimensions make no difference other than on the broad basis of passenger cars and trucks. Thus, changing vehicle dimensions would not appear to change highway costs. It is quite obvious that such a statement is not theoretically sound. As an example, a substantially wider vehicle would unquestionably increase the geometric capacity requirements. Drastic changes of vehicle height, length, and performance could also affect highway geometrics.

ACKNOWLEDGMENTS

The basis for the preceding paper was the research at The Ohio State University undertaken by the writer working closely with Robert Chieruzzi and Richard W. Bletzacker, Research Associates of the Engineering Experiment Station. Most of the philosophies and principles described herein were evolved through many hours of discussion and analyses. In retrospect, it is difficult to determine the source of an idea or its ultimate treatment. The writer is indebted to his two associates for their permission to utilize the material presented.

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REFERENCES

IN NEARLY every discussion about public policy one reads or hears statements regarding the need for more highways, more schools, more housing, more defense or more of almost anything except certain agricultural commodities. These statements are true if they are interpreted as meaning that more of each of these various goods and services, without loss of any other goods or service, would add to our general welfare. Such statements may not be true, however, when one takes into consideration the fact that the resources required to produce various goods and services are limited in quantities, and therefore, in order to get more of one thing one must usually give up some amounts of other things.

Perhaps the word "need" should not be used in such discussions. Rarely, if ever, is there a situation such that one could not survive unless he had more of a particular thing. Instead, the problem might be viewed as one of cataloguing the various things that could be produced—given the available resources and ways of converting them into product—and attaching values to each possibility so that one can be compared with another. Some of the problems involved in making such comparisons with reference to the problem of providing highway services are discussed in this paper. In particular, it is noted the kind of information that is required and some of the implications are indicated for highway research.

Reference has been made to the problem of determining how much to produce of highway service, or schools, or anything else, as one of evaluating all the possible bundles of things that might be made available. This paper will not pursue this approach directly. Perhaps in a controlled economy this procedure is employed. In the economy of the United States it might be done in evaluating various kinds of defense programs. But to construct a complete catalogue of what might be produced would be virtually impossible, and to value each collection in accordance with generally accepted evaluation procedures—if such exist—also would be very costly. Instead, one can employ a procedure making use of certain conditions that would be fulfilled in order for a collection to be an optimal one (that is, a "best" one). In particular use can be made of the market system in obtaining information about how a change in the collection of things that might be produced will be evaluated by the population.

Unless the economy is organized inefficiently (involuntary unemployment is one kind of inefficiency) it costs something to expand the output of a particular good or service. Under certain conditions this cost represents the value of other goods and services that must be sacrificed in order to obtain more of the particular commodity in question. Let the price that people are willing to pay per unit of the good represent its value. If price exceeds the additional cost per unit, more of that good and less of the others would constitute an improvement, since the value of more of the good would exceed the value of less of other goods. Conversely, if the price of the commodity is less than the additional cost, more of the commodity and less of the others would make things worse. Comparisons of prices and costs can tell which things should be produced in greater quantities and which in smaller ones. One might then say, "We need more of something if its price exceeds its cost and less of something else if its price is less than its cost."

For comparisons of prices and costs to give one a true picture about his needs, the prices must give good approximations as to what things are worth, and the costs must yield accurate estimates of what must be sacrificed. Some things one would not consider selling, and for them a meaningful price cannot be established. For other things, the price underestimates the true value. The price that one is willing to pay for something that he will use represents only the value to him of consuming the particular good and excludes the value to other people of his use of that good. Elementary education is frequently cited as a case of a service that would be produced in insufficient amounts if one followed the price-cost comparison because he is willing to pay something for...
children's education, but the price you are willing to pay doesn't depend on my feelings about your children's education. For still other things, the price overestimates the value because one person's welfare is influenced adversely (other than by what happens to prices) by increased consumption of the good by another person. Thus, fuels that contribute to air pollution may be over-priced (or under-costed). Users wouldn't be willing to pay as much for them if they had to bear pollution costs.

Costs also may be poor representations of what has to be sacrificed because they include monopoly elements or the results of restrictions—including taxes—imposed by government. However, imagine that such things don't exist or that they can be accounted for properly. Then, for a commodity whose consumption by one person has no effect on another person's welfare—except through its impact on price—one can usefully talk about whether too little or too much of it is being produced with reference to the relationship between its price and its cost.

What does all of this have to do with highways? One will contend that, for the most part, highway services are such that if they were priced and if costs were computed appropriately, one would be supplying his "needs" when one produced that amount such that the price—the amount charged for a passage by a particular vehicle—equals the cost resulting from that passage.

First, it should be made clear that the benefits from investment in highways have properties such that a highway investment can be evaluated in the same manner as can any investment designed to produce goods and services that are to be sold. To speak of highway services as if they constituted a single homogeneous commodity is to err in the same way as to speak of food as a single good. Discussion will be avoided of how such service should be defined except to assert that some of the difficulties in analyzing highway problems arise from inappropriate definitions of highway service.

Traveling a particular distance, at a given speed and with given comfort and safety may be as different—in the mind of the highway user—from traveling this same distance at another speed and with other degrees of comfort and safety as a pound of sirloin steak is from a pound of potatoes. Truck travel differs from auto travel, etc.

Although there are many different kinds of highway services, nearly all of them benefit the highway user—in the case of services provided by passenger car travel—or the benefits are passed on to other persons from whom a collection can be made—through commodity prices, in the case of truck services—in the same way as are the benefits from technological improvement or additional capital used in a farm or factory. In general, highway services are like food in that one person has no interest in another's consumption pattern (except for its effect on prices). The case for distributing highway services and for determining their appropriate levels of output by a price-cost mechanism is as strong as that for any other commodity group.

The statement that highway services comprise a commodity group such that price-cost criteria should guide their distribution and production does not mean that one should set up toll stations at every street corner and every cross road. Because of collection costs and inconveniences that might be more distasteful than congestion, toll roads can play a very limited role in the highway system. However, one can establish motor fuel taxes, weight-distance taxes, license fees, and other charges in a way such that the over-all fee schedule yields a rational allocation of whatever road and street facilities are available. And, one can account for costs and revenues so that he will get about the right amount of highway investment and distribute it fairly well geographically. In fact, the structure of charges to highway users already may be fairly reasonable and is constantly improving, although one is without some information required to construct

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1 That different degrees of highway congestion are not all equally satisfactory to a highway user might appear to destroy the assertion that one man's consumption is of no concern to other men, and vice versa. However, if one considers travel at one speed, safety, etc., as a different commodity from travel at another speed, safety, etc., there is no contradiction in the formal statement. More congestion is analogous to the higher price for steak that would result from an increase in its demand. The highway user would be indifferent to some higher fee with lower congestion and the low fee with more congestion.
a good fee catalogue. The provision of facilities probably is less rational, relatively speaking, than is the fee schedule, although only rough guesses can be made about this from existing data.

Except on toll roads, the basic charge for the passenger auto should be, and is, the motor fuels tax. Fuel consumption is an index of distance traveled for any vehicle, although distance traveled and amount of service are not uniquely related as long as highways differ. However, to account for highway quality difference by differences in fuels taxes probably is not feasible. Since passage for the passenger auto is the least costly to provide the fuel tax can be used as a kind of toll. Special fees for passenger cars may be warranted in large cities where congestion is a problem, such fees being in accordance with the higher costs of providing a given level of service in areas where land values are high. Similarly, special assessments or special license fees for residents of very sparsely settled areas may be advisable. In this case, such fees are in accordance with the high value of the service rendered by the highway.

For trucks and busses, fuels taxes are supplemented by license fees in recognition of differences in costs imposed by passage of vehicles of different characteristics. However, license fees cannot be varied sufficiently to equitably tax the many different classes of weight and distance combinations. Weight-distance taxes are preferable and could permit different fees for different routes. In fact, weight-distance taxes might be administered in a manner similar to that used in collecting the personal income tax from self-employed persons.

Some of the implications of using price-cost comparisons to a greater extent in making highway decisions are of interest.

If prices and costs are appropriately determined, not only the highway system as a whole, but each separate entity should "pay for itself" in an accounting sense when the system is optimal (because of indivisibilities, equality between imputed revenues and imputed costs may not be achievable). Otherwise sectors of the system that are "making a profit" and ought to be expanded may be supporting sectors that ought to be contracted. This possibility cannot be detected when only the revenues and costs of the system as a whole are examined.

That highway users should pay for the highways has much, though not universal, support. However, that each clearly distinguishable sector should pay for itself is less widely supported—except possibly for toll roads. In particular, it is believed that generally there has been relative over-construction of rural non-trunk highways, although this belief can neither be adequately supported nor refuted with existing data.

The prices that have to be paid for resources are taken as reliable estimates of the value of the product that has to be sacrificed in order to expand production of one good. Government pays the same prices for labor and materials as do other users. However, it borrows money at more favorable terms (at a lower rate of interest) than does the typical private borrower. This lower interest rate reflects primarily the confidence of the lender in government's ability to repay—not in the relative merits of the projects. Government can tax (or print money, if it is the federal government) to repay loans. Private borrowers must repay out of earnings. If government borrows at, say, 3 percent, whereas private producers borrow at, say, 6 percent, and both government and private producers use amounts of capital such that rates of return are equal to borrowing costs, government will be using too much and private producers too little. Shifting capital from the government to the private sector would expand total product. Government also should not invest in projects unless they would yield, say, 6 percent, if capital is to be allocated in the best manner. Thus, decisions to build highways and to make other governmental investments should not be based on the rate at which government can borrow but on the rate of return on capital in other uses.

Tax differentials, as well as differentials in costs of borrowing affect the relative prices of governmentally produced goods in comparison with privately produced goods. In the transportation field are special excise taxes affecting some kinds of transport (but not others) that encourage use of the highway system rather than alternative forms of transportation. These taxes ought to be abolished. However, there are also property taxes applying to nearly all private property. A complete evaluation of the property tax is not considered to be appropriate for this discussion. However, to obtain a better
distribution of resources among various kinds of transportation, imputed property taxes on highways ought to be considered in arriving at highways costs, just as a "shadow" interest rate equal to the marginal rate of return on capital in private investment rather than the cost of borrowing ought to be employed.

To try to make the last two points clearer, imagine that there are two services—call them "rail transport" and "highway transport"—both of which could be produced at the same constant unit costs, if resource prices were the same to both industries. Assume also that the amount of either service demanded varies inversely with its price and directly with the price of the competing service. With the same interest charges and no taxes, the prices would be identical and certain amounts of each service would be produced. However, if one industry were charged more for capital than was the other and also had to pay taxes proportionate to the volume of service produced, its service would be priced higher than that of the other industry. Less of it and more of the other would be used than would be economic, that is, than would be the case if "true" costs determined prices.

It should be noted that if the highways were to "pay for themselves" in the sense of yielding revenues equal to costs, including the imputed ones, there would be diversion of highway revenues to the general governmental fund. This diversion would be equal to imputed property taxes plus, say, 2 or 3 percent of capital outlays—this 2 or 3 percent being a rough estimate of the differences in borrowing costs to government and private borrowers.

Although it is not economically feasible to collect tolls except on a very small percentage of the highway system, tolls can be equitable rationing devices and can permit accurate accounting of the revenues attributable to a particular sector of the highway system. For these reasons, rather than minimizing the number of toll roads, one would employ them wherever feasible. However, certain practices in administering toll roads are not consistent with best use of the highway system. In particular (a) requiring that toll roads pay for themselves out of tolls is uneconomic. Motor fuels tax receipts also should be credited the toll roads. To do otherwise will result in under-utilization of such roads and over-utilization of or over-investment in, freeways, (b) tolls should be much more flexible than toll authorities have been inclined to make them in the past. Varying tolls with the demand would smooth the traffic flow and could make it approximate more closely that for which the road was designed. Ideally, tolls might fluctuate as do the odds at pari mutual betting booths or as do stock market quotations. In areas such as Manhattan where access is by tunnel or bridge, tolls to the island certainly should exceed those away from the island during the morning rush hours, and perhaps vice versa during the evening hours—although if there are too many autos in Manhattan there is no reason why entry fees should not always exceed exit fees.

Fluctuations in tolls not only would aid in controlling traffic flows. They also would permit improved estimates of the demand for highway services. Such data are required for determining how much investment to make in highway facilities and very few of them are available.

To minimize errors in locating and investing in highway facilities, the demand for and costs of providing various services must be known. Highway facilities provide services over a long period of time, and no one can forecast with perfect accuracy, the conditions that will prevail in the future. However, one could make use of more of the attainable cost and demand information than has been made available.

First consider costs. Economists divide the elements determining costs into two classes: (a) The technological and (b) the market. The first class consists of a description in purely physical terms as to how resources can be converted into product. How to construct a flexible pavement and a concrete pavement that would carry certain loads with a given deterioration for a given period of time would be part of such a description. The market describes the prices that have to be paid for resources. If there is more than one way to do a given job, the way that is least costly at one set of prices obviously will not be the least expensive at every other set of prices.

A great deal of technological information about highways is available and more is being assembled. However, it is believed that some of this information is not in a form such that it permits relevant cost comparisons, that is, comparisons of the cost of
carrying one type of vehicle rather than another. To appropriately assess the maintenance cost attributable to the passage of a vehicle with particular characteristics over a given section of the highway, the wear and tear on the road has to be measured in terms that can be converted into costs. The cost of restoring the road section to its condition prior to the vehicle passage is the required information, and no way can be seen of converting fatigue data into the desired informational form. Comparisons of construction costs and attempts to allocate them are numerous. However, it is maintenance plus construction costs that are relevant, and more maintenance but less construction becomes economic as interest rates are increased.

With reference to the demand for highway services much less is known than about costs. Ideally one wants to know how much of a particular kind of service buyers are willing to take at particular prices. From this one can determine, for example, how much people believe it is worth to be able to travel with a given degree of safety at 50 mph between two points rather than at 40 mph. If the additional cost of providing facilities for the higher speed was less than the value, these facilities should be constructed.

As was stated previously, varying tolls permits obtaining demand information. Perhaps arrangements could be made with selected toll road authorities so that the effects of various tolls on the traffic pattern could be observed.

Another method for obtaining demand information is through asking users how they would behave if certain conditions prevailed. Drivers might be asked how much more they would be willing to pay per trip if the traffic density were such that they could drive at one speed rather than another, for example. Such surveys typically permit presenting a wider choice of possibilities than could be presented in an experiment such as varying the tolls on a particular road. However, the possibilities are hypothetical ones and the responses may differ considerably from actual behavior under the circumstances. Nevertheless, such surveys have yielded information useful to business firms trying to estimate the demand for a new product and could be used in estimating more accurately highway users' preferences.

To determine whether a particular sector of the highway system is "paying its way" one needs to know its traffic pattern. Many traffic counts have been made and one can tell a good deal about traffic patterns from the wear and tear on a particular highway. However, much less is known about the composition of traffic on various sections of the system than one should know.

SUMMARY

In this short discussion, it has been asserted that highways compete with other activities, including other transportation facilities, for the use of resources. In determining the amount of highway services to provide, one should compare the value of these services with the other things that could be provided. Highway services are such that comparisons of their prices—if they could be priced—and their costs—if resources are obtained for providing such service under the same terms as in other uses—could tell whether too much or too little is being produced.

Employing tolls to sell highway services directly is economic only on a rather small part of the highway system. For the remainder, the schedule of fees acts as a schedule of prices. The price to any vehicle ideally should be the cost incurred in handling that vehicle. To put highway services on the same footing as other competitors for resources, costs should be estimated using the same interest rates and such other cost factors as property taxes as these other users pay. Thus, some diversion of highway revenues to the general fund would be justified.

To make this price system function effectively research is needed that will provide estimates of the demands for highway services, and to know more about costs is needed. Toll road experience can provide some information about demand, and tolls might be varied specifically for this purpose. Market surveys also could be employed.
Price Theory and Tax Equity in Highway Finance

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Highway user taxes act as prices for the use of highways, thus influencing the allocation of traffic (and resources) among the various transportation agencies. Assuming that optimal use of the transportation system is one of the aims of public policy, it is important that highway user tax rates be constructed so as to foster attainment of this goal. Although this calls for a pricing or market approach to highway finance, it is equally important to segregate, identify and allow for those values (indirect benefits) which are not reflected in the market choices of individuals.

It appears that the traditional allocation of highway cost between users and non-users does not in general represent a response to indirect benefits. Rather, it reflects administrative problems and certain notions about equity or justice. The theoretical conditions under which a non-user share is appropriate may be specified, but application of the theory raises difficult practical problems. Notwithstanding these practical difficulties, it seems clear that the allocation of shares between users and non-users should follow, not precede, the determination of prices for highway use. Moreover, the non-user share should be scrutinized carefully, so that user rates are not diminished or distorted by deductions for indirect benefits which accrue in the form of rents, windfalls and surpluses. Such indirect benefits must be considered in the light of general standards of tax equity.

Economically efficient highway user tax rate structures can be constructed by adhering to the economic price criterion: Price should equal marginal cost. For an optimally utilized highway plant, "program cost" is a reasonable approximation of marginal cost. An equally satisfactory approximation for roads which have excess capacity and low marginal costs is not available. However, such roads may be financed economically through use of the "two-part tariff". The two-part tariff combines a low price which varies with use with a lump sum tax which does not vary with use.

To provide practical guideposts for application of the marginal cost standard, highway design, price theory and financial administration may be interrelated and integrated into an operational framework or "model". The crucial element in establishment of the "model" is the separation of special or incremental pavement cost from common or geometric design cost. Speculation concerning the impact of the framework suggests the possibility of establishing the gasoline tax rate so that gasoline tax "earnings" on the primary roads cover primary road common cost. Additional or incremental pavement cost may be recovered through the use of lump sum registration taxes or weight distance taxes. Lightly traveled roads may be financed through the use of gasoline tax "earnings" supplemented by lump sum license taxes on light vehicle classes. The general conclusion is that it is possible to manage the highway financial structure in the interest of economic efficiency without creating serious inequities.

○ Within the past few years the notion that highways should be financed "equitably" has been supplemented by the view that the highway user tax structure should also
foster the economic utilization and development of the highway plant. This change in emphasis implies a partial shift from the use of ethical standards of tax equity to the use of more or less objective standards of pricing in the development of the highway financial structure.

The aim of this paper is to set forth the relationships between price and tax standards as they apply to highway finance and to establish criteria for the combination of prices and taxes into a comprehensive system of charges for the financing of highways.

Abstract economic theory has established the principle that, within the limits of a given distribution of income, maximum economic welfare is approached when production and consumption are adjusted so that marginal cost and price become equal (1). If income redistribution is not an explicit aim of the highway user tax structure, it might be appropriate to eschew benefit and ability-to-pay standards of taxation and to establish highway user taxes in relation to a marginal cost pricing standard. One of the implications of a pricing or "market" approach is the assumption that the benefits or utilities relevant to highway finance accrue, in one form or another, directly to highway users. However, consideration of the indirect or so-called non-user benefits which accrue to various individuals may lead to a system of taxation based on the premise that individuals should pay in proportion to "benefits-received". Simultaneous application of both price and tax standards may introduce conflict into the overall financial structure—what is paid as a tax by the non-user does not have to be paid as a price by the highway user. The possibility of unwarranted subsidy to one group or another is obvious. In order to anticipate this problem, the discussion begins with a consideration of the traditional allocation of cost between highway users and non-users.

THE NON-USER QUESTION

A recent pricing proposal set forth by Brownlee and Heller demonstrates the validity of a pricing approach insofar as primary or "trunk" road finance is concerned (2). However, there have been objections to this proposal from proponents of a user-non-user allocation of highway cost who maintain that the pricing proposal abstracts the most difficult parts of the problem—the relationship of indirect or social benefits to secondary road finance (3). Some progress in the way of clarifying this issue can be made by recognizing explicitly that the allocation of a share of secondary road cost to non-users is more a response to administrative problems than to indirect benefits. Richard Zettel (4), among others, has noted that property taxes, special assessments and other forms of revenue are simply a crude means of collecting directly from the highway user that portion of his highway bill that cannot be collected through the use of ordinary user charges. The expenditure of "general" or non-user funds for highway purposes does not necessarily imply that highways yield indirect benefits nor does it imply that highways ought to be financed in terms of tax equity. Moreover, the administrative problem of collecting from the user does not call for an allocation of highway cost between users and so-called non-users or indirect beneficiaries. Basically, the cost allocation is among those who use the highway.

Recognition of the administrative basis for non-user revenue sources does not resolve the economic issues raised by valid indirect benefits. In order to examine the economic basis of a non-user share, it is necessary to examine the conditions under which value-of-service or benefits-received allocations of cost are appropriate. There are two such situations: (a) joint cost or supply and (b) joint or collective demand. Joint supply creates a problem of cost assignment because two or more physical products emerge from a single application of resources. Joint or collective demand creates the problem of distributing the cost of a single product (whose cost is determinate) among more than one beneficiary. An examination of these two possibilities may provide the theoretical standards for evaluating allocation of cost between users and non-users.

Joint Cost

Joint cost arises when products cannot be produced separately. The classic example is the case of beef and hides; there are two distinct products whose separate costs are indeterminate. It appears to be settled that the "solution" in such cases re-
quires an allocation of total cost on the basis of the value-of-service or value-in-use of the separate products (5). Highways do create some joint products, and this might justify an allocation of cost to non-users or general taxpayers. Highways create fire stops, openings for light and air and various other physical products which have value. These examples of jointness do not appear to weigh heavily in the usual allocation of cost to non-users. Moreover, the physical by-products of highway development do not appear to play a significant role in decisions concerning expansion and contraction of the plant. On the whole, highways are built for actual or potential highway use and little more. It appears that the physical by-products of highway development do not provide an important basis for a non-user share. On the other hand, these elements should be considered, especially when street programs are affected by plans for municipal redevelopment.

**Joint Demand**

Joint demand arises when one individual gains or receives benefit from the consumption of another. Economists describe such phenomena as "external economies." A person who provides for the physical protection of his own property also provides indirectly for the protection of his neighbors' property. Similarly, a farm to city highway which is constructed and paid for by farmers indirectly benefits merchants, landowners and others located in the city. Although the farmers will use the road, others stand to benefit from that use. Since only farmers use the road, costs may be allocated directly to farmers. The question that arises relates to the circumstances under which downtown merchants and others would (or should) subsidize the farmers' use. In view of the fact that downtown merchants receive many and varied benefits, it may seem "fair" that they share the road bill. This notion of justice, that is, the benefit theory of taxation, might lead to an initial allocation of cost between users and non-users. In addition to being incorrect technically, such an allocation requires a considerable amount of research time and cost. A far better approach would require attention to these questions: (a) Is it necessary to subsidize the user? (b) Is it "fair" that indirect beneficiaries shoulder a part of the bill? The first question can be evaluated in terms of objective standards; the second requires the adoption of a standard of justice.

**SUBSIDY TO THE USER**

Figures 1-3 depict the user-non-user relationships relevant to highway finance. In order to simplify the presentation, it is assumed that: (a) highway cost varies directly with some unit, say vehicle-miles, (b) there is only one class of vehicle, (c) highway service is produced under conditions of constant average and marginal cost. Another simplification is made by employing straight lines for the demand curves of individuals. These assumptions and simplifications do not affect the generality of the graphical presentation. Three situations are presented: (a) No indirect benefits of highway use; (b) Indirect benefits which require a non-user share, and (c) Indirect benefits which do not require a non-user share.

**No Indirect Benefits**

In Figure 1 the horizontal axis measures vehicle miles, $M_c$ represents the price or marginal cost, $D_a$ represents the demand of individual A for highway use. $D_a$ depicts the quantities of vehicle miles that individual A will purchase at each of a series of prices. If there is no indirect beneficiary, the charge is $P$, and individual A pays the entire highway bill. The total payment made by A is shown by the area OQRP. The proper procedure, to be described in a subsequent section, requires that user tax rates be established in accordance with market or price standards.

**Indirect Benefits Which Require a Non-User Share**

Figure 2 represents the situation when individual B is a non-user who receives indirect benefits because of individual A's use of the highway. Individual B may represent
a downtown merchant, real estate promoter or some governmental agency which has an interest in encouraging highway use. It is important to note that indirect benefits accrue to B only if the highway is used. The mere existence of a highway does not create indirect benefits, although it does create the joint products previously described. Individual B, the non-user who receives indirect benefits, also has a demand for travel between the same two points as individual A. As a non-user, however, B does not use the road directly. The demand, \( D_b \), of the non-user is for A's direct use of the highway. Both demands may be measured along the same horizontal axis because both demands relate to the same unit of service. Figure 2 might represent the relationship between farmers and downtown businessmen. If the current price is \( P \), and the individuals do not (or cannot) take their interdependence into account, A will purchase \( Q \) vehicle miles. Since B is a non-user he can purchase none. In recognition of the interdependence, however, B may offer a subsidy to encourage A's use of the highway. Individual B has already received a windfall in the form of indirect benefits because he would have been willing to pay a price \( P_a \) for each vehicle mile that A has traveled. This windfall is depicted by the area \( OQSPQ \). Indeed, B stands to gain if he offers to subsidize A's purchase of another vehicle-mile. Individual A is willing
to purchase an additional unit at a price slightly below \( P \), while the value of an additional unit to B is a positive quantity slightly below \( P_a \). Assume that B offers an amount \( U \) to individual A in order to encourage A's use of the highway. With this offer, the price of an additional unit to A is \( P-U \), and A will increase his purchases to \( q \). Individual B will increase the subsidy offered as long as additional units are forthcoming at a subsidy per unit below his demand price for those quantities. Similarly, A will continue to purchase additional units until quantity \( Q' \) is reached such that his (A's) demand price for \( Q' \) plus B's subsidy offer (B's demand price for \( Q' \)) become equal to \( P \), the going price. The equilibrium is depicted by point \( M \) where the respective contributions of A and B toward the purchase of \( Q' \) are \( P_a \) and \( P_b \) (\( P_a + P_b = P \)). The total amounts paid by A and B are depicted by the areas \( OQ'WPa \) and \( OQ'V PB \), respectively. It should be noted that the user charge is below marginal cost reflecting the general or social desirability of increased highway use.

Other points like \( M \) could be determined by assuming a different market price. This series of points determines the joint or collective demand \( (D_c) \) for highway use. \( D_c \)
can be constructed directly by a vertical summation of $D_a$ and $D_b$. When the economics of the market place is considered, the demands of individuals are summed horizontally (6). However, when a service yields indirect benefits it takes on a "public" or "collective" character because all individuals demand the same physical product. Police protection, national defense and many other programs instituted in the public interest may be conceptualized through a vertical summation of individual demands. The procedures employed in Figure 2 were set forth originally in Sweden by Wicksell and Lindahl and have been developed recently in the United States by Howard Bowen (7) and Paul A. Samuelson (8). Implicit in the solution is a "neutral" theory of taxation reflecting the voluntary choices of individuals in a collective context.

The allocation of shares depicted in Figure 2, is akin, but not identical, to the traditional allocation of cost between users and non-users. Actual determination of the non-user share poses significant problems of measurement. The subsidy will not be offered by the non-user unless it brings about increases in A's use of the highway. That is, if a subsidy offer in the form of a non-user share would result in no or in negligible change, the subsidy is superfluous and charges for the road are assessed against the users of the road. Although the downtown merchant may benefit from the use of the road, it does not (on economic grounds) follow that he should defray part of the cost of the farm to city system. It is almost certain that rents and windfalls of various sorts will accrue to many individuals. The inclusion of these elements in the highway financial structure may lead only to a redistribution of income from those receiving windfalls to highway users. However, if aims are to be given, there may be others who occupy a higher place on our scales of preference.

Silence on the part of indirect beneficiaries is evidence that the indirect benefit is of a surplus character and does not have to be considered in a framework of economic efficiency. If the subsidy is required, businessmen and others will exert pressure on the legislature or the highway authority to provide expanded facilities. As a general rule, collective or political action of some sort will be required. The task of the highway analyst is to reconstruct the pressures and the collective action. The highway financial analyst receives an expenditure program along with the record of legislative and executive hearings and other evidences of collective action. The program is a result of traffic studies initiated by the highway authority and the views of various non-user groups which are affected. A scrutiny of the program and the hearings may indicate the indirect benefits which ought to play a role in highway finance. By inference, the highway analyst can attempt to reconstruct relationships involved in the collective action and within wide limits may be able to determine appropriate payments. Before him are always the following questions: (a) Does this group or individual receive an indirect benefit? (b) If so, is a payment by the indirect beneficiary a necessary condition for receipt of this indirect benefit? (c) What is the minimal amount that he would have to pay to bring about a situation that yields this amount of benefit? The problems are difficult, but not insurmountable. Although perfection may be impossible, it is felt that the approach suggested is superior to the broad and often illusory conception of indirect or "social" benefits so frequently brought into highway financial analysis. Moreover, the opposite extreme of overlooking indirect benefits entirely is avoided. At least a few
Indirect Benefits Without a Non-User Share

Figure 3 represents the situation when there are indirect benefits which have no significance unless a standard of tax equity is adopted. The horizontal summation of $D_a$ and $D_b$ yields the collective demand, $D_c$. At price $P$, both $D_c$ and $D_a$ yield a quantity $Q$. At output $Q$ the demand of $B$, the non-user, for additional increments of traffic is zero. An increase in traffic beyond $Q$ does not yield any additional advantages to the indirect beneficiary. No subsidy is offered and $A$ pays for the highway. The shaded area in Figure 3 represents a windfall or rent which may or may not be extracted from the indirect beneficiary depending on equity. These rents and windfalls, of course, would provide an excellent source of revenue for redistributive purposes. However, the notion that "like things should be treated alike" along with principles of tax equity such as "neutrality" or "reasonable classification", imply that rents and windfalls associated with the highway function should be treated in the same manner as any other rents or windfalls. On administrative and opportunistic grounds, the case for the extraction of such rents is much stronger. For example, the uncapitalized rents associated with a new highway program are easy to measure and in this writer's opinion represent an excellent source of general tax revenue. This opinion is based on opportunistic and administrative grounds coupled with a notion about justice. However, such opportunistic taxation should not be related to the highway tax structure without first assessing the implications of reducing the share assigned to users.

Perhaps the most significant practical conclusion is that the traditional allocation of cost between users and non-users is primarily a response to an administrative problem. However, the proper place to consider administration is after costs have been allocated, not before. The first step in highway financial analysis should establish the cost of highway use. If the "socially" desirable amount of highway service (depicted by $D_e$) "clears the market" at a cost-determined price, a non-user share is not required. If the "socially" desirable amount does not "clear the market", highway use must be encouraged through subsidy in the form of a non-user share. Equity may also call for a non-user share; this requires evaluations concerning the distribution of income. Although the attainment of equity is desirable, it does not provide a principle for the determination and allocation of highway cost. The practice of incorporating either a "benefit" or "ability to pay" theory of taxation within the analytical framework of cost allocation may serve only to reduce the amounts assessed against users, and could lead to an unwarranted subsidy disguised in the form of a "scientific" allocation of cost. The result might well be a misallocation of resources and traffic in the domestic transportation system.

HIGHWAY PRICING

It has been suggested that the determination of prices for the use of highways ought to be the first, not the second, step in highway financial analysis. In the abstract, the appropriate price is found at the point on the theorist's marginal cost curve which corresponds to the quantity of service taken. Theoretical marginal cost curves are interesting analytical tools, useful in demonstrating the principle, but of little help in applications. The ensuing discussion deliberately eschews the traditional theoretical machinery in favor of an applied interpretation of the marginal cost standard.

Marginal cost has been defined as the difference in total cost at two consecutive levels of output (9). Alternatively, it is the cost which could be avoided if an additional unit, block of units, or class of units were not produced. According to James E. Buchanan (10), there are two components of marginal cost relevant to highway finance: (a) The direct marginal money cost imposed by a user and (b) the indirect additional burdens imposed on other users, that is, delays and inconveniences associated with congestion. Direct marginal money cost is "that portion of total maintenance costs which vary directly with road usage." Indirect or "real" marginal cost cannot be translated easily into a money equivalent. Employing this two-pronged conception of marginal cost, Buchanan concludes that:
1. Secondary road users who cause little congestion should be required to pay less per ton or vehicle mile than primary road users.

2. Heavier and larger vehicles should be charged higher rates than lighter and smaller ones because both the direct and indirect components of marginal social cost are greater.

3. Slower vehicles which add more to congestion should pay higher rates than faster vehicles.

4. Vehicles known to travel more during congested time periods should be charged higher rates. Higher rates should be charged on week-ends and holidays and during rush hours.

One difficulty with Buchanan's conception of marginal cost is the assumption that maintenance cost is the relevant marginal money cost. This eliminates construction expenditure from the purview of the highway price structure. Although the cost of sunk, fixed or previously committed resources is not marginal (11), it does not follow that construction cost is without significance to highway pricing (12). Expansion and contraction of the highway plant through variations in construction expenditure is a daily occurrence. Although such expenditures become sunk costs, new construction expenditures are continually being made and, therefore, are marginal. To have any real significance, marginal cost must refer to those resources which are currently available for other uses and which management may or may not choose to appropriate. In a similar vein, Lerner maintains that marginal costs "are costs the incurrence of which is in question" (13).

"Costs the incurrence of which is in question" are found in the program or plan of the authority. The program is continually in question and represents both production and planning (short and long run) costs; it does not include costs that have been incurred previously. If the program is well conceived, it is geared as evenly as possible to the demand that is expected to present itself at a series of future dates. If the demand develops as anticipated, the highway plant will operate as near to the optimum as possible. From time to time the program will be revised in response to changes in the outlook, and program cost will either be increased or decreased. If demand declines and additional construction is not required, program cost will decline to the level of maintenance; if demand increases, program cost will increase so as to include the cost of added capacity.

The difficulty with program cost is obvious. It is a valid interpretation of marginal cost only on the assumption that the program refers to an optimally adjusted plant. This assumption may be questioned. Particular roads or the system as a whole may be characterized by congestion (excess demand) or under-utilization (excess supply). In the event of under-utilization, additional traffic can be handled at a very low additional cost. On the other hand, congestion creates a situation which is characterized by high marginal costs some of which are exceedingly difficult to measure. Such conditions may arise because of (a) short run or temporary excess supply or demand (b) indivisibilities, that is, the physical impossibility of adjusting the plant and (c) peak load. Although these conditions are closely interrelated, each may call for a particular kind of price policy.

Before examining these situations it may be helpful to distinguish between "temporary" and "permanent" indivisibilities of the highway plant. Temporary indivisibilities are those that can be eliminated by increases or decreases in demand or supply. For example, additional lanes are added in anticipation of the demand a few years hence. There is excess supply of a temporary nature because of the inability to make frequent and small adjustments. Permanent indivisibilities appear on secondary roads. Typically, such roads have excess supply because of an inadequate demand coupled with the fact that roads must have certain minimum design features to withstand the elements and to provide a reasonable minimum quality of service. In the ensuing discussion, permanent indivisibilities (secondary roads) are treated separately. However, temporary indivisibilities are treated as a short-run maladjustment.

**Short Run Excess Supply or Demand**

If there were no peak load problem or permanent indivisibilities, excess supply or
excess demand could be removed through appropriate adjustment of the plant. However, the plant cannot be adjusted immediately. An attempt to eliminate congestion or excess capacity immediately through price variations involves difficult administrative problems. Moreover, it is possible to maintain that price discipline is not a necessary condition for effective short run utilization of the highway plant. An adjustment to temporary excess capacity or congestion occurs more or less automatically because traffic has a tendency to distribute itself so as to reflect marginal real cost. Congestion raises real cost to the motorist; excess capacity reduces such cost. The motorist, in reducing real cost, will attempt to select that time and route which has the lower marginal real cost. Of course, this automatic adjustment for excess capacity and congestion is limited, especially in rural areas, by the number of alternatives available to motorists. Another aspect of this adjustment is the fluctuation in user tax earnings. If user tax rates are established on the assumption of optimal operations, congestion will result in "profits" to the highway authority while excess capacity will lead to "losses." The accumulation of profits may be interpreted as a reflection of rising marginal cost while the incurrence of losses may reflect declining marginal cost.

The adjustment described above may also be interpreted as a reflection of the intimate relationship between the volume or density of traffic and the quality of service. Although rates are not varied, the motorist receives a lower quality of service on a congested highway and a higher quality of service on a highway which has excess capacity. The effect is much the same as that which would be obtained if the quality standard were maintained and price variations were used to adjust the volume of traffic. Instead of price variations, the adjustment may occur partially through quality variations which are "built-in" to the system.

In passing, another implication should be noted. The addition of a vehicle imposes additional "real" costs on other vehicles, although the additional money outlay of the highway authority is quite low. These "real" costs may be measured by considering the impact of the vehicle on the "practical" capacity of the highway. Practical capacity has been defined in the Highway Capacity Manual (14) as: "the maximum number of vehicles that can pass a given point on a roadway or in a designated lane during one hour without the traffic density being so great as to cause unreasonable delay, hazard or restriction to the drivers' freedom to maneuver under the prevailing roadway and traffic conditions." Every diminution of available capacity can represent an increment of cost imposed on other vehicles. Thus, the marginal cost imposed by each vehicle is a function of vehicles inconvenienced or even displaced (reduction in capacity). Since every vehicle is marginal, prices could be established on the basis of relative capacity utilized on the assumption that the more capacity utilized by a particular vehicle, the more the practical capacity is reduced. The capacity approach provides a means for translating real cost into money cost. However, if the road is capable of handling additional traffic, without any impact on practical capacity, the marginal cost can be no greater than that portion of maintenance cost which varies directly with road use.

The burden of the argument is that highway users who do not bear the brunt of high marginal costs in terms of higher user tax rates must still bear real cost in terms of delay, inconvenience and frustration. A policy of maintaining rates at the program cost level has more to commend it than the argument of administrative feasibility. Although more refined rate variations in response to temporary excess supply and excess demand would be difficult to administer, it may be desirable in some instances to add price discipline to the "built-in" adjustment already described.

Permanent Indivisibilities

Frequently it is impossible to adjust the highway plant to the demand for its use and there is a permanent condition of excess capacity. None of the possible adjustments described in the preceding section can be made. Marginal cost on a lightly traveled road is well below the unit program cost for that road. However, the marginal cost argument for low rates is not especially strong as the demand for such roads probably is relatively inelastic; therefore, the excess capacity cannot be removed through in-
creases in traffic brought about by low marginal cost prices. Nevertheless, a formal adherence to the pricing standard requires low rates for lightly traveled roads.

Marginal cost pricing requires that secondary roads having excess capacity be operated at a "loss." In a sense this offers an excellent theoretical rationalization for a non-user share on secondary roads. The question of "losses" due to marginal cost pricing has been discussed by many writers (15). One solution to the problem is the "two-part" tariff (16). Under this proposal the consumer pays a low marginal cost price at the time of purchase. In addition, lump sum charges independent of use are employed to cover the losses that arise. An application of this idea to highway finance leads to a lump sum tax not to exceed the value-of-service to the user, combined with a low user charge based on marginal cost. The gasoline and weight distance taxes are appropriate candidates for the marginal rate while license taxes, driver's license fees, property taxes on automobiles, special assessments against those abutting property owners who use the road and many others appear to be suitable for the lump sum charge. It is felt that license taxes and driver's license fees are best suited for this purpose because their purchase is voluntary. Thus, the payment does not exceed value-of-service. Of course, this does not preclude the use of any other lump sum tax provided it is paid by the user and does not exceed value-of-service.

**Peak Loads**

Elimination of peak load does not involve conceptual problems that have not been described by Buchanan and others, but application to highways does involve significant administrative problems. Although there are opportunities for peak load pricing that ought to be examined by highway administrators, it is likely that the general problem is solved as well as it can be by the "built-in" adjustment. Motorists do not drive headlong into congestion unless their demand is highly inelastic; if possible, they tend to arrange their affairs in order to avoid the traffic. Reasonable rate differentials probably would have little impact on the peak load problem, although other solutions of a more general nature are possible, e.g., subsidized transit systems. In reaching this conclusion relative to the peak load problem, it is not implied that peak load pricing should be abandoned. In some instances, appropriate peak load price policy of the sort advocated by Buchanan might result in a more effective utilization of the highway system. The problems relative to peak load are administrative, not conceptual.

**THE FRAMEWORK OF APPLICATION**

It has been suggested that a highway user tax structure consistent with the marginal cost standard might be based on program cost. Temporary congestion and excess capacity are eliminated partially by a "built-in" adjustment described earlier. If such conditions persist for any length of time, they will have an impact on program cost and will lead either to higher or lower rates until the plant is adjusted. If it is practical, a system of peak load and short-run prices may be incorporated into the financial structure. Modifications for lightly traveled roads which have high average program costs but low marginal costs are also required. After all adjustments have been made, the revised price structure may deviate considerably from the initial price structure based on program cost.

The basic element in the establishment of the price structure will be an incremental allocation of program cost. The usual incremental cost allocation involves a direct assignment of special cost to vehicle classes along with an apportionment of common cost among all vehicles. To have empirical validity, these cost assignments usually are based on engineering design criteria. These "design-cost" assignments or "cost responsibilities" must be converted into economic cost-price relationships. Finally, cost-price relationships must be combined with administrative relationships in order to provide a workable solution. The problem is largely one of arranging various categories into a single framework that integrates the factors impinging on the total highway program. The relationships that shall be considered fall into three classes:

1. Design-Cost—Cost of supplying highway services determined from highway design criteria.
2. Cost-Price—Prices for highway services determined in accordance with the marginal cost criteria.
3. Price-Administrative—Collection of prices in accordance with administrative criteria.

**Design-Cost Relationships**

All variations in highway design due to variations in either traffic volume or to the size, weight and performance of vehicles can be related either to pavement requirements or to geometric design. Pavement design refers to pavement characteristics—surface, base and subbase; geometric design deals with length, width, curvature, gradient and alignment. Fundamentally, the geometric design of a highway is a function of (a) the volume of all classes of traffic, (b) the dimensions and speeds of vehicles and (c) the quality of service (speed, ease of driving, risk, etc.) that has been selected. Assuming given soil and weather conditions, pavement design is a function of the axle load of vehicles and, possibly, of the number of repetitions of the axle load (volume of particular weight classes of traffic).

Volume relationships relevant to the geometric design have been established by studies of highway capacity (14). These relationships are not so "lumpy" as one would suppose. When a two-lane highway becomes congested, the jump to a four-lane highway is not inevitable. The two lanes may be widened, grades and curvature may be reduced and many other elements of geometric design may be varied in an attempt to adjust the geometric design to the traffic. Of course, the possibility of adjusting the plant on the drawing board is a different problem from adjusting the plant in an economic sense. Moreover, the possibility of making adjustment in the geometric design is severely limited with regard to facilities which carry a very low volume of traffic because of the minimum design form necessary to provide a reasonably satisfactory service.

Volume or quantity relationships for pavement thickness are not as well established as those for geometric design. The pavement thickness, for example, may be affected by the number and frequency of repetitions of a particular axle load. However, pavement design does not consider this relationship in a manner such that a definite relationship between number of repetitions and pavement thickness can be determined (17). The chief difficulties in isolating weight related pavement costs appear in the low-volume roads which are not designed for "infinite" repetitions of a maximum permissible axle load (17). As a result of these problems, different methods and a considerable amount of judgment are required in order to isolate weight-related costs for a highway system having both high and low volume roads. In order to simplify the discussion, it will be assumed that the system of highways is composed of two classes of road each designed in accordance with the following standards, limitations and assumptions:

1. Primary or high-volume roads are designed for an infinite number of repetitions of a legally permissible maximum axle load. Incremental weight costs can be calculated and assigned to the various weight classes using the road (18).
2. Secondary or low-volume roads are designed to the higher of two standards: (a) to withstand the elements over a given period of years or (b) to withstand the maximum axle load which appears with a sufficient frequency to affect design standards. Secondary road pavements are capable of handling mixed traffic in proportions that are not known. Provided they appear in "limited" numbers, heavy vehicles do not impose measurable incremental weight costs (17).

It should be noted that these standards, limitations and assumptions will vary depending on the state of engineering knowledge. Although a more sophisticated series of design relationships could be derived, those that have been presented are sufficient for the analysis which is to follow. It is also worth noting that geometric design creates highway capacity while pavement thickness creates the ability to bear loads. Since highway capacity is created on behalf of all vehicles, geometric design may be interpreted as imposing only common cost. Interpreted in this manner, the geometrics of the extra foot or two ordinarily associated with truck traffic is a common, not a special cost, because the additional capacity is available to all vehicles. If the available highway ca-
pacity is either increased or decreased, the conditions under which all vehicles operate are changed because of the effect on congestion. This does not hold for pavement thickness which imposes special cost. The removal of an increment of weight or axle load (size, speed and volume of traffic remaining constant) reduces highway cost, but does not affect the conditions under which all vehicles operate.

Assuming that the pavement of primary highways is designed to withstand "infinite" repetitions of a maximum axle load, the marginal cost of pavement is zero because the addition of one more vehicle does not increase the total cost of pavement. On the other hand, if a continuous relationship is established between the numbers (and frequency) of a particular axle load and the pavement requirement, marginal pavement cost can be determined by evaluating the impact of an additional vehicle on the pavement thickness requirement. The ensuing discussion proceeds on the assumption that a continuous relationship between repeti­tional loading and pavement thickness has not been established. However, the implications of this possible relationship will be noted in the course of the discussion.

With this background it is possible to establish a series of tentative relationships around which a system of highway finance may be constructed. The relationships described below are of two sorts—geometric and pavement; they are deduced from the assumed criteria for highway design.

A. Geometric Relationships

1. Geometric design provides capacity.
2. Capacity is utilized by all vehicles. Therefore, geometric design imposes common cost.
3. Changes in geometric design create marginal costs which do not include incremental (special or weight-related) pavement costs.

B. Pavement Relationships

1. Specific or finite changes in volume of traffic are not considered in the determination of the pavement structure.
2. Because of "infinite" design, the marginal cost of pavement structure is presumed to be zero on primary roads. However, large increments of pavement can be assigned to all weight classes below the legal maximum on primary roads.
3. Increments of pavement structure cannot be assigned on secondary roads where heavy vehicles appear in "limited" numbers. Insofar as design is concerned all costs on such roads are common costs.
4. The pavement structure (but not the geometrics) of a secondary road is equivalent to the pavement structure of a primary road designed for the same weight class of traffic.

These relationships provide the basic ingredients in the development of a marginal cost system of highway finance. By relating the system to highway design, the problem is placed in an empirical or applied setting.

Cost-Price Relationships

The starting point in an analysis of cost-price relationships is the segregation of special pavement cost. One may assume that this special item has been segregated in accordance with the usual incremental cost procedure. With the elimination of special pavement cost, the simplified highway network under consideration is designed for a single weight class of traffic, although it still considers differences in dimensions and speeds of vehicles. The pavement is designed either to withstand the elements or to withstand infinite repetitions of the first or lightest vehicle class. With this "basic" structure, the limits which have significance to both design and economic analysis are geometric in nature. These geometric relationships have a special significance to highway pricing.

The marginal cost basis for the allocation of common or geometric cost by evaluating the impact on practical capacity was described earlier. An additional increment of traffic on a fully utilized facility diminishes its practical capacity and requires improve-
ments in the geometric design. Since every vehicle is marginal, marginal cost is the cost of improving the geometric design, that is, adding capacity. Capacity relationships are ideal for marginal cost pricing. The elimination of one unit provides capacity for all other units; the addition of one unit displaces others. Marginal cost of a particular use can be determined by evaluating these displacements.

It appears that data are available for establishing prices consistent with the view that has been presented. According to the Highway Capacity Manual (14): "approximately the same operating conditions will prevail on an expressway through rolling terrain when there are 1, 500 passenger cars per lane per hour as when there are 115 trucks and 1,040 passenger cars per lane." Thus, 115 trucks displace 460 passenger vehicles. In this particular case, passenger vehicles are responsible for about two-thirds (1,040/1,500) of total common (geometric) cost, while commercial vehicles are responsible for about one-third (460/1,500). This is an "opportunity cost" basis for the determination of marginal cost. The addition of a single commercial vehicle displaces capacity for four passenger vehicles. Such ratios are available in the Highway Capacity Manual which lays the foundations for the marginal cost pricing of highway services. In addition to the common costs described above, commercial vehicles will receive an assignment of special pavement cost to be defrayed either through lump sum or use taxes depending on the relationship between pavement thickness and number of repetitions of the axle load.

There are many elements of cost that are not considered in highway design. Thus, design provides almost no empirical basis for the allocation of cost of administration and maintenance. However, these costs may be either special or common and they may or may not vary with incremental additions of traffic. To the extent that these costs do vary with traffic, they may be added to the marginal costs implied by design criteria in order to arrive at a total price to be charged on the basis of use. To the extent that they do not vary with incremental additions to traffic, marginal cost is zero and "losses" will have to be covered through lump sum taxes.

The relationships described above do not hold when there is a significant amount of under-utilized capacity. In such instances an additional vehicle will have no measurable impact on the practical capacity or design of the highway. However, it might be held that any increase in traffic imposes marginal "real" costs on other traffic even if it does not affect highway design or practical capacity. Since workable distinctions of this sort are difficult to maintain, the ensuing discussion of secondary road finance adheres to a money cost interpretation.

The determination of marginal money cost on secondary roads which have excess capacity raises difficult problems. An additional vehicle has no impact on highway design, although it might have some impact on maintenance. In short, marginal cost is far below design cost. Although marginal cost would be exceedingly difficult to calculate in such situations, adherence to the pricing standard requires that these roads be operated at a "loss". An examination of applied marginal cost pricing proposals reveals that the so-called two-part tariff includes a variable or marginal charge based on operating expense (maintenance cost) and a fixed charge based on overhead (19)

Strictly speaking, maintenance expense is not a marginal cost. But this seems to be the only interpretation of marginal cost that can be applied realistically in excess capacity situations. A more satisfactory term for this concept is "out-of-pocket" cost. All serious attempts at realistic applications of the marginal cost standard rely on the out-of-pocket concept. This is not acceptable under increasing cost situations, but it probably comes close when there is obvious permanent excess capacity. One now has two crude, but workable, marginal cost standards for two types of road. These are summarized below:

1. Program cost (exclusive of special weight cost) represents an approximation to primary road marginal cost. If the road is fully utilized, this cost may be allocated among vehicles on the basis of the proportion of capacity utilized by each vehicle.


The two standards suggested above determine two extreme points on the traditional marginal cost curve; one for a "high" volume road, the other for a "low" volume
road. Highway financial analysts are not without experience in "smoothing out" or "filling in" the missing links. Meanwhile, the discussion is based on the extremes. It is necessary now to consider the pricing criterion to be employed for vehicles which impose special pavement costs. The special weight cost applicable to a given weight class is a common cost with respect to the vehicles in that class and other heavier weight classes. On the assumption that these weight costs do not vary with the number of repetitions of load there is no justification for penalizing additional use of these pavement increments. Insofar as the marginal cost standard is concerned, the use of such increments by heavy vehicles should be encouraged through low prices. (Of course, any encouragement that this might offer for increased use of the highway may be offset by the impact of additional heavy vehicles on congestion, that is, geometric requirements.) Pursuit of a low or zero price policy for the pavement component would involve "losses" due to economical or marginal cost pricing. These losses would be equal to special pavement cost. If the service is to be continued, beyond the design life of such highways, these losses must be recouped. The losses on each increment may be recovered from the operators of the heavy vehicles requiring such increments, through the use of lump sum charges.

These conclusions concerning pricing for special weight increments do not hold if a relationship can be established between number of repetitions of axle loads and pavement cost. If pavement cost is a continuous function of number of repetitions, an additional vehicle will impose additional pavement cost and a price based on use should be employed. It seems possible that a relationship might be established between special weight cost and axle miles. In this event, the axle-mile standard for the inter-class allocation of special pavement cost might be appropriate. This appears to be the current practice. This is an interesting example of the relationship between the state of engineering knowledge and highway pricing. The assumption of "infinite" design leads to lump sum taxes while the assumption of "continuous" design leads to prices which vary with use such as axle-mile or ton-mile taxes.

Tentative Price-Administrative Relationships

The usual procedure in establishing the highway user structure involves the calculation of a "bill" (cost responsibility) for the motorist. Once cost responsibility is calculated, various taxes and tax rates are adjusted so that this amount is collected from each user. In attempting to administer the system of highway finance without toll gates, one may take advantage of any fortuitous relationships that will further his purpose. The ensuing discussion suggests two possible price-administrative relationships that do not have as strong a foundation as the design-cost and cost-price relationships. Nevertheless, the relationships that shall be suggested appear to have enough validity to qualify as tentative hypotheses awaiting empirical verification. The two price-administrative hypotheses are:

1. If there is but one weight class of vehicle, a single price for the use of both primary and secondary systems is more likely to conform to marginal cost principles than to full or average cost principles, that is, cost responsibility.
2. Gasoline consumption provides as adequate a measure for pricing in accordance with capacity utilized as can be had without the use of toll gates or elaborate reporting devices.

To evaluate the first hypothesis one may recall the two pricing criteria established in the cost-price section. These are: (a) Marginal cost on the primary system is determined by unit program cost, and (b) marginal cost on the secondary system is determined by unit maintenance cost. Unit program cost on the secondary system is considerably above unit program cost on the primary system. However, average maintenance cost on the secondary system is considerably below unit program cost of the secondary system. Thus, unit program cost on the primary system may have a closer relationship to unit maintenance cost on the secondary system than to unit program cost on the secondary system. If one translates theoretical cost curves into metaphor, this involves saying that the marginal cost of a small plant operating with excess capacity is likely to have a closer relationship to the marginal cost of an optimally operating
large plant than the average cost of the small plant has to the average cost of the large plant. This relationship assumes that average cost declines over the range embracing the small and large plants. A graphical demonstration is not necessary to grasp the nature of the relationship between the average and marginal costs of small and large plants operating under conditions which involve a large proportion of fixed costs. This possible relationship between the two marginal costs provides a means for rationalizing the administrative problem. If it is hypothesized on the basis of the possible relationships described above that the two marginal costs are roughly equal, it follows that a single price can be charged for both primary and secondary roads in the absence of heavy axle loads.

The second hypothesis is suggested by a proposal set forth by Leland James (20). Although James' figures and theory have been questioned (20), no one appears to have disputed the existence of the gasoline consumption-capacity utilized relationship. A comparison of relative gasoline consumption and space occupancy ratios indicates that this relationship might have considerable validity. An empirical test is not attempted in this paper, although the design for such a test involves no difficulties. In order to demonstrate the possibilities, it shall be adopted as an hypothesis for administrative purposes. In addition to providing another possible tool for marginal cost pricing, gasoline consumption makes possible a significant analytical short-cut. If the relationship between gasoline consumption and capacity utilized were "perfect", the common (geometric) cost of primary roads would not have to be apportioned directly among vehicles. After special pavement cost is assigned, the task would be completed by establishing a gasoline tax rate such that gasoline tax "earnings" on the primary system would cover its common cost. It seems that there is a good possibility of achieving two ends in one maneuver: (a) Establish marginal cost rates and (b) obviate the calculation of total cost responsibility for each vehicle. Only special cost responsibility would have to be calculated. Moreover, if marginal pavement cost is presumed to be zero (because of "infinite" load bearing capacity), the problem resolves itself into the determination of a gasoline tax and the establishment of a system for recovering losses through lump sum taxes.

SUMMARY OF TENTATIVE RELATIONSHIPs

It is now possible to bring the relationships that have been developed into a complete, albeit speculative, system of highway finance and administration. The more important relationships are:

A. Design-Cost Relationships
   1. Changes in geometric design create measurable marginal costs.
   2. Changes in pavement thickness create special cost.
   3. The pavement structure (but not the geometry) of the secondary system is equivalent to the pavement structure of the first increment of the primary system.

B. Cost-Price Relationships
   1. Price should be established at the marginal cost level.
   2. Common (geometric) cost may or may not be significant to highway pricing depending on the amount of capacity available. (a) If there is under-utilization, the economic cost of providing additional service is below the design-cost of providing additional capacity. Maintenance cost represents a reasonable approximation of marginal cost. (b) If there is full utilization the economic cost of providing additional service is at least equal to the design-cost of providing additional capacity. Program cost is a reasonable approximation of marginal cost for applied purposes.
   3. Marginal cost of special pavement structure may be either zero or some positive quantity depending on the limits of engineering design.
   4. Losses due to marginal cost pricing must be recovered from users in the form of lump sum taxes not to exceed the value of service.
C. Price Administrative

1. If there is but one class of vehicle, a single price charged for the use of both (primary and secondary) facilities is more likely to conform to marginal cost standards than to full or average cost standards.

2. Gasoline consumption provides as adequate a measure for pricing in accordance with capacity utilized as can be had without the use of toll gates or elaborate reporting devices.

It is important to note that the relationships are integrated. Highway design, price theory, and financial administration are now parts of a single model. The three sets of relationships described above may be arranged in whatever manner appears to suit the institutional fabric and may be extended, refined and validated through further research and testing. It is felt that they represent a reasonable application of an abstraction, the marginal cost principle, to highway design, highway pricing and highway administration. In order to demonstrate a possible application of these relationships, a provisional synthesis is offered.

A SYNTHETIC SYSTEM OF HIGHWAY FINANCE

Assume at the outset that special pavement cost, along with the axle loads to which it applies, is isolated (A2). (Notations refer to the relationships described in the preceding outline.) Now, the pavements of primary and secondary systems are structurally equivalent (A3). Uniform rates established at the marginal cost of the primary system will result roughly in marginal cost prices on the secondary system (C1). Now, set the gasoline tax rate so that "earnings" on the primary system cover the common cost of the primary system (C2). The result is approximate marginal cost prices on all systems.

Gasoline tax earnings on the primary system will cover all but special pavement costs of the primary system. Gasoline tax earnings on the secondary system may cover maintenance costs but this is not assured. If the primary road system is congested, "profits" will be earned at the established gasoline tax rate. If highways are provided under long-run increasing cost conditions, revenue yielded at the established rate may prove inadequate for optimal expansion. In this event, (a) the gasoline tax rate will have to be raised or (b) "intolerable" conditions may persist until an adequate surplus is accumulated. If there is persistent excess capacity on the primary system, losses will occur and the plant must be contracted. Secondary roads will incur losses because of permanent excess capacity. The amount of secondary road losses will be the difference between secondary road program cost and secondary road gasoline tax earnings. Such losses will be large or small depending on the amount of excess capacity. Where marginal cost is lowest, the losses will be greatest.

Regardless of the specific conditions under which they arise, losses due to conformance with the marginal cost standard call for lump sum taxes levied on the user. These taxes cannot exceed value-of-service or the direct benefits accruing to the user. Although any lump sum tax may qualify for this purpose, license taxes are indicated. Their imposition would not interfere greatly with use and they cannot exceed value of service because they are voluntarily purchased. Since primary roads tend to operate under optimal or congested conditions, losses will be incurred on secondary roads where excess capacity is prevalent. Therefore, the license tax on light vehicles may be reserved for secondary road purposes.

Special pavement costs must now be considered. In this simplified system, such costs are incurred on the primary system. The current state of engineering knowledge indicates that the marginal cost of pavement is either zero or some positive quantity. If marginal pavement cost is presumed to be zero, additional lump sum taxes may be imposed on appropriate vehicle weight classes. If marginal pavement cost is positive, axle-mile or other third-structure taxes may be indicated. It is possible that a combination of lump sum and third structure taxes may be required. To a large extent a specific solution to this problem depends on the state of engineering knowledge and on administrative and jurisdictional considerations. To summarize this synthetic system:
Primary road finance relies on gasoline taxes levied on the assumption that all vehicles are of the lowest weight class and on lump sum and/or third-structure taxes designed to recover special pavement cost imposed by heavier vehicles. Secondary road finance relies on gasoline tax earnings for all or a portion of maintenance expense and on local license taxes on light vehicles in order to recover the balance.

SOME SPECULATIONS RELATIVE TO HIGHWAY FINANCIAL POLICY

Assuming that the basic relationships on which the model rests bear the scrutiny of students and administrators, it is interesting to consider some of the possible implications to public policy. If the direct benefits to users exceed the cost of the highway program, a "user pay all" policy can be established. Surpluses, rents and other windfalls may be considered by those responsible for justice or equity in the tax system as a whole. However, as a practical matter the highway analyst may have to make the value judgment concerning the appropriation and disposition of these surpluses. If the direct benefits accruing to users do not exceed the cost of a given program, payments established on the basis of the foregoing principles will not cover cost. This does not imply that the highway system is overexpanded. However, the highway program will have to be reviewed in the light of the indirect benefits which may have played a role in the investment decision, but which have not yet played a role in the financial structure. Appropriate non-user taxes to cover the "losses" due to "social" expansion of the plant may be determined in accordance with the theory of joint demand presented at an earlier point. An appropriately determined non-user share results in an adjustment of user taxes to a level below marginal cost. To economic theorists this represents the adjustment for "external economies" or social value. In this writer's opinion this adjustment would be minimal.

The motorist or truck operator probably will pay a higher price because the bulk of the present non-user share has been eliminated. However, the non-user funds released would be available to finance other governmental programs of a more "general" nature. It is possible that the present non-user share which is devoted primarily to secondary roads will be roughly equivalent to any increase in gasoline or license tax revenue for secondary road purposes. Secondary road users might simply trade one form of tax for another. This study may lead only to a rearrangement of administrative relationships, especially those having to do with the jurisdictional distribution of centrally collected funds. The validity of such a rearrangement ultimately rests on factors other than those with which this paper is concerned. On the other hand, if the present non-user share has led, on one way or another, to a distortion of the primary or commercial rate structure, there is a possibility that the present allocation of resources is inefficient. This raises again the questions of the proper level of commercial truck rates and the propriety of utilizing rents, windfalls, and surpluses for highway purposes. Because such surpluses appear to have been restricted to secondary road finance, it is likely that the impact on the commercial rate structure may have been minimal.

Although some exceptions have been made to the analyses, procedures and techniques that are employed in the establishment of the highway user tax structure, it appears that the highway user tax structure has survived and remains a powerful tool for the attainment of economic efficiency. It is reasonable to agree with Zettel (4) that: "When we consider that user taxation was conceived in expediency, born of necessity and nurtured of politics, it is surprising that the offspring is as healthy and works as well as it does to serve sound economic objectives." The chief concern, however, is not with the decisions that have been made in the past, but with those that are about to be made for the future. A vastly expanded Federal Highway Program has been inaugurated. The means for the financing of this program are still tentative. The Congress and students of highway problems are now awaiting completion of studies undertaken by the Bureau of Public Roads. This will represent the third federal study of highway problems, and like the Coordinator's Report, probably will establish a nation-wide pattern for a host of state and local investigations. The congressional request for investigation and research is broad enough to allow for either a benefits-received or pricing approach to highway problems. If one reads between the lines of the First Progress Report of the Bureau of Public
Roads, it is possible to distinguish some disenchantment with the benefits-received approach and a renewed interest in economic efficiency. The decisions now being made will have an important bearing on the possibilities for the attainment of economic efficiency in the highway user tax structure.

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Use of Economic Criteria for Highway Investment Planning

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Road and bridge building—one of the finest manifestations of man's ingenuity and peaceful, constructive endeavour—is team work par excellence. It represents a most complex productive effort, extending from the gathering of the basic data through the survey and planning work right to the payment of the final bill and to the settlement of the last legal claim. In this process use is continually being made of a great many experts in different fields: of surveyors, draftsmen, location and soils engineers; of highly skilled specialists in the various construction phases; of traffic and safety experts; of appraisers; statisticians, geographers, planners, financial and legal talent; above all of decision-makers throughout.

What part can economic analysis play in this process? This paper attempts to appraise critically some of the basic economic assumptions, ideas, and working techniques which might be used in this intriguing sphere of highway planning and finance. To maintain logical continuity, the discussion follows decision-making in investment planning, step by step, from broad, general issues down to detailed technical problems.

BASIS OF INVESTMENT DECISIONS

A private entrepreneur's decision to invest in a factory or other productive asset will arise from the expectation that such investment will prove profitable. The businessman will carry out the new venture when the anticipated returns from the investment are at least equal to the costs of borrowing the necessary money. Hence, the incentive to all private investment arises from all business men's assessment of the profitability of investment related to the rate of interest on money for investment.

Keynes (1) called the expected profitability of new investment the "marginal efficiency of capital." In this connection "marginal" refers to the returns from producing one more capital asset (the marginal one). Logically, the entrepreneur or promoter, confronted with a whole range of possible new projects, will choose the one which can be expected to yield the highest rate of return over cost. Therefore, the marginal efficiency of capital will denote, at any given moment of time, the highest net rate of return from the most promising of all projects to be found in the entire economy. In ordinary language it might be called the expected annual profit rate on the most promising of all real investments.

It is, firstly, important to appreciate the dynamic nature of Keynes' concept of marginal efficiency of capital and the way in which it provides a link between the present and the future. Many entrepreneurs and potential promoters of capital investment schemes will simultaneously turn their attention to a great variety of ventures. They will, by market research, forecasts or by sheer guess-work, try to foresee the future and the performance of the projects under consideration. They will reject ventures which show a combination of high risk, slow maturing and low returns, in favour of those with the opposite characteristics. In interaction, each entrepreneur individually and all of them collectively will therefore in effect establish a system of project priorities at any given time, with the most profitable venture taking top place and all the others being ranked according to their merits. Investment funds will then be borrowed and the projects carried out until the expected rate of profit from the least profitable scheme equals the rate of interest at which capital can be attracted. In equilibrium, the marginal efficiency of capital, expressed in percent per year, will be equal to the rate of interest on money.

It is important, secondly, also to note the inherent tendency to self-adjustment of this process. The business promoters will compete, as it were, for a necessarily limited number of feasible new projects. The supply of worthwhile ventures at any
time depends on a great variety of technological and environmental factors: for example growth of population and markets, the rate of technical progress and innovation, trends in income, employment and purchasing power. As over time more and more new projects are realized there will be a tendency for the marginal efficiency of capital to decline; but then growth and technological progress may again provide better investment opportunities and hence raise the schedule for the marginal efficiency of capital. On the whole, however, the marginal efficiency of capital will adjust downward to the money rate of interest, itself determined by factors which need not enter into discussion at the moment.

Thirdly, it is important to appreciate the monopolistic nature of the investment planning process. Whatever project the entrepreneur contemplates, it must be something which his competitors cannot emulate, at least not for the time being. The venture may involve the introduction of an entirely new commodity or service, in which case the entrepreneur will attempt to protect his monopolistic position by patents and commercial strategy. If the product or service sponsored by him is not entirely novel, he will at least endeavour to create a 'mental' monopoly, by advertising, introduction of a brand name and so on. In addition he will attempt to build spatial or functional monopolies, by seeking government protection and licensing, supply and sales franchises and exclusive rights within a territory, or by oligopolistic maneuvers.

The net profits that accrue to the entrepreneur or his firm are the result of many heterogeneous factors: gains from risk-taking and uncertainty-bearing; the presence of a favourable market and technological environment; outstanding managerial and organizational ability; and perhaps a good deal of luck, bearing in mind Goethe's maxim that only the able enjoy consistent luck. But always there will be a strong element of monopoly present in the process which determines investment and, in interaction with the rate of interest, the marginal efficiency of capital.

PLANNING OF INDIVIDUAL PROJECTS

A synthesis of the general investment process with the planning of individual projects must now be attempted. In other words, it remains now to describe how a list of worthwhile projects might be drawn up and how the profitability and performance of each one of them might be judged.

Basically, the prospective entrepreneur will select from equally risky alternative ventures, for first consideration, the one with the highest potential net yield. Similarly, he will prefer the least risky one of a number of ventures which promise to yield identical returns over time. This implies that he has knowledge of net returns (that is, gross revenues less costs) over the planning period for a number of ventures.

How can the most profitable combination of price, cost and output for an individual project be achieved? This problem, demonstrated in Figure 1, resolves itself into the process of maximizing the difference between total gross revenues and total costs, in other words maximizing net revenues; if that position is reached then the most advantageous outputs (quantities of goods or services) are also being produced.

On the revenue side, fundamentally, one will have to assume the presence of one very important aspect of monopolistic market strategy: "price discrimination," also called "charging what the traffic will bear," or euphemistically, "differential pricing," the term preferred by A.M. Milne (2) in his excellent textbook on transport economics.

Assuming that this can be done, through market analysis, motivation research or experimentation, the entrepreneur will attempt to assess the potential maximum benefits derived by each user or group of users from the consumption of the new product, and the total quantities of this product provided cumulatively at each point. These benefits can at the same time be taken to represent the maximum differential charges which can be extracted from each user, as long as the basic condition "benefits offered are at least equal to prices charged," is satisfied.

Curve DBM in Figure 1 represents such an assessment of marginal differential benefits and prices charged. It shows that gross revenues will be maximized if total quantities OM of goods or services are supplied and charges identical to the ordinate values of the benefit (marginal revenue) curve DBM are imposed. Total gross re-
venue—which is the integral of the demand function—will tend to become equal to the area under the arc DBM as the number of users approaches infinity.

Is Perfectly Differential Pricing Permissible?

Gross revenues are charges multiplied by quantities; in this case the sum of an infinite number of rectangles, each of a height corresponding to price charged and with an infinitesimally small base representing quantity consumed (Fig. 1). It is sometimes argued that such a rate policy, with infinitely small variations of prices charged, would not only be unethical, but also at least impractical. The latter contention may be true and in the real world it may be more convenient to let rates go down in definite "steps". As a matter of fact, many electric power companies employ rate structures that go down in such steps after certain quantities of consumption are exceeded. But this does not in the least detract from the validity of the revenue maximization formula. The same electric power companies would not hesitate to apply it, were it not for the fact that the extra revenues thus obtained would be more than offset by the additional administrative and organizational expenses of a perfectly variable tariff system. Analytically, one might accommodate this phenomenon by calculating gross revenues net of collection costs. Diagrammatically then a whole series of marginal gross revenue curves would be obtained, one for each pricing system adopted, consisting of a series of "steps" and in the extreme case consisting of a straight line. The one marginal revenue curve which encloses the largest gross revenue area—and hence the one with the greatest number of steps—will represent the best solution.

Very little remains of the other arguments against differential pricing once the moral and emotional disguises have been removed. Of course all economic life is ruled by the supreme rule of "charging what the traffic will bear." It is applied with great vigour on as many occasions as possible by all sellers of goods and services. Whenever feasible it is presented as a price reduction and advertised as "quantity discount," "loyalty discount," "off-peak inducement toll" and the like. Another method would be to vary service qualities, including differing treatment in the granting of credit facilities, while holding direct money prices constant.

Only because generations of economists have been brought up on the quite unrealistic assumptions of pure and perfect competition have we come to regard the uniform market

Figure 1.
price, set at the marginal cost level, as the rule rather than the exception. Partly this has been due, as Schumpeter (3) points out, "...to the specific bias of the economic theorist that has nothing to do with political preference, the bias for easily manageable patterns." One learns slowly that the so-called imperfections, the monopolies, duopolies, oligopolies, are all-prevasive, that advertising, control of entry, licensing, government regulation, brand names, special service features, credit terms, even such market strategy as the opening of a retail store in a particularly favoured location, are all very logical attempts to create little economic "niches" which are sheltered from the chill winds blowing across the desolate market place of pure and perfect competition.

It is very important for the subsequent discussion of specific highway problems to accept the principle of differential pricing (which is really the same as differential benefit assessment), at least as an investment planning tool. A quotation from Milne may give this principle of discriminatory pricing, which is so particularly important in the field of transport economics, some further theoretical respectability: "The phrase 'charging what the traffic will bear' can assume two meanings. First it may mean that prices are to be fixed in such a way that in respect of each traffic carried the maximum revenue is obtained regardless of the particular costs involved. In accordance with this interpretation of the principle no traffic should be charged a lower rate or fare when it will bear a higher rate or fare. The second meaning of the phrase—the meaning which is relevant to our discussion...—can be more conveniently couched in negative terms and can be expressed in the form that no traffic should be charged a price which it will not bear when, at a lower price, the traffic would be prepared to move. When interpreted in this second way the principle may promote a greater utilization of indivisible and fixed resources and may thereby permit indivisible and fixed costs to be spread over a larger volume of traffic. In this way the practice of discriminatory pricing may confer economic benefit, a benefit represented by the fact that transport rates and fares are rendered lower than they would be in the absence of discriminatory pricing (3)."

Further proof how economies can be brought about by differential pricing will be provided in the following sections. (Judging from information contained in studies by Owen and Dearing (4), Dearing (5), Duzan (6) and others, toll roads in the United States appear to apply differential pricing. This point is pursued in detail by Kuhn (7), Chapter IV "Toll Road Model—Final Consideration.")

Cost Analysis and Output Determination

By contrast from the marginal benefit (and differential price) curve DBM in Figure 1, the marginal cost curve ABN requires only brief explanations. Due to the amazing interest taken in the United States in marginal cost pricing (or incremental cost charging) of highway services and the great volume of literature produced on the subject, little needs to be said on the topic.

No significance should be attached to the way the marginal cost curve ABN is drawn in Figure 1; it is assumed here that marginal costs of providing the first few quantities of goods or services are relatively high and that they then fall as economies of scale are reaped or initial fixed costs are spread over a greater number of production units. For purposes of illustration it is further assumed that at very large output quantities marginal costs rise again, due to diseconomies of scale, the bidding up of factor prices and so on. Neglecting indivisibilities of factors of production—(This is a somewhat unrealistic assumption, but the main line of reasoning presented here does not depend on it. The theoretical problems posed by indivisibilities of factors of production, fixed and variable costs, etc. can be resolved fairly easily (9).) —and thus implying that infinitely small additions to output requiring infinitely small incremental cost doses are possible—a smooth marginal cost curve will be obtained.

The most advantageous output to be produced and consumed, from the entrepreneur's point of view, will be determined by the intersection of the marginal cost and revenue curves (at point B in Figure 1) and will be quantity OC. Marginal costs associated with the production of the different quantities of output are identical to the ordinate values of the marginal cost curve. Total costs will tend to become equal to the area
OABC under the curve AB as the number of goods or services supplied approaches infinity.

If the cost and revenue conditions depicted in Figure 1 prevail, the entrepreneur will choose to supply OC quantities of goods or services, since he cannot increase his net earnings by supplying any other quantities of output. At output level OC the extra cost of supplying the additional last, very small increase in quantity of goods or services, is equal to the benefit enjoyed by the additional user of that last unit of output. Since under a regime of "charging what the traffic will bear" price equals benefits, it follows that at output OC the marginal cost of supplying the last unit is equal to marginal benefit derived from that unit, and hence to price.

If this is so, then the optimum position from the entrepreneur's point of view has been reached. If he were to increase his output to (say) OF, the costs incurred by him in order to supply the quantity increment CF would be equivalent to the area CBHF. At the same time additional benefits conferred upon users, and hence charges collected would only be equivalent to CBGF. The loss to the entrepreneur of supplying additional quantities CF would therefore be equal to the area of the curvilinear triangle BHG.

Similarly, if he were to decrease his output by (say) quantity CI he would stand to lose. At output OI the marginal cost of supplying the last unit would be only IK, but benefits conferred would be as much as IL. At output OI his total net earnings would only be equivalent to the area ADLK. Compared with the optimum output OC, determined by the intersection of the marginal cost and marginal revenue curves, the entrepreneur would therefore lose net earnings equivalent to the area of the curvilinear triangle LKB.

While output OC is the optimum one from the entrepreneur's point of view, is it also a logical one as far as the users are concerned? If OC units of goods or services are being offered and consumed no user could possibly be worse off than prior to the operation of the new factory or facility, since benefits will be equal to charges. Users are not compelled to buy the new goods or services and their choice is a purely voluntary one. They cannot be 'overcharged' since the slightest over-all increase of the rate schedule over and above the maximum level of the benefit schedule would presumably induce them all to refrain from the purchase of the goods and services offered.

Is output OC the optimum one from the community's point of view? Will adoption by the entrepreneur of the particular production and investment plans associated with output OC lead to the best allocation of scarce resources within the economy as a whole? It might be argued from a social or community point of view that the entrepreneur, by pursuing ruthless "charge what the traffic will bear" practices, will be reaping excessive monopolistic profits to the detriment of the public. It might be said that the entrepreneur would actually be "underproducing" and hence "under-employing" productive resources, since at outputs larger than OC his total gross revenues would still exceed total costs, and consequently net revenues would still be accruing to him. For example, he might be compelled by government decree to operate, in the public interest, at output level OM in order to satisfy all demands for the proposed goods and services. True, in that case quantities OC to OM would be provided at a loss equivalent to area BMN (the difference between cost area CBNM and benefit-marginal revenues area CBM). But the loss sustained by providing these additional units of production would be more than offset by the excessive profits (equivalent to area ADD) made on the preceding units of output. In other words, it might be argued that the entrepreneur would still be in business as long as the potential loss from providing services to the community at less than cost (area BMN in Figure 1, for instance), was smaller than the net earnings extracted at lower output levels (area ADB).

This line of reasoning, within the framework of the present analysis, must be rejected absolutely. It is most misleading since it introduces different criteria, such as income distribution desiderata, monopoly pricing and control problems which were deliberately not brought into the discussion at this stage. The line of reasoning is primarily directed at the implications and consequences of a regime of "charging what the traffic will bear." It seeks to attack the fact that a potential consumers' surplus (area ADB in Figure 1) is priced away and is turned into a producers' surplus. The argument in the preceding paragraph is thus concerned with the alleged "excessive" size of net earnings or the "unreasonably high" rate of profit accruing to the entrepreneur.
Desirability of Investment Decision

It is important at this point in the analysis to obtain a reliable answer to the question whether or not the entrepreneur or entrepreneurs will plan the investment of productive resources in the most efficient and socially most worthwhile way. It may help to briefly recapitulate the conclusions previously arrived at:

1. In an economy where there is freedom of investment planning, entrepreneurs will promote projects which promise returns in excess of the rate of interest on money for investment. Since ventures which show the highest relative returns at equal risk will logically be selected first, an order of project priorities based on expected profitabilities will be established.

2. This process is continuous and self-adjusting. The entrepreneurs will be 'competing' for the necessarily limited number of investment opportunities, the 'supply' of which is determined by technical innovation and progress, the extent of the market, population and income growth, geographical expansion, etc. The marginal efficiency of capital—the expected rate of return from producing the most promising additional capital asset at any one time—will have a tendency to decline. There will be no more investment once the marginal efficiency of capital falls to the level of the prevailing interest rate.

3. For purposes of project selection entrepreneurs will carry out demand and cost studies for all proposed ventures. Differential charging, made possible by the monopolistic characteristics inherent in the situation, will be applied whenever practicable. Thus gross revenues will be determined by the maximum charges which can be extracted from the purchasers of various output quantities. Then costs associated with the various output levels will be ascertained.

4. The output at which marginal costs exactly equal marginal revenues (themselves equal to the benefits conferred upon the user of the marginal unit of goods or services) will be the most profitable one from the entrepreneur's point of view. At this point the expected net revenues (that is, the difference between gross revenues and costs) from the proposed project will be maximized.

Once these preliminary steps have been completed each entrepreneur individually and all entrepreneurs collectively will have compiled lists of profitable ventures. These will be arranged in order of logical priorities, for example by relating net revenues either to capital investment, or to total costs. (A good discussion of highway priority calculations and appropriate arithmetical methods is contained in a paper by Van Glinstra Bleeker.) Entrepreneurs will select the projects with the highest priority rating, that is, those promising to yield the highest (marginal) efficiency of capital, for most immediate implementation. Projects from which lower returns are expected will be carried out subsequently until finally the marginal efficiency of capital invested in new ventures will have been brought down to the rate of interest on investment money.

Thus in the sequence of events as described, investment will not lead to high profits, but rather high profit expectations will induce investment and this in turn will, in the long run, cause realized profits to fall. The so-called 'unreasonably high rate of profits' is, therefore, in the planning stage, nothing but an indication that exceptionally good investment opportunities exist within the economy.

It is certainly most desirable from the community's point of view that entrepreneurs should invest in those projects, and select those particular output levels, which promise to yield the greatest benefits relative to costs. For the economy as a whole aggregate investments will then also produce maximum benefits relative to costs; thus the desired objective for the allocation of scarce resources for productive purposes will be fully met.

PRIVATE VERSUS PUBLIC INVESTMENT ACTIVITIES

Having established the economics of the purely private investment process, it now remains to introduce investment activities of the State. Two problems arise: not only must public investment planning per se be analysed, but the conflicting desires of private and public agencies in allocating scarce resources to promising capital investment projects must be reconciled.
To deal with the latter problem first, one can very crudely state that the most efficient allocation of investment resources will be achieved when all projects—regardless of their private or public characteristics—are assessed on their merits in the same way and are carried out in order of expected rates of net return. In other words, public projects should compete, as it were, on equal terms with private ones and logical priorities for all of them should be based on the expected efficiencies of capital for the various ventures.

Such an approach, although useful as a starting point, represents gross over-simplifications. It ignores the institutional setting and behaviour of private and public agencies and unrealistically implies either the complete planning of all investment by the State, or the voluntary and successful adoption of private enterprise behaviour by public authorities. It further presumes that the returns from a public investment project can be measured and compared directly with those from a private venture—again an entirely untested condition.

The problem of the proper delimitation of private and public spheres of influence in economic life is perhaps one of the most pressing at the present time and should certainly receive more attention in economic research than in the past. (It should be noted that recently an expansion of the supply of public goods and services, rather than of private ones, has been advocated by Galbraith (10) and others. It is argued that in North America man is approaching the limits of physiological needs, that the greatest gains in standards of living can be made in the area of things consumed in common and that therefore the wealth-producing machinery of the modern economy should be used increasingly for the provision of needed social facilities and services.) It is impossible, within the limited scope of this paper, to do the question justice. At the same time, as will be shown in the next section, highway provision clearly is a proper function of public authorities, and therefore an attempt must be made to at least sketch the basic theoretical framework. Since, except for the technical features, there is nothing special about highways from the economic theory point of view, the following remarks generally pertain to what might be called "the economics of public works" and apply with equal force to the planning of investment in public airports, docks and harbours, sewage systems, water works and the like.

It is self-evident that society as a whole cannot at any time use up—whether by current consumption or by capital investment—more goods and services than the economy produces; in effect, for the entire economy, output and income must be equal. At any given level of employment total income is necessarily equal to incomes created by production of investment goods and services plus incomes created by the production of consumers goods and services. Investment is total current output less output of consumption goods. Similarly, savings are total aggregate income less consumption expenditures. Therefore investment must be equal to savings, because both are in turn equal to output (=income) less consumption.

As Keynes shows, investment has a key role in the economic process. If investment falls short of savings then there will be a reduction in output and a fall in employment until, with lower savings put aside from lower incomes, aggregate investment again equals aggregate savings. Conversely, if investment increases, then income will increase until savings out of the higher incomes will once more be equal to higher investments. It is usually assumed that the volume of aggregate savings is a fairly predictable and stable function of national income. Investment, on the other hand, because it requires predictions about the unknown future and is based on such dynamic factors as the state of business confidence, population growth, technical progress, etc., is autonomous and subject to violent, erratic fluctuations.

Most governments are now dedicated to policies of full employment. To individual enterprise wage payments are just like ordinary variable costs which do not have to be met once there is no employment. To society as a whole, on the other hand, payments to labour—either in form of wages or welfare support—go on regardless of the degree of employment and they are therefore really like unavoidable fixed costs. If so, the argument goes, it is better to let workers contribute to national income by productive employment, than to let them be idle. Or, more concisely, it is argued that the marginal cost to the economy of employing otherwise idle labour is zero or almost zero.
In addition there are, of course, many humanitarian, political and social reasons for pursuing the economic objective of full employment.

From the foregoing discussion it will have become clear that there is a fundamental difference between private and public investment planning: as private investment autonomously and erratically moves up and down, the State (provided the bureaucratic apparatus is in possession of the facts) will normally attempt to adjust its own public works programs in such a way that full employment is attained. Thus, as private investment goes down, public investment will normally be increased, and conversely. This process can be fairly well accommodated within our earlier concept of a mixed priority list of worthwhile private and public investment projects: as through a decline in the businessmen's confidence and promotional fervour, etc., more and more private ventures drop out, the opportunities for the realization of public projects will become greater. This is, of course, the idea behind the so-called 'shelf of public works'—quite a sound one whatever the practical drawbacks of this device may be. The limiting cases, at full employment, will be all public and no private investment, or, at the other extreme, only private and no public investment at all. But normally, in a free society, both forms of investment will be represented in varying degrees and this brings with it all the complications of a mixed system.

Great difficulties of measurement arise when one begins to compare the net returns from a public investment with those of a private project. How could one ever hope to assess in identical units of measurement the social returns from, for example, a new court house and from a new steel plant? In the latter case money net returns, based on money gross revenues less money costs at the optimum output level, will be the appropriate index. But although the costs of constructing the court house can be stated in money, it would be very difficult to directly translate the social advantages flowing from the administration of justice and the maintenance of law and order into dollars and cents.

Conceptually the steel plant and the court house are poles apart, but very serious efforts should be made to reduce the analytical gap between them. From the entire community's point of view it would be advisable to broaden the very narrow cost and revenue concepts used in the steel plant planning process, by including social costs (those which the entrepreneur escapes and imposes on the community at large, that is, smoke and noise nuisance, deterioration of a residential neighborhood, etc.). Similarly, some ways and means might be found to calculate more accurately the true returns from social investments. Usually little analytical difference is found between private and public investment planning in the field of transportation and this may be particularly true of highway provision. (An analytical toll road 'model', discussed in Chapters II, III and IV by Kuhn (?) can be used to demonstrate the great similarities between private and public highway investment planning, provided the toll road entrepreneur has a wide enough planning horizon and the highway authority is acting efficiently.) In this way, by empirical and theoretical research, social and private planning criteria might eventually be made more compatible thus leading to a more efficient allocation of scarce resources.

There still exist difficulties on the money (or resources) supply side of investment planning. It was shown earlier that private investment will normally continue until the marginal efficiency of capital declines to the interest rate level. In terms of Keynesian economics, the interest rate is determined by "liquidity preference" (the desire of people to hold cash for a number of motives, rather than to tie it up in investments) and the amount of money. Since the amount of money is set by the monetary authorities and normally cannot be influenced by private enterprise forces, the rate of interest becomes a price or reward for the "not-hoarding" of cash and equates the demand for ready money with the supply.

The circumstances are quite different in the case of public bodies. In the first place they can and do expand or contract the amount of money by printing bank notes or by withdrawing them from circulation. Secondly, the State can by taxation simply withdraw from the private sector funds which would have been used for consumption or investment. It can then, thirdly, either increase or decrease its own ordinary or capital spending, frequently without balancing tax receipts and government disbursements.
Consequently, whereas private enterprise is subject to money market forces in its investment planning, the State does not experience automatic checks and controls to the same extent. As an over-all policy, as was mentioned before, the objective of full employment will normally be pursued. However, even so the freedom of action of the State within those given terms of reference are very great; thus during a recession taxes might be reduced, or government spending be increased, or the amount of money be enlarged, or these methods be used jointly with differing emphasis.

In the last analysis reliance has to be put on a blend of political and economic forces to bring about rational solutions in this very complex field of public finance. The anguish of the taxpayers felt when remitting money to the income tax department—somehow collectively expressed—may be just as effective a force as the "liquidity preference" of private individuals in the Keynesian model of the economy. The desire to avoid large budget deficits and/or inflationary price trends will also constitute powerful restraints to State action. Efficiency of government operations and spending, finally, may best be promoted by vigilant parliamentary control, by informed criticism and by the evolution of better economic, planning, statistical and accounting tools. A useful first step in the right direction would be for government departments to show expected net social and money returns for each major public investment project that lends itself to such analysis. Only those ventures which show anticipated net returns in excess of the prevailing rate of interest should be considered for implementation.

THE ECONOMIC PROBLEMS OF PUBLIC HIGHWAYS

The general investment process, both in the public and the private sphere, has been described in some detail in order to fully understand the political, institutional and economic framework within which road investment planning has to operate. Next the rationale of public, rather than private, provision of highways must be established.

Should Highway Provision Be a Public Function?

It can be observed in the world at large that the provision of roads and streets is overwhelmingly entrusted to public bodies. There are some exceptions, especially a number of toll roads and bridges, but even those are subject to a great degree of State control or support. The institutional arrangements vary, from the ubiquitous government highway departments to the public authorities in the United States, or the Crown Corporations as these organizational devices are called in Canada and the United Kingdom. But essentially all these highway organizations are creatures of the State.

There are compelling reasons for this state of affairs and these should be examined.

Prevalence of Monopolistic Conditions

In practice the public highway and street system enjoys a largely unchallenged monopoly position. Admittedly, there is some competition on certain segments where the otherwise captive motorist customer can turn to air, rail, water transport and in rare instances to toll roads. However, on most sectors, particularly in the sphere of urban arteries, residential streets and sidewalks, local access and farming roads, development and mining highways, there are no substitutes whatsoever to the public road.

The proposition can therefore be accepted that public highway authorities exercise a very wide degree of monopoly power and that, indeed, this monopoly power is probably greater than that of a private monopoly which tends at least to be limited by the threat of potential competition, public control or nationalization. The prevalence of monopoly conditions means that one will have to employ monopoly theory and that it would be misleading to introduce spurious comparisons with competitive situations into analyses of highway economics.

Absence of Market in Highway Sphere

Linked to the existence of monopoly conditions is the fact that there is no real market in which highway services are sold and bought. Reasons are: firstly, the lack of compulsion for the monopoly supplier to sell his services since revenue would be forth-
coming from general fiscal funds in any case; secondly, the fact that almost insuperable technical and administrative obstacles arise when the attempt is made to negotiate sales of individual highway service units with the respective purchasers.

The absence of a market for highway services means that one is confronted with the absence of all the economic checks, balances, controls and procedures which are normally associated with the working of the market mechanism. To find practicable substitutes for these market forces is one of the key issues in highway economics.

The System Aspect of Public Highways

The "system" aspect is one of the most important characteristics of public highways; yet it is a concept which is very difficult to define and which has received relatively little attention in the literature.

By a system it is meant a heterogeneous set of things and parts, which, when connected, form a complex whole. The individual components of the system are joined together because thus arranged they function more efficiently and render better service.

This principle can be widely observed in the field of so-called "public enterprises." If many electric power stations are linked together by means of a grid system they are jointly able to provide better services at lower unit costs, than when they are operating separately. In the connected network the power consumption load can be distributed more widely over many generating plants; peaks of demand for electricity on one region are offset by troughs in other districts; coal-burning plants are able to make up for hydro-electric power deficiencies created, for instance, by a drought. In addition to these economies of scale of production, very substantial economies of marketing and distribution will also accrue to an electric power system. If every user had to be connected individually to the power plant by means of separate cables and transformers, electricity distribution costs alone might prove prohibitively high. Since, however, whole districts can be served by one main connection from the power plant, mass consumption at low unit costs for all users becomes possible. Similar considerations apply to almost all other public or publicly regulated enterprises—sometimes called "natural monopolies"—such as water, gas, sewerage, urban transportation, telephone and railway systems.

The same principles fit the public road system: as private laneways are joined to the street, as other streets are added, as important points of traffic attraction develop and these in turn are connected, by main thoroughfares and long-distance highways, to focal points in other districts and cities, the various combinations of traffic origin, destination and routing which the system as a whole will make possible are increased to staggering proportions. Ultimately, the public road system will serve all users which can be reached by land and will provide access to an almost unlimited number of points. In economically more advanced countries practically every house, farm and place of work has road access and almost every citizen draws to some degree on road services every day.

Does the Integrated Public Road System Possess Inherent Demand and Supply Advantages?

From the users' point of view, the services rendered by a well-developed public highway system are infinitely superior to those provided, for example, by a number of separate roads which connect only a few points each. The integrated public road network allows users to choose freely from a great variety of routings and at any moment of time—given knowledge of conditions—users will tend to follow the most rational traffic flow pattern, that is, the one which minimizes total road transport costs for all traffic. Very important are, further, the economies derived by all traffic from the joint use of the highway facilities: large commercial vehicles, farm trucks, delivery vans and passenger cars will all be users of the highways, thus contributing jointly to the costs of construction and maintenance of the roads at lower unit cost shares for each of them. Again, this is made possible by the highway system which attracts and serves such diverse forms of traffic.
On the supply side the economies of scale and operation to be reaped from treating highways as an integrated whole, rather than as so many road bits and pieces, are also very important. In many cases these economies have probably not yet been fully exploited by public highway authorities. By standardizing technical processes, specifications, materials and equipment, by centralizing certain functions which serve all segments of the system, such as planning, research, purchasing, by generally using mass production methods, very great savings in unit costs of rendering highway services can be realized.

It might be noted that sometimes in the past the negative aspects of the system characteristics of highways seem to have received undue attention. This may partly be due to some misunderstandings and misapplications of economic theory. Instead of assessing and promoting the economies of joint use of highways by trucks, vans, buses and automobiles, a formidable amount of research work has been devoted to the punitive aspects, such as the minute economics of cost allocation between one vehicle and another. This does not detract, of course, in any way from the great contributions such analyses are making to engineering knowledge.

Furthermore, it appears to be misleading to ignore the Tremendous economic advantages to be derived from an integrated road system and to express concern that certain secondary roads and streets "are not paying their way"; surely, the contributions these subsidiary feeder facilities are making to the system as a whole cannot be ignored. (For appropriate assessment techniques see (7), pp. 196-202.)

Finally, some very real system economies to be reaped from the free flow of traffic, taxed and regulated in a reasonably uniform way, have been lost in many instances by a veritable jungle of weight, size, safety, licensing, rate and taxation provisions. Some of the objectives promulgated, such as dipstick laws, corridor area concepts, regional boundary control and the like, seem to belong more appropriately to the era of petty European principalities than to the motor age and the great North American Continent. Due to determined efforts over many years this "balkanization" of highway transport has been reduced considerably, but many people would claim that there is still great scope for improvements in the interest of the highway system as a whole.

To conclude: a highway system can be regarded as a combination of many different parts which, when working jointly, produce greater quantities and better qualities of highway services at lower total costs, than when being operated separately. The ultimate economic limits of the system will be reached when the last (marginal) network extension or improvement will yield benefits which are equal to the costs attributable to the marginal project.

Highways Operated "In The Public Interest"

Very closely linked to the system concept is the fact that roads are supposed to be operated by government bodies "in the public interest." It is difficult, though, to derive precise working rules from so vague a concept. Broadly speaking, promotion of the public interest means that available resources are used in such a way that they yield the greatest aggregate benefits relative to costs for the community at large. This definition compels an answer to such questions as "What exactly are 'aggregate benefits'?"; "How are they to be measured?"; "What do costs mean in this connection?".

As soon as one sets out to promote the public interest one leaves behind cash profit maximization, the basic motive guiding the actions of private entrepreneurs. From the economics of private enterprise and the profit-making firm, such as described under the headings "Basis of Investment Decisions" and "Planning of Individual Projects" and illustrated in Figure 1, one must turn, for better or for worse, to the so-called "economics of welfare." (This term, originally coined by Professor Pigou of Cambridge, is now generally accepted. Basic works on the subject are by Pigou, Little, Baumol, Phelps-Brown, and others.)

New Investment Planning Methods and Criteria

This implies that the planning horizon must now be set as wide as possible—certainly
wider than that of the private entrepreneur; the reasons are, firstly, that the promotion of the public interest is entrusted to a self-perpetuating, permanent body and secondly—if perfect knowledge of the future is assumed—that public interest should know no time limits, but only priorities.

It further follows that activities or works which create external economies must be promoted and those which cause external diseconomies must be discouraged. Finally, works which are too big for individual enterprise must be undertaken as long as they are economically worthwhile; in that case the State performs a 'catalyst' function.

In short, the maximization of social benefits and the minimization of social costs within a very wide planning horizon must be the aim of highway development. Highway investment must be conducive to economic growth and development generally. Hence, highway investment criteria must be equally applicable to an urban expressway project, to an inter-city highway, or to resource development roads in the Yukon or in Central Africa. The state of economic development is a relative term: City slums or densely settled but congested industrial regions may be just as 'under-developed' in the economic sense as pioneer areas with unexploited resources. The economic criteria for highway investment planning must therefore be comprehensive enough to lead to the maximization of net returns on social capital in all these varied situations.

This calls for a redefinition of the working variables employed in "Basis of Investment Decisions" and "Planning of Individual Projects" and in Figure 1 of this paper. All activities external to the private entrepreneur, which were favourably or unfavourably influenced by his activities, are now internal to the economy as a whole and hence of direct concern to the highway department. Hence all benefits attributable to and all costs caused by public highway provision must be taken into account in road investment planning. Examples of factors to be taken into account are given below.

### Highway Benefits (Curve DBM in Figure 1)
- Savings in time, cost, inconvenience, etc., realized by road users directly.
- Transportation cost, production cost and distribution cost savings accruing to the entire economy.
- Employment-creating effects of highway investment.
- Beneficial effects on land use, growth of secondary industries, development of natural resources, tourist trade.
- Increases in the range of choice for users by opening new possibilities of travel, products, etc.
- Enlargement of supply and marketing areas for products and services.
- All other social benefits.

### Highway Costs (Curve ABN in Figure 1)
- Direct costs incurred by highway department.
- Highway dust, fumes, noise.
- Accident costs.
- Detrimental effects on land use, values, etc.
- All other social costs. (The more rapid depreciation in the value of existing fixed assets, e.g. railway installations, due to the introduction of a highway facility is not a true social cost factor, but belongs to the category of historical costs and is therefore irrelevant.)

### Practical Problems of Cost and Benefit Measurement

Briefly, in common sense terms, highway planning—like all other economic planning—must therefore take all relevant circumstances into account. It must not be forgotten that the transport industry is a service industry and that the provision of highways should serve some wider economic, social and political purposes beyond the mere mechanical conveyance of vehicles from one point to another.

With some justification the criticism can be put forward that such broad definitions of highway costs and benefits are unrealistic, simply because there are no measuring techniques available to match these wide definitions. Admittedly, there will be practi-
tical difficulties in assessing all benefits and all costs to a great degree of accuracy in all circumstances, but this does not mean that the aims should not be set high. One must start off with the cost and benefit assessments from the safe but narrow base of measurable items, such as savings and losses in time, vehicle operating costs, accident costs; this will eliminate at least some areas of doubt which might adversely affect the highway investment decision making. It should then be the prime aim to narrow down further the scope of guesswork by improving the measuring techniques.

First Progress Report of the Highway Cost Allocation Study (11)

It appears that the Highway Cost Allocation Study, which is currently being conducted in the United States, proceeds in this way from the well-known and well-established facts into new spheres where ignorance still prevails. This is gratifying, because so many times investigations in this field seem to start off from a very wide basis, with sweeping terms of reference to inquire into the general economic nature of roads and road transport; but then, in order to produce tangible results quickly, the scope of research is narrowed more and more—partly by taxonomy—until the final conclusions are all but useless since they apply to such a limited aspect only of the original subject.

There is a strong tendency running through much of the literature on highways and highway economics to cling to things which are measurable. Bearing called it a "futile quest for arithmetic certainty (12)." No doubt the strong engineering flavour of the subject of highways has something to do with it. This should be overcome, as was suggested, by proceeding from the narrow area of measurable costs, benefits and other ascertainable economic facets, to broad and general concepts. There are great opportunities for co-operation between engineers and economists in this field. Already a substantial body of information has been built up on the favourable effects which highway improvements have on direct vehicle operating costs.

To quote but one example of many possible ones: Controlled tests conducted in the United States have established the very marked effects which rises and falls in the highway profile have upon fuel consumption and travelling time of motor vehicles, particularly of heavy tractor-trailer combinations. As soon as one takes the next step and tries to assess in money terms the savings made possible by, for example, a reduction in the rate of rise and fall of the highway profile, one moves into the realm of economics. As the First Progress Report points out, the economic character and importance of the load which can thus be carried more efficiently has to be assessed; time savings have to be translated into money savings by taking into account the faster turnover of vehicles, reductions in overhead costs (license fees, insurance charges, etc.) per ton-mile or per vehicle-mile, proportionate reductions in labour costs and so on; allowances also have to be made for the use of lighter tractors made possible by lower power requirements, for differences in services performed (line haul versus pickup and delivery), differences in ratios of payload to tare weights and for many other factors.

It can readily be seen that there is great scope for further research, particularly in view of the fact that so far relatively little information has been compiled which goes beyond basic vehicle operating test and engineering data. The field for fruitful inquiries widens even more when one takes into account broader social benefits, such as reductions in accident costs, industrial development, improvements in land use, creation of better marketing possibilities and decentralization of population.

It is impossible within the scope of this paper to deal exhaustively with all the methods which could conceivably be employed to assess the beneficial or detrimental effects of road development. Changes in property values should certainly be studied, since they lend themselves easily to estimation. The creation of business opportunities brought about by highway improvements, on the other hand, cannot be measured very simply and special techniques may have to be evolved. It is suggested that the effect of road and street improvements in large urban centers offers a particularly profitable field for investigation in the widest sense. In urban areas the social costs caused by the lack of efficient road transport facilities appear to be quantitatively especially important, as for example the readily observable decay of the central core of many a large city testifies.
Quite clearly other scientific disciplines, such as economic geography and history, should also be brought to bear on the subject. Location theory may make valuable contributions to highway planning. Advanced statistical and mathematical techniques are already being used in the field of traffic engineering. Town-planners, architects, social scientists have a great stake in urban problems. No doors to future scientific inquiries in this field should remain unopened.

PUBLIC HIGHWAY INVESTMENT PLANNING—FINAL CONSIDERATIONS

The scene is now set for the completion of the highway investment analysis. The vexing problems of the proper delimitation of spheres of government activity and those which should rightfully be reserved for private enterprise were touched upon earlier. Let it be assumed now that the levels of both total taxation and of total government expenditure are optimum, in the sense that a higher or a lower level of either would result in an economically less advantageous situation, or in politically less preferred circumstances, for the community as a whole.

Re-stated, the problem of the State under these assumptions is therefore the optimum allocation of disposable funds or resources, the total level of which is optimum, to different government functions. In the abstract, the most beneficial allocation of resources and the maximum contribution to the social product will be achieved when the marginal net returns from marginal government outlay on Function A are equal to the marginal net returns from an equally large outlay on Function B, and when both are equal to net returns from government outlay in all other spheres.

As a concession to reality one has to admit right at the outset that a large proportion of government outlay, because of the familiar difficulties of measurement, will not be subject to the economic cost/net return calculus and will thus presumably be determined by collective political judgment. It may well occur that in this economic-political sphere of government budgeting each department will be vying with the others for fund allocations and all will have as their opposing counterpart the Ministry of Finance which tries to keep the taxes down.

Going further, two divisions within one department may be competing with each other for funds, for example the one responsible for airport development with the highway department or the waterways authority. How are the inherent conflicts of interest to be resolved? Pseudo-competition, as "an excellent antidote to bureaucracy and vested interest," between the various agencies concerned with transportation in the United States has, for example, been suggested by Pagrum (13). Little (14), on the other hand, favours the over-all planning approach provided the central board adopts suitably efficient policies.

Similar problems and their solutions are, of course, also to be found in the sphere of private enterprise. A comparable dilemma exists when the budget of a large company is to be allocated between, say, advertising, research, new production facilities and so on. In the final analysis the department which can most effectively "sell" its proposals will obtain the largest fund allocation. Similarly, inside government: The agency which succeeds in presenting the most convincing case will likely get the largest budget allocations. It is for these politico-economic reasons that the so-called "highway needs studies"—which serve simultaneously as internal masterplans for highway departments and as documents to guide legislators in the allocations of funds for highway purposes—have been so eminently successful in the United States and elsewhere. (The first Canadian needs study, prepared with the help of the Automotive Safety Foundation of Washington, D.C., was completed by the Ontario Department of Highways in 1956. It has been most successfully implemented and extended since then.) It is suggested that any improvements in the technical quality and competence of plans prepared by the highway department, whether in form of a full-scale needs study or otherwise, should influence government policy in favour of road spending. The adoption of efficient planning, management and housekeeping arrangements within the highway department will therefore in most cases also result in the allocation of desired funds. In that way the public authority finds itself in a situation rather comparable to that of a private company which has to attract capital in the money market by showing proof of successful and efficient operations.
Road Revenue-Expenditure Equation as Guide to Public Policy

It has been seen that highway budget allocations will be partially or completely sub­ject to political decisions. Would it be possible, though, to let actual or potential road user revenues determine the highway budget allocations? Could one not, by drawing on the example of public utilities, run highways as a self-supporting activity and stipulate that the highway authority spend no more and no less than it intends to collect?

If we employ revenues collected from road users in form of motor fuel taxes, license fees and other imposts as the criterion for the "social profitability" of highway expenditures, then the underlying assumption is that the existing imposts are related to benefits and that they are at the "ideal" level. As Winch (15) shows, these assumptions are inadmissible: Firstly, user revenues do not always measure benefits; for example, certain road improvements may actually decrease tax receipts although project benefits may be great; secondly, highway account deficits may either mean that taxes are too high and therefore discourage traffic which might otherwise pay project costs, or that taxes are too low so that users pay less than their share although they might be willing to pay more.

On the theoretical level of discussion, therefore, no a priori reasons exist to be­lieve that: (a) highway user revenues should determine highway expenditures, (b) de­ficits indicate the curtailment of road spending, and (c) surpluses dictate increases in road expenditures.

In practical terms it is also interesting to note that this allegedly ideal balancing of road expenditures and road revenues is by no means universally practised. In Europe highway tax receipts generally greatly exceed expenditures. In Great Britain, during the period 1948 to 1955, fuel tax and vehicle duty revenues of about £ 1,680 million accounted for nearly 800 percent of highway expenditures, which were only £ 219 mil­lion. Good arguments could be put forward for increasing road expenditures in Great Britain—on social investment grounds—and also for lowering road user imposts—on taxation grounds. But it would not follow that balancing the outlays and revenues would be either good investment policy or good taxation procedure. Also, it does not neces­sarily follow that in Canada, where road user revenues fall considerably short of road expenditures, urgently needed highway and bridge projects should be cancelled, or that license fees and fuel tax rates should be raised.

Proper Sequence of Decisions in Highway Sphere

It is suggested that the determination of the magnitude and priorities of road pro­jects must come first. How this might be done by means of cost and benefit analyses has already been discussed at length. The proposed highway development program, complete with cost and benefit estimates, must then be reconciled with the claims for funds of other government departments. Within the over-all limits imposed by (a) total planned public expenditures, (b) expected revenues, and (c) the government's fiscal policies, all projects which promise to yield net social benefits over and above social costs should be considered. Since the total proposed expenditures on worthwhile public projects may exceed total budgeted government expenditures, a proper sequence of priorities must be worked out. Government priority planning procedures will resemble closely those employed, for example, by the entrepreneurs when calculating project priorities, except that in the public sphere costs, benefits and other variables are in­terpreted in the widest social sense.

In other words, all the techniques and analyses described earlier as applying to private investment planning, will basically be valid. The only changes in Figure 1, for example, will be that the horizontal axis now denotes "quantities of highway ser­vices" and the vertical one "marginal social costs and benefits." Hence curve DB can be called "marginal social benefit curve," curve AB "marginal social cost curve" and the difference between the two "net social benefits" or "net social returns." Again, projects yielding the highest net returns relative to capital investment or to total costs will be given first priority consideration.
Subsidiary Highway Planning Decisions

Once worthwhile projects have been selected in this way and have been given appropriate priorities, many subsidiary technical and managerial problems have to be settled within the basic framework of the main investment decisions. An example of such secondary planning problems is the precise determination of the appropriate highway design and construction standards according to the weight, volume, speed, dimensional, etc., characteristics of the traffic to be served (see (7), Chapter III, for a three-dimensional diagram illustrating these problems).

Another group of problems calling for technical or managerial decisions arises from the fact that certain given quantities and qualities of highway services can be produced with different admixtures of fixed and variable costs, since these are inversely related to each other. The same output results over time may be achieved, for example, by high fixed costs (in other words, very durable highway construction) coupled with low maintenance expenditures; or alternatively by low initial construction expenditures combined with high costs of upkeep. Provided that no deteriorations of service qualities or diminutions of service quantities are incurred, the combination offering the lowest total costs including interest on money invested over the project planning period will be chosen. Appropriate methods for arriving at solutions are analytically fairly simple and need not be discussed here.

Fluctuations in Traffic Demand Over Time

Yet another category of problems is introduced when fluctuations in demand for highway services over time are taken into account. Great variations in highway travel will normally be experienced over a period of 24 hours. Daily traffic volumes will, for example, show sharp hourly peaks between 8 and 9 a.m., possibly between 12 noon and 1 p.m. and finally during the traditional 5 to 6 p.m. "rush-hour". There will also be weekly, monthly and seasonal variations. Superimposed on top of each other these traffic variations may produce exceptionally high compound peak traffic volumes. (A good example of a combined daily, weekly and seasonal peak is quoted in the Ontario Department of Highways' study "A Plan for Ontario Highways:" "...on Sunday, July 10th, 1955, between 8 p.m. and midnight, only 720 motor vehicles traveled northwards on Highway 400 from Toronto towards Barrie, but 12 times as many vehicles, a total of 8,700, traveled in the opposite direction. This is in marked contrast to the general experience on most other routes where the peak volume of traffic going one way is usually not more than twice as high as that in the opposite direction (16)." In addition to these repeated fluctuations there will be a long-term secular growth (or a secular decline) of traffic. If one will take an extreme view, each year, each month, each week or day, and in the last analysis each hour or even minute, will therefore have its own, unique demand schedule for highway services. Consequently, there will be different sets of desirable output values, depending on the demand conditions and cost requirements of the various traffic peaks. The question then obviously arises which one of the many demand schedules should be selected for investment and production plans.

D.M. Winch in his "The Economics of Highway Planning" (17) demonstrates ably how the different demands for highway services which arise when "time" is introduced can be reconciled and how the most economical final output solution can be found. The guiding basic principle is that of cost minimization and utility (in our case, benefit) maximization. A number of different plans will be drawn up, each showing the optimum volume of traffic as determined by the point of intersection of the specific demand (marginal benefit) and marginal cost curves. Thus there may be a plan for morning traffic, one for noon traffic, one for afternoon rush-hour traffic and one for midnight traffic; similarly, weekly, monthly and seasonal variations may be introduced by preparing additional plans to cover the various situations. Finally, it is pointed out by D.M. Winch, these plans "must be reconciled, and the optimum compromise will be that plan which involves the least total unnecessary costs at times when it is not the optimum (18)." And: "Thus by this method of totalling unnecessary costs of sub-optimum solutions at each time one can calculate the best compromise solution, and the problem of the peak can be solved mathematically (19)."
Secular growth of traffic is treated in a similar way, with the difference that unnecessary costs of each plan in future years "must be discounted at the current rate of interest to arrive at its current capitalized value (19)." D.M. Winch points out that over longer periods of time compound solutions become possible, such as a plan which calls for land acquisition for a 4-lane divided highway and construction of only a 2-lane road now, with the second 2-lane road to be constructed later when needed. He finally states: "However many plans, compound and single, are considered over whatever period of time, with whatever complex peak and growth patterns of demand, this method will always give one method as the best. In complex cases the calculations will be complicated, or rather there will be a very large number of simple calculations, but there will always be a determinate optimum solution for any given set of data (20)."

By extending these analyses it will also be possible to work out, for example, solutions which apply simultaneously for different choices of traffic routing, as well as for various traffic peak and growth situations. Planning of highway systems can also be expedited in this way. However, enough has been said to indicate the general nature of the methods which can be used. (The mathematically inclined student of highway planning problem should refer to Studies in the Economics of Transportation (21), Part I, for further detailed discussions of the subject matter.) There is certainly great scope for the practical application of these techniques in the field of highway transport and determinate solutions to very pressing problems could thus be obtained. As D.M. Winch concludes: "Given all the data there is no problem so complex that it is not capable of theoretical solution, and working on the above principles there is no reason why the detailed calculations could not be delegated to an electronic computer (22)."

It now only remains to discuss highway pricing as the appropriate tool for the attainment of the desirable levels of output allowed for in the investment planning phase. This is done in the following section.

SOME NOTES ON PRICING OF HIGHWAY SERVICES

In the preceding parts of this paper economic analyses and techniques were evolved which will enable an entrepreneur or a highway department to achieve optimum investment, priority and output solutions. In conclusion some attention must be given to the closely related sphere of highway pricing problems. Since pricing of highway services is a subject fraught with controversy, a careful and systematic approach is indicated.

In connection with the over-all allocation of funds for highway purposes, it was decided earlier to treat the provision of public roads and streets as one of a number of government functions. In particular, no direct fiscal or bookkeeping link between road expenditures on the one hand and road user revenues collected by the government on the other hand was established. Subject to some other criteria still to be discussed, there therefore exists almost complete freedom to adopt any pricing policy which appears expedient as far as the revenue-producing side of highway taxes is concerned. This initial lack of fiscal encumbrances will greatly facilitate clarity and directness of the highway pricing analyses.

It was seen earlier that optimum output for any one highway, or segment of the road plant, will be achieved when marginal costs of the last service unit rendered are equal to the marginal revenues and hence to the price charged for the last unit. For brevity's sake "marginal cost-pricing rule" shall be referred to in the future, which, when applied to extreme output values, determines the optimum quantities of services to be rendered. The marginal cost-pricing rule does not restrict one very much as far as the pricing of intermediate service units (those between zero output and optimum output) are concerned. Here the maximum limit of charges is determined by "what the traffic will bear." If the price for highway services exceeds this ceiling, then traffic will be lost and the carefully planned highway plant will be operating below the optimum level of output. At the optimum output point the "charges the traffic will bear" are, of course, identical to marginal costs.

As far as the consumption-rationing side of highway pricing is concerned, the charging policy therefore has to adhere to two rules. The first rule calls for the rationing
of highway use to optimum output by means of marginal cost-pricing of the last (or extreme) service unit. The second rule demands that no highway service unit should be priced at more than "the traffic will bear." Subject to these two prime rules, which apply simultaneously, and under all circumstances, there is freedom to set highway prices as desired, since thus there will be no interference with the objectives of investment planning and optimum output operation.

Extraneous Pricing Objectives

In addition to these simple rules and objectives, which really form an integral part of optimum resource allocation for highway purposes, there are a host of other pricing objectives. Some of them lead far afield into political, legal, fiscal and—in connection with the concept of "equity"—pseudo-ethical spheres. They are strictly extraneous objectives as far as this analysis is concerned and they shall therefore be subordinated to the two prime rules which were stated before. This does not mean that they may not be useful and desirable objectives in their own right. However, they should not be confused with the primary economic objectives.

In the following paragraphs some outstanding examples of extraneous objectives which can be encountered in the highway sphere will be discussed. This will set the stage for a subsequent demonstration of the many different pricing policies a public highway authority may conceivably adopt.

Maximization of Government Revenue

Maximization of government revenues is probably the simplest and most straightforward pricing objective a public authority or a public enterprise can pursue. It amounts to "charging what the public will bear" in the widest sense, with limitations set by political and economic considerations. Imposts on road users and other highway beneficiaries are simply treated as lucrative sources of revenue for the government. Unless there are weighty political considerations which dictate a more moderate course of action, the upper limits of charges are identical to those found in a perfectly discriminatory monopoly situation.

Competitive Neutrality

Sometimes the attempt is made to adjust the taxation system in such a way that "competitive neutrality" between rival economic activities prevails. In the field of transportation it is held, for example, that each agency "must pay its way" and that one form of transportation must not "subsidize" the other. This opens up the very wide field of competition in transport which cannot be discussed here; may it suffice to say that under the most frequently encountered working definition of "competitive neutrality" each individual user is charged exactly according to costs of providing the service—not more and not less—and for the transport activity as a whole, revenues must exactly equal costs.

Encouragement of Maximum Use of a Public Service

In cases where the social benefits conferred by one particular government activity are widely dispersed throughout the whole community, where no one user or group of users is particularly favoured, or where the provision of the service leads to very large external economies, the service is sometimes rendered free in order to encourage maximum use. Examples are the free provision by the State of parks, playgrounds, education, libraries, art galleries and in some cases—alas not in North America—of broadcasting services. The costs of these services are borne from general tax revenue, ideally from income tax sources.

Equity of Pricing

Equity of pricing is an objective which is very frequently pursued in the highway sphere; it is unfortunately also the one objective which is most difficult to define, since
it involves principles of justice, ethical judgments, and social policy decision. Just to illustrate the complex nature of the equity concept, it might be noted in passing that one writer found it worthwhile to devote an entire book to the study of fairness and equity in the field of public utility operation.

In one sense a perfectly dissimilar charging regime might be regarded as achieving complete and universal equity, since every user pays exactly the price of "what the service is worth to him." Even social justice is served since the poor man will pay little and the rich man will pay a great deal.

This is, however, not the way in which "equity of taxation" is most commonly interpreted in discussions on highway pricing matters. Sometimes charging on the basis of costs is regarded as equitable, in which case the "competitive neutrality" requirement is also satisfied. Sometimes taxation equity is interpreted as implying equal charging for all service units regardless of costs. Since the cost charging case is already covered under the "competitive neutrality" objective, the second interpretation of taxation equity shall be used for the subsequent discussion.

Other Objectives

Various other taxation objectives can be encountered in practice. There is the public utility approach, which calls for an over-all balancing of revenues and expenditures, but may leave freedom of charging for individual service units to the management of the enterprise. Sometimes subsidization of some users is prescribed for social or political reasons. Yet, another approach calls for the simulation of private enterprise behaviour in similar circumstances. Finally, there is pricing on the basis of benefits received; the last objective is sometimes interpreted as "equalization of charges for all service units," sometimes as "charging what the traffic will bear."

Usually a number of these objectives are combined when solutions to highway taxation problems are sought. Thus the First Progress Report remarks with reference to experience in the United States: "Each State, when confronted with the mounting need for funds to modernize its highways, has found it necessary to review its road-user tax structure from the double standpoint of productivity and equity."

These introductory remarks and definitions will have shown what a great variety of highway pricing policy objectives can be pursued. Some of these objectives conflict with each other, others can be reconciled. It is absolutely essential in any consideration of road user taxation problems that the policy objectives are stated clearly; only in this way can appropriate solutions be found.

Equipped with preliminary working definitions and bearing in mind the two prime rules which satisfy optimum output requirements, one can now proceed to a demonstration of possible pricing policies which could be adopted by a public highway authority.

Possible Pricing Policies of Highway Authority

The analytical apparatus and the diagrammatical techniques employed in the subsequent section are the same as those used throughout this paper; they therefore require no special introduction. Likewise, the concepts "costs" and "benefits"—unless otherwise stated—are to be interpreted as "social costs" and "social benefits", as defined earlier. This means that "pricing of highway services", or "charging for highway services" does not only include the imposition of fees on direct road users, but also covers taxation of other direct and indirect beneficiaries, such as adjacent land owners.

It is assumed that the highway authority or other government body responsible for the highway function, has complete freedom of charging in any fashion it desires for the services it provides and that it is only bound by the objectives it sets itself. The results of the various pricing policies will be judged entirely in the light of these objectives.

Case 1: Simulation of Private Enterprise Behavior—Monopoly

Possibility (a)—Dissimilar Charging (Figure 2).—This simply calls for "charging what the traffic will bear", following the procedures of the private entrepreneur. Output is optimum OD, net revenue is ABC.
Results and Objectives Achieved. —Optimum output, maximization of government revenues, equity in the sense that each user pays "what the service is worth to him."

Objectives Not Achieved. —Public utility requirements (since excessive profits are being reaped), competitive neutrality, charging on the basis of costs, equalization of charges for all service units.

Possibility (b) —Uniform Charging (Figure 3). —In this case the highway authority will fix output and uniform price in such a way that the area between the marginal revenue and marginal cost curves is maximized. Output is sub-optimum OE, price is OH, net revenue is AFGH.

Results and Objectives Achieved. —Large—although not maximum—government revenues, equalization of charges for all service units.

Objectives Not Achieved. —Optimum output, public utility requirements, competitive neutrality, charging on the basis of costs.

Figure 2.

Case 2: Simulation of Private Enterprise Behavior—Competition

Possibility (a) —Optimum Output (Figure 4). —This objective calls for a uniform market price, determined by assuming competition—a highly unrealistic working basis. Hence the pseudo-market price may coincide with the optimum level DB=OI (Possibility 'a'), may be below optimum level (Possibility 'b'), or may be above the optimum price level (Possibility 'c'). Under Possibility (a) output is optimum OD, price OI and net revenue IAB.

Results and Objectives Achieved. —Optimum output, moderate government revenues, equalization of charges for all service units.

Objectives Not Achieved. —Public utility requirements, competitive neutrality, cost charging.

Possibility (b) —Price Level Too Low (Figure 5). —Price set too low at, say, level OK. Output is determined by intersection of assumed market price with marginal revenue curve at point P; hence output is supra-optimum ON. There may be a net profit or a net loss, depending on whether area KAF is greater or smaller than area FBP.
Results and Objectives Achieved. — Equal charges, subsidization of some users, encouragement of use of public services.

Doubtful. — Size of government revenues, public utility requirements.

Objectives Not Achieved. — Optimum output, competitive neutrality, charging on the basis of costs.

Possibility (c) — Price Level Too High (Figure 6). — Price set too high at, say, level OH. Output determined by intersection of assumed market price with marginal revenue curve at point G; hence output is sub-optimum OE. Net revenue is AFGH. Results may conceivably be similar to those of Case 1(b) — non-discriminating monopoly.

Results and Objectives Achieved. — Large government revenues, equalization of charges.

Objectives Not Achieved. — Optimum output, public utility requirements, competitive neutrality, charging on the basis of costs.

Case 3: Public Utility Approach — Equal Charging

Possibility (a) — Increasing Marginal (Figure 7).

This public utility approach calls for a balancing of revenues and expenditures. This concept of "reasonable profits" permitted to be made by the public utility, is merely a modification and requires no special explanations. Price will be set in such a way that profits AKF earned on service units OE are exactly balanced by losses FPM sustained through provision of "unremunerative services" EN.
Results and Objectives Achieved. —Public utility requirements, equalization of charges, encouragement of use of public services beyond output OD, subsidization of (presumably deserving) users of output quantities EN.

Objectives Not Achieved. —Optimum output, maximization of government revenues, cost charging, competitive neutrality.

Possibility (b) —Decreasing Marginal Costs (Figure 8). —The requirement of equal charging, coupled with decreasing marginal costs in the critical output range, leads to sub-optimum output OE. It is a case which has received considerable attention in the theoretical literature. Revenues balance expenditures, with losses AFK cancelled out by profits FPM.

Results and Objectives Achieved. —Public utility requirements, equalization of charges, subsidization of some users.

Objectives Not Achieved. —Optimum output, maximization of government revenues, cost charging, competitive neutrality.

Case 4: Public Utility Approach—Differential Charging

Possibility (a) —Optimum Output (Figure 9). —The most logical way to achieve both optimum output and a balancing of revenues and expenditures is by charging exactly according to marginal costs. The so-called "incremental cost method" proposes this approach.

Results and Objectives Achieved. —Optimum output, public utility requirements, charging according to costs, competitive neutrality.

Objectives Not Achieved. —Maximization of government revenues, equalization of charges.
Possibility (b) — Maximum Output (Figure 10). — The two objectives of maximum output (that is, serving all users however small a charge they can pay) and balancing of revenues and expenditures can be achieved in a number of ways. An "equity" notion is introduced here by fixing charges "in proportion to benefits received" (that is, in proportion to "what the traffic will bear").

Solution. — Determine the proportionate relationship of magnitude of total revenues which could be collected under a perfectly dissimilar charging regime (that is, size of area OCBL) to total costs incurred when providing maximum output OL (that is, size of area OAFBML). Let one assume that the ratio of total costs to total revenues is 4 to 5. Now fix all charges at four-fifths of the theoretically possible maximum level; this procedure provides the actual price curve HFL. Output is maximum OL, total revenues OHFL are equal to total costs OAFBML, profits HAF on service units OE exactly balance losses FLM on service units EL; users of service units EL are subsidized.

Results and Objectives Achieved. — Maximum output, public utility requirements, subsidization of users (that is, encouragement of maximum use of a public service), charging in proportion to benefits received, charging in proportion to "what the traffic will bear."

Objectives Not Achieved. — Optimum output, charging on the basis of costs, competitive neutrality, maximization of government revenues.

Some Observations on Pricing Possibilities

What conclusions can be drawn from the foregoing demonstration of the various possibilities for pricing policies? In the first place there seems to be a great variety of choice for the public authority. It should be emphasized in this connection that additional models and combinations of objectives could, of course, be readily devised. Secondly, even if the public authority conforms with the prime rules established earlier, in order to satisfy investment and output requirements, optimum output can be achieved in three different ways. Case 1(a) (Figure 2), as well as Case 2(a) (Figure 4) and Case 4(a) (Figure 9) are equally satisfactory from that point of view.

In order to arrive at a definite solution, the three possible cases have to be judged in the light of other criteria. Case 1(a) yields maximum government revenues and might therefore be preferred for fiscal reasons, provided there is not too much political resistance to an all-out "charge what the public will bear" regime. It appears that this is the prevailing situation in the United Kingdom, where road transport is an extraordinarily lucrative source of government revenues; yet road users in Great Britain—and this is just a very general observation not based on detailed study of conditions prevailing in that country—appear to object more to the inefficiencies of the road plant and the obvious underinvestment in highways, than to the high level of motor fuel taxes and license fees.

Case 2(a) does not seem a practicable possibility, since it would be a great coincidence indeed if the pseudo-market price happened to be set at exactly the right level. How would a public authority, in practice, determine what the price level would have
been if there had been several competing providers of highway services? It is known that there will never be a number of competing toll roads linking two towns, just as there will never be different electric circuits, water systems and telephone connections in one house, installed by competing companies. Hence, it will be better if one realistically bases his policies on the assumption of monopoly, rather than on a nebulous competitive ideal.

Case 4(a), finally, appears to meet more objectives of public pricing policy than any other solution. It is also the approach which is most frequently advocated in the United States; it is generally known as the "incremental cost method."

Benefit Charging, Value of Service, Average Cost Pricing

Very briefly some other pricing methods should be mentioned which occasionally come up in discussion. "Charging according to benefits received" is probably the best known of these. Unfortunately, the advocates of this approach frequently do not explain what they mean by "benefits". Are benefits to be assessed in accordance with utility measurements or a hedonistic calculus? Will the luxury-car owner pay more than the driver of an old farm truck? Does a truck load of timber accommodated on the highway represent greater highway benefits than a bus filled with sightseers? Does the rich man receive greater benefits from highway use than the poor man and hence pay higher charges, or does it work the other way? Can benefits conferred when a vehicle travels on a poor gravel road be compared to those of travel by the same vehicle on a modern expressway?

Obviously, as economic theory tells us and common sense confirms, no satisfactory answers can be given to these questions. Utility, or benefits, cannot be measured directly as a sort of psychic or physical reality, independent of external observations. If, however, one will assess benefits by the most convenient observable effect—namely by the amount of money users are prepared to give up in order to avail themselves of these benefits—then one will be back to a perfectly dissimilar charging regime and Case 1(a) (Figure 2) applies without any modifications.

Occasionally the proposition is put forward that benefits are proportionate to the number of service units received by individual users. Highway services, under this approach, are supposed to be homogeneous benefit units as measured by ton-miles, vehicle-miles, passenger-miles, axle-miles, etc., and would be sold by the highway authority at a standard price, in much the same way as loaves of bread are sold by the baker. All the objections which might be raised, to "homogeneity of service units", apply to this proposition. Proportionality of benefits to service units by itself does not provide any guidance for the fixing of the actual (uniform) price level; therefore this version of the benefit approach is usually coupled with some other objective, such as "expenditures must equal revenues." Depending on the circumstances, the cases illustrated by Figures 3 to 8 apply. Rather surprisingly, the benefit method of pricing is sometimes confused with a pure cost approach.

Charging on the basis of the "value of the service" is also encountered in the field of transportation. It is a term which dates back to the earlier days of the railways and was really used as a substitute phrase for "charging what the traffic will bear." It was and is regarded as the more expedient term, since it does not carry the same strong suggestion of discriminatory monopoly pricing. Complex railway rate tariffs and pseudo-scientific rate theories have been built around the "value of service" principle, with goods commanding high wholesale or retail prices being charged higher railway tariffs than less highly priced merchandises in otherwise identical circumstances.

Charging on the basis of the value of the service can be likened to benefit charging; it is covered by Case 1(a).

Finally, charging on the basis of average total costs is occasionally suggested. Case 3(a) (Figure 7) and Case 3(b) (Figure 8) illustrate average cost pricing. In neither case will optimum output be achieved by average cost pricing. Depending on the configuration of the marginal cost curve, excessive use of the highway plant (that is congestion) will be encouraged when marginal costs are above average total costs (Figure 7); optimum use of the highway plant will be discouraged when marginal costs are below average total costs (Figure 8).
The Public Service Approach

Taking an entirely different approach, one might also ask: why have any specific pricing and taxation policies for highways at all? Could one not regard the provision of highways as a public service, to be rendered free to all, and dispense with road user taxes and imposts on other beneficiaries altogether? This approach might very easily be justified in cases where it is important to encourage road transport for development reasons or where the benefits conferred by roads and streets are widely and uniformly distributed throughout the entire economy. There exists no rationale—apart from revenue collection considerations—for specific highway pricing policies and imposts in countries where all citizens are pedestrians and nobody owns a vehicle, or alternatively in countries where all persons are owners of automobiles.

The First Progress Report considers the public service approach in the following way: "The proposition that there should be no road-user taxes, as such, is worth examining, at least as a point of departure. Considered by itself, general tax support of highways might not be inherently unjust, even under modern conditions. The use of the automobile is almost universal, except in large cities. As for commercial vehicles, freight trucks and combinations distribute and deliver the food, clothing, building material, household goods, and general merchandise of the Nation. The benefits and savings their operators derive from highway improvements are distributed in large part to their customers; for if this were not so their business would not increase. The same is true of buses within their more limited sphere of operation. Thus, the provision, out of general revenues, of roads adequate to support the heavier weights of commercial vehicles would not of itself, in the absence of competitive conditions, severely violate principles of equity." (pp. 10-11). In terms of the present diagrammatical representation, the public service approach would lead to maximum output OL (Figure 10), with almost all benefits presumed to be social benefits and social costs presumed to be very small. There would be no government revenues accruing from the highway function and no "rationing" of highway services by means of user imposts and other levies would take place.

The discussion throughout has emphasized the many possibilities which exist for pricing policies. The various choices which confront a public highway authority have by no means all been described, but the ones dealt with in this chapter may serve as representative cases. There can be no conclusion that one approach is "right" in all situations and that another method has only defects and no merits. All the economist can do is to point out the various ways in which different policy objectives can be achieved most efficiently.

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3. ibid., p. 168.
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18. ibid., p. 32.
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General Discussion

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FAR MORE intensive reading and analysis than has been possible in the time available is essential to full and final evaluation of the papers previously presented. Therefore, this presentation is limited to discussion of general points.

The first point to be stressed is the wide area of agreement, explicit or implicit, in the several papers on the economic propositions that construction, maintenance, and operation of highways require scarce resources that could be utilized in other types of production, either in other transport or in other fields; that the values of such resources in other uses comprise the opportunity costs of their devotion to highway use; and that all such opportunity costs must be taken into account in highway investment decisions and possibly in pricing decisions.

In placing highways in an economic setting, Professor Brownlee has admirably stated, in simple terms, the condition that must be fulfilled in order for highway investment and pricing to be optimal in an economic sense. Thus, comparisons of highway service prices and costs can show which highway needs should be satisfied and which should not if the prices are "good approximations as to what things are worth" and the costs "yield accurate estimates of what must be sacrificed." Viewing the highway function in terms of the economy as a whole, rather than as an entity having no consequences for resource allocations in other areas, Brownlee implies that far more consideration than in the past must be given to the rates of return which capital can earn in other employments and to imputed property taxes on highways if comparisons of prices and costs are to yield fully economic highway investments. Without adding those cost components—that is, interest at the opportunity rate rather than the government rate, and imputed property taxes—the total costs to be justified by priceable benefits are understated and a tendency exists to overinvest in highways more or less continuously.

A second point is the general recognition in these papers that although there are indirect benefits to be considered, in most cases the highway users should pay highway costs. Brownlee makes this point explicitly in supporting "the contention that the benefits from investment in highways have properties such that a highway investment can be evaluated in the same manner as can any investment designed to produce goods and services that are to be sold." Although the studies by Baker and his associates were intended as purely engineering studies, it is to be noted that comparisons were made of the cost responsibilities for various highway groups and the taxes paid, with the interesting conclusion that the "effect of the revenue derived from the axle-mile tax... is to make cost responsibility more consistently equal to taxes paid (1)." Kafoglis gives a theoretical case for a nonuser share in joint demand possibilities, but stresses that where the socially desirable amount of highway service clears the market at a cost-determined price, such a share is not needed and windfalls to nonusers can become a source of general tax revenues. He also finds that as "highways are built for actual or potential highway use and little more... the physical by-products of highway development do not provide an important basis for a nonuser share." Where highways are truly needed more than other things, there is little reason to believe that the effective demand at appropriate user fees, tolls, or road taxes (where differential user fees are unworkable) will not yield a volume of priceable benefits equal to the total costs involved in adding to highway supply (with possible exceptions for undeveloped areas.) Finally, Kuhn states as a principle that "public projects should compete, as it were, on equal terms with private ones and logical priorities for all of them should be based on the expected efficiencies of capital for the various ventures."

Kuhn's interesting paper deals in some detail with economic criteria for highway investment. Recommending a broader planning horizon than for private entrepreneurial investment and the widest consideration of external economies (indirect benefits) and external diseconomies (social costs), Kuhn sets forth the ideal as "the maximization of social benefits and the minimization of social costs."
However attractive in an abstract sense, there are numerous difficulties with such broad criteria as guides to economic highway investment. First, although the difficulties of measuring social benefits and costs not considered in the market are mentioned, no formula is given for their concrete evaluation. Second, some highway benefits mentioned for consideration, such as transportation cost, production cost and distribution cost savings accruing to the entire economy, are no different than similar general gains to the economy from an improvement in the art of railroading or in the manufacturing of steel. In any case, double counting may be involved if savings to users are counted as benefits and if they are again counted in terms of effects on the entire economy. Third, Kuhn appears to stress the difficulties of the market mechanism in determining the optimum highway investment without substituting anything as workable as the market, with all its defects, has been in toll road investment and in many areas of "free" road investment on the basis of user fee revenue, traffic, and other indicia of effective demand. Kuhn admits that under his criteria "a large proportion of government outlay, because of the familiar difficulties of measurement, will not be subject to the economic cost/net return calculus and will thus presumably be determined by collective political judgment." In the United States many failures to attain optimal highway investment, involving both overinvestment and underinvestment, can be attributed precisely to the vagaries of such collective political judgment. Perhaps more effort should be given to the task of improving the market in which highway services are produced and sold, including attention to tolls as selective supplements to user fees, off-and-on peak pricing to encourage or discourage utilization and to lessen tendencies toward overinvestment, adjustment of user fee schedules to reflect use more fully, and differentiation in user fees according to cost and quality variations.

Another general point worth emphasis is that these excellent papers reveal the close and dovetailing relationships between engineers and economists so far as the highway function is concerned. Economists must depend on engineers for knowledge of design, maintenance, and operating practices and the facts needed for making explicit the assumptions basic to the application of economic analysis to highway investment and pricing problems. Engineers, at least in most cases, must depend on the economists for the principles of resource allocation and use that comprise the economic way of thinking. Engineers cannot avoid economic questions and economists trying to apply economic principles to highways cannot avoid engineering questions. But because it is impractical to expect engineers to be full-scale economists and economists to be professional engineers, what is urgently needed is the willingness of both engineers and economists to assume the responsibility of assisting members of the other discipline to comprehend the technical knowledge and principles sufficiently well for each group to do its principal job better and for the joint product of the two professions to assist state legislatures and the Congress to establish sound highway and general transport policies.

The mutual dependence of engineers and economists on one another can be illustrated from the stimulating conceptual paper by Kafoglis. In treating the problem of establishing an economic user price structure, he assumes that "geometric design imposes only common cost," whereas "pavement thickness imposes special cost." After making this division of design costs into those (geometric costs) for which all vehicles are responsible and those (weight costs) for which only the vehicles with heavier-than-basic vehicle axle loads are separately responsible, he then suggests that engineering studies of highway capacity have established the volume relationships relevant to the geometric design. However, he states that "volume or quantity relationships for pavement thickness are not as well established as those for geometric design." He notes that "the pavement thickness...may be affected by the number and frequency of repetitions of a particular axle load," but concludes that "pavement design does not consider this relationship in a manner such that a definite relationship between number of repetitions and pavement thickness can be determined."

Nevertheless, two rather significant inferences were drawn for marginal cost pricing. The first is that no geometric costs need be considered as special long-term marginal costs for the heavy and large vehicles. The second is that the weight costs that are separable for the heavy vehicles do not impose short-run marginal costs with use by such vehicles because "high-volume roads are designed for an infinite number of repetitions of a legally permissible maximum axle load."
The pricing implications of these cost behavior generalizations which Kafoglis has drawn from engineering fact are rather sweeping. If pavements on primary highways can stand "infinite" repetitions of the maximum axle load, then "the marginal cost of pavement is zero because the addition of one more vehicle does not increase the total cost of pavement." Such cost conditions would justify low highway service prices for heavy vehicles to encourage use and the risking of revenue "losses" equal to special pavement cost. However, recognizing that special pavement cost must be recovered if the highway pavement service is to be continued, lump sum charges such as graduated registration fees without a mileage or use component are suggested as appropriate pavement charges. On the other hand, Kafoglis states that should it be confirmed that "pavement cost is a continuous function of number of repetitions, an additional vehicle will impose additional pavement cost and a price based on use should be employed."

Obviously, with such widely and significantly different marginal cost increments resulting in the short run depending on whether pavements are designed for infinite repetitions or according to number of repetitions of special axle loads, it is of critical importance that this engineering question be solved as rapidly as possible. So long as such important functional relationships are not known or are practically unascertainable by economists, they cannot with confidence prescribe economic highway service prices even if the rule that such prices should be equated with marginal costs is adopted as the general economic guideline. However, even if it were confirmed that engineering design of pavements is uniformly on the basis of infinite repetitions of the maximum axle load, the question would still arise as to the short-run marginal costs of vehicles having axle loads above the designed maximum load. It is highly doubtful that they could be regarded as equally at a zero level. And the question of long-run marginal costs of pavements must be faced, since heavy axle-load traffic is increasing, highway construction (as acknowledged by Kafoglis) is a continuous process, vast sums will be invested in the future in supplying the strength essential for bearing heavy axle loads, legal or nonlegal, and the increments of investment cost for this purpose will apparently vary according to the magnitude of the axle load and the relative repetitions of the different nonbasic vehicle axle loads.

The assumption of Kafoglis that all geometric costs are common, since highway capacity is created on behalf of all vehicles, also appears to require additional engineering confirmation. Incremental cost studies in the past have assumed, on the basis of expert engineering opinion and design practices, that some lane and shoulder width, some curvature requirements, and some grade reductions or passing lanes on steep hills have been required because of the size and power characteristics of large vehicles. If these elements are not essential for the basic vehicles, then the long-term investment costs involved must be attributable to the larger vehicles and those without power to take hills at average light-vehicle speeds. Although it would be desirable to simplify calculation of the special investment and use costs for the large and heavy vehicles, this should not be done to the point that special-vehicle and basic-vehicle costs are lumped together for convenience.

In describing the problems of initiating studies of highway cost relationships with vehicle size such as those done at Ohio State, Baker concludes that the "theoretical" approach of utilizing only rational expressions relating cost with vehicle size "is not a practical possibility because of the many functions which have not been established on a rational base." He then assumes that any solution achieved during the next few years will require empirical techniques, and views current design techniques as the best source of differential cost relations. Even on this basis, it appears that detailed studies of cost, such as the Ohio State report, have thrown much technical light upon differential costs. Nevertheless, as it is not made operationally clear how important elements of highway cost vary with vehicle dimensions and highway use, more research was recommended.

The practical question can be raised: Will multiplying technical studies ever result in sufficiently clear and reliable differential cost relationships that highway improvement and pricing decisions can be taken by the policy makers with full reference to their economic significance under marginal cost pricing or some alternative scheme
of economic pricing? One practical answer to this question calls for interdisciplinary teams of engineers and economists to work together to increase mutual understanding and to determine the best approximations of cost functions that are possible. With all the highway research appropriations currently authorized, it would seem sensible to authorize experimentation along those lines.

A final general point concerns the economist's ideal that highway service prices should equate with marginal cost. In addition to the point already made that much cost and technical information about highways is not in such form as to permit ascertaining relevant marginal cost, it should be recognized that not all economists postulate the equation of price with marginal cost as ideal pricing for efficient resource allocation. Depending on the assumptions made with respect to cost behavior and the period of time relevant to the question at issue, either price equality with marginal cost or with average cost can satisfy ideal conditions. Even where the short run is the pertinent period for pricing and great excess capacity exists, as on many secondary roads, holding prices to marginal costs when below average or program costs, as suggested by Kafoglis, may be pointless if, as also was assumed, the demand is infinitely or highly inelastic. In this case, this other than for administrative reasons, the highway user price might well be established at a figure considerably higher than marginal cost without depressing highway use. And considering the fact that traffic congestion is widespread and quickly develops even on new and improved facilities, at least at peak periods, short-run marginal cost pricing may be more feasible in temporarily limiting highway demand, bringing about reroutings over less congested highways, and possibly in lessening the ultimate investment through encouraging better use of existing facilities. However, in cases where tolls have been set too high, greater utilization of toll roads can be induced, as the Ohio experience apparently indicates, by lowering tolls, possibly to equality with short-run marginal cost.

In conclusion, the papers under discussion give food for much thought and discussion by both engineers and economists. Just as engineering facts concerning critical highway cost functions are hard to come by, the economic way of thinking in a function as complex as highways is difficult to perceive, except abstractly. Whatever is ultimately done concerning benefits to those other than direct users in testing highway investment and in determining prices, it seems that what the economists are saying is that all costs, including opportunity costs, must be counted. In addition, they are contending that highway costs must ultimately be expressed in terms relevant to economic reasoning if optimal highway investment and utilization are to be stimulated. Furthermore, it seems clear that more effort is desirable to cast highway benefits into demand schedules and to determine the effective demand for highway services to the extent practicable.

REFERENCES


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THE PAPERS contained here have presented highly stimulating and varied ideas which should contribute to improved highway investment and financing. However, there are three troublesome aspects of the application of the pricing theory to highway finance which need some comment.

First, one is forced to wonder what the results would be if the pricing theory were applied to the immediate highway financing issue before the Congress; namely, the
financing of the National System of Interstate and Defense Highways. Would it be proper to require the highway users to defray the entire cost of this system when five transcontinental routes, for example, were not justified by use of the pricing theory of economics and, in the writer's opinion, all five cannot be so justified?

Second, under the pricing theory the cost of a highway would include an interest charge, or a rate of return, on the investment. Highways in the United States are being financed predominantly on a pay-as-you-go basis, therefore highway users and other payers of special highway taxes in effect provide highway capital in advance of highway construction. Consequently, it would appear to be unfair to impose upon them the kind of interest imposed when borrowed funds are being used.

Third, in the meeting of the Committee on Highway Costs the statement was made that a political reality is the necessity of taking care of the problem of financing local and secondary roads before attempting to solve the problem of financing state highways. In view of this political reality, one wonders how the pricing theory can be applied to the local and secondary road problems.

The comment that several routes of the Interstate System cannot be justified by application of the economic pricing theory and Brownlee's reply to the effect that highway users should not be expected to pay for economically unjustified highways, may have created the impression that the writer is critical of the Interstate System. Actually, his view is that the Interstate System is well designed to meet the realities of the current political structure and the requirements of national security. With regard to the latter, recognition was given the fact that the United States is faced with a serious military threat and needs a system to encourage decentralization of the major metropolitan cities, to distribute the population and industry more widely, and to provide alternate routes in the event enemy attacks should cause massive destruction.
The National Academy of Sciences—National Research Council is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The Academy itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the Academy and the government, although the Academy is not a governmental agency.

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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.